

Lecture 14

Special relativity I:

Speed limit 186000 mi/s

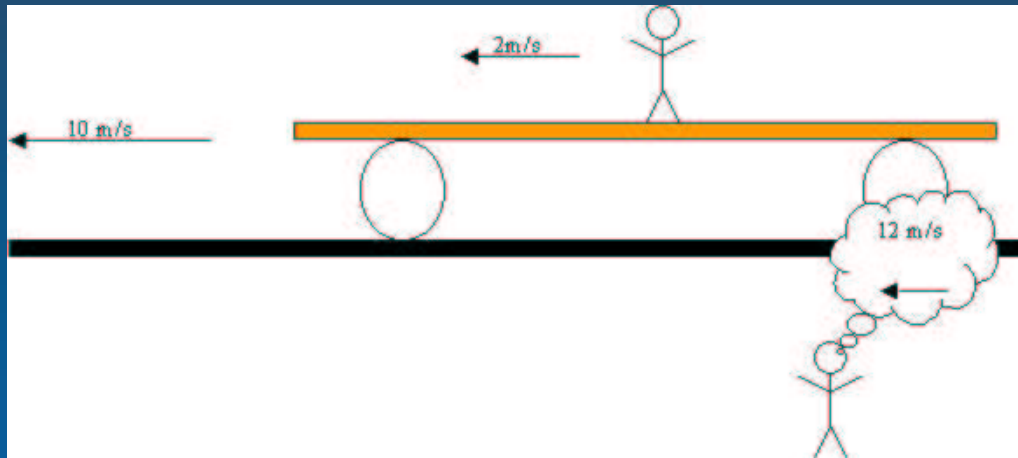
and common sense makes
no sense

A few definitions ...

- **Inertial Observer:** An inertial observer is an observer whose rest frame is inertial
- **Invariance:** A quantity is said to be invariant if all inertial observers would obtain the same result from a measurement of this quantity
- **Relativity:** A quantity is said to be relative if different inertial observers obtain different results from their measurement.

Examples

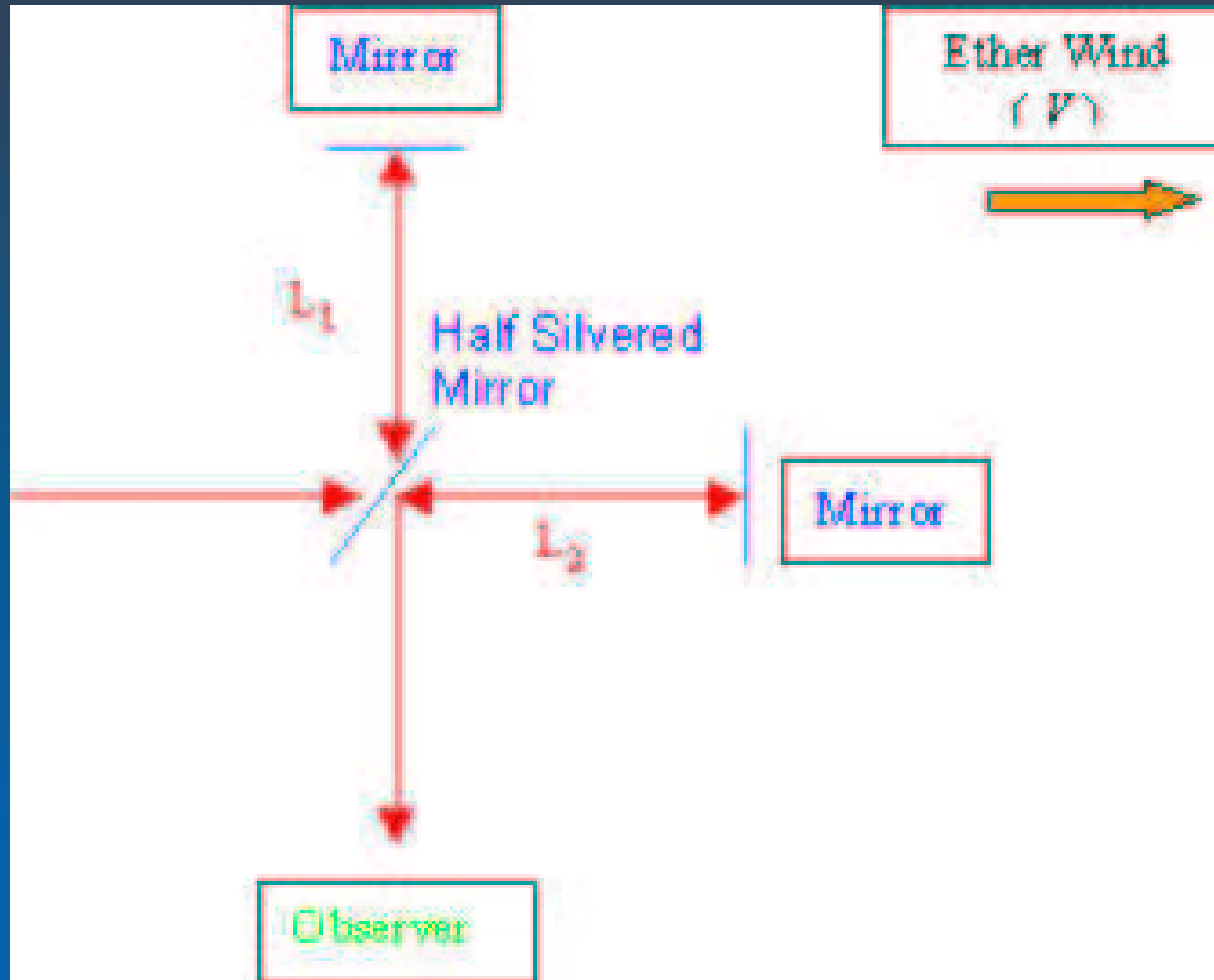
- **invariant:** time, mass, acceleration, force
- **relative:** velocity, position



