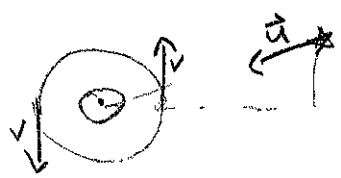
Einsteinian Relativity

- Einstein took our familiar relativity principle ("All inertial frames are equivalent") and added a new assumption/postulate

"There is a finite speed c that is invariant. That is, if some motion has speed c in one inertial frame, it has speed c in all inertial frames."

- What motivates this? Electrodynamics (electricity + magnetism)
  - Maxwell's equations in differential form imply that light can move in waves of speed $1/\sqrt{\epsilon_0 \mu_0}$
  - With respect to which reference frame? Maxwell's eqns don't specify a frame. People thought there must be an ether (or aether)
- Troubles with ether:
  - It's very hard to rewrite Maxwell's equations accounting for ether
  - Aberration of Starlight - motion of earth in the ether



Imagine that you look at a star as the earth moves around the sun

If light rays move in ether at velocity $\vec{u}$ + earth moves at velocity $\vec{v}$, light in earth frame is $\vec{u} - \vec{v}$.

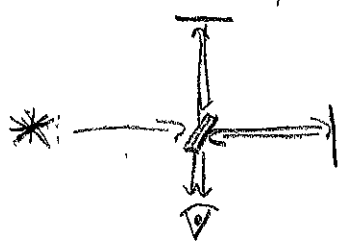
This means we actually are looking at light moving in a slightly different direction when it leaves the star

In the end, star appears to move in sky as earth's velocity changes

In ether theory, this happens because earth moves through ether

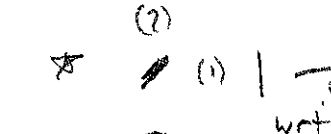
Data says earth does not disturb ether

  - Michelson-Morley Expt another expt to detect motion through ether



Consider a device as in diagram

1) Light enters, is split by beam splitter
2) 2 beams move perpendicularly to each other
3) Recombine + observe interference patterns



Now suppose it moves through the ether as shown. Remember, light moves at c wrt ether. Then light bouncing in beam (1) moves at speed c±v wrt expt. Along (2) it has speed $\sqrt{c^2-v^2}$ wrt expt (because vector sum must be magnitude c)

This means, if you rotate expt (or let earth rotate), interference changes. No change observed. Earth must drag ether perfectly.

- These two experiments contradict. In fact, ethers are also quite confusing.

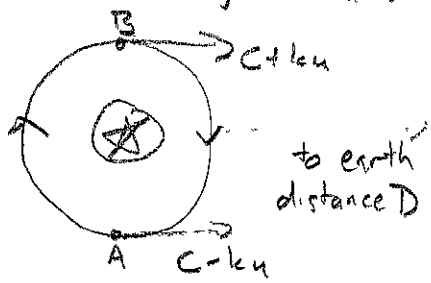
— Ether theory chooses a special inertial frame — "rest frame of ether"

Einstein 1) declared light need not travel through a substance

2) re-asserted the relativity principle.

- These experiments make sense if light always moves at $c = 1/\sqrt{\epsilon_0 \mu_0}$ (in vacuum) relative to any frame
- Note that only speed of light is invt. Direction of velocity changes
- c will become a limiting speed. As we will see later, no signal may travel faster than c.

• Tests: Could light travel at different speeds?



— "Ballistic Model" light picks up speed from emitting object. If motion is all along x,

light speed = c + ku

u = velocity of emitter, k = constant

— Relativity says k = 0 within error

- Can look at binary star system. "At point A, light is slow and has travel time $D/(c-ku) \simeq D/c\,(1+ku/c)$

"At point B, it is faster, with travel time $\simeq D/c\,(1-ku/c)$

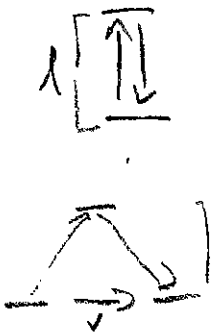
- But light from B is emitted later. Still, if it catches up, there is a double image

• For period T, the fact that we see no double image tells us

$$\frac{1}{2}+\frac{D}{c}\left(1-\frac{kv}{c}\right) > \frac{D}{c}\left(1+\frac{kv}{c}\right) \Rightarrow k < \frac{c}{v}\left(\frac{cT}{4D}\right)$$

— Book lists a system that gives $k \lesssim 10^{-5}$. Consistent with Einstein.

• An immediate but strange consequence: time dilation



— Consider a clock consisting of light bouncing between two mirrors. Ticks when light hits bottom mirror.

This is every $2l/c$ seconds ($=T'$ in S' frame)

— Now take a frame S with mirrors moving to right at v.

• The light still has speed c but must travel l vertically and $vT/2$ horizontally for half a tick time T

• $T = 2\sqrt{l^2+(vT/2)^2}/c = \sqrt{(T')^2+\left(\frac{vT}{c}\right)^2}$ or $T' = T\sqrt{1-v^2/c^2}$

— The proper time (or time where the clock is not moving) is the shortest

"Moving clocks run slow"

• Means we cannot synchronize all clocks in all frames

• Independent of clock design. This is a feature of space + time

• Invites us to reconsider boost transformations

(we will discuss length contraction then)