⇒ Galilean relativity

but: Maxwell's equations (electromagnetism)
are not Galilean invariant !!!

The Michelson-Morley experiment



Result of the Michelson-Morley experiment: the big surprise

- **Expectation:**
 - only in the reference frame of the ether, the speed of light should be
$$c = 299\,792\,458 \text{ m/sec}$$
 - in other reference frames, the velocity should be different (e.g. by 30 km/sec, the speed with which the Earth orbit the Sun)
- **Observation:**
 - the velocity of light was the same to less than 5 km/sec \Rightarrow **there is no ether !!!**

FitzGerald's proposal

- Objects that move through ether at velocity v are physically contracted in length according to

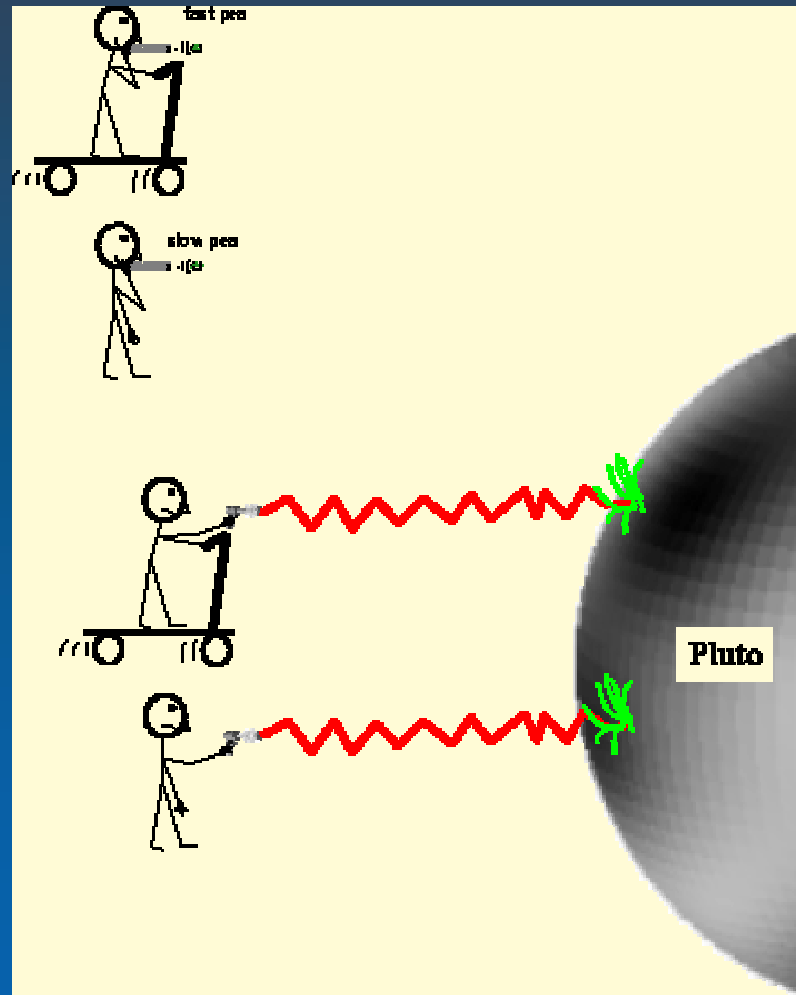
$$L(v) = L_0 \sqrt{1 - \frac{v^2}{c^2}}$$

⇒ strange proposal ?!

Einstein's new relativity

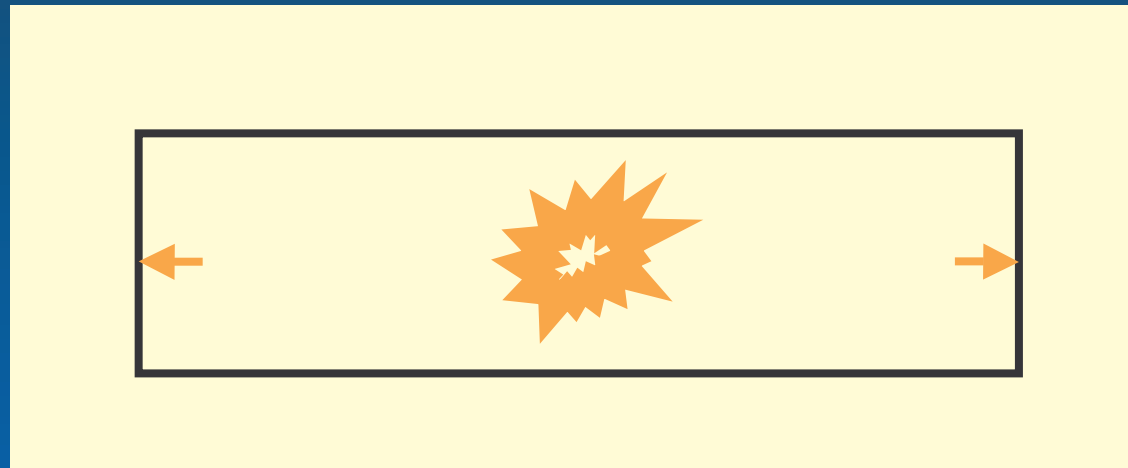
- Galileo:
 - The laws of mechanics are the same in all inertial frames of reference
 - time and space are the same in all inertial frames of reference
- Einstein:
 - The laws of physics are the same in all inertial frames of reference
 - the speed of light in the vacuum is the same in all inertial frames of reference

Constancy of speed of light



Consequence I: Breakdown of simultaneity

- Consider observer inside a space ship moving at a speed comparable to the speed of light:



⇒ for an observer inside the ship, light hits the outer walls at the same time

Consequence I: Breakdown of simultaneity

- For an outside observer (relative speed to the ship v):

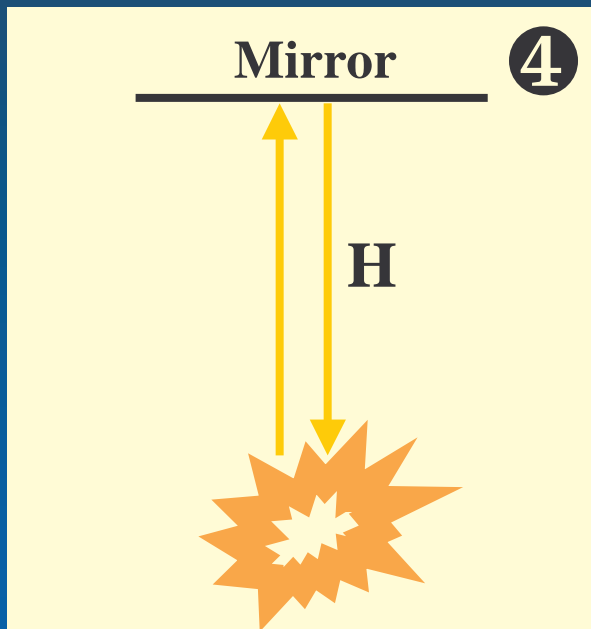


⇒ for an observer outside the ship, light hits the outer walls at the different times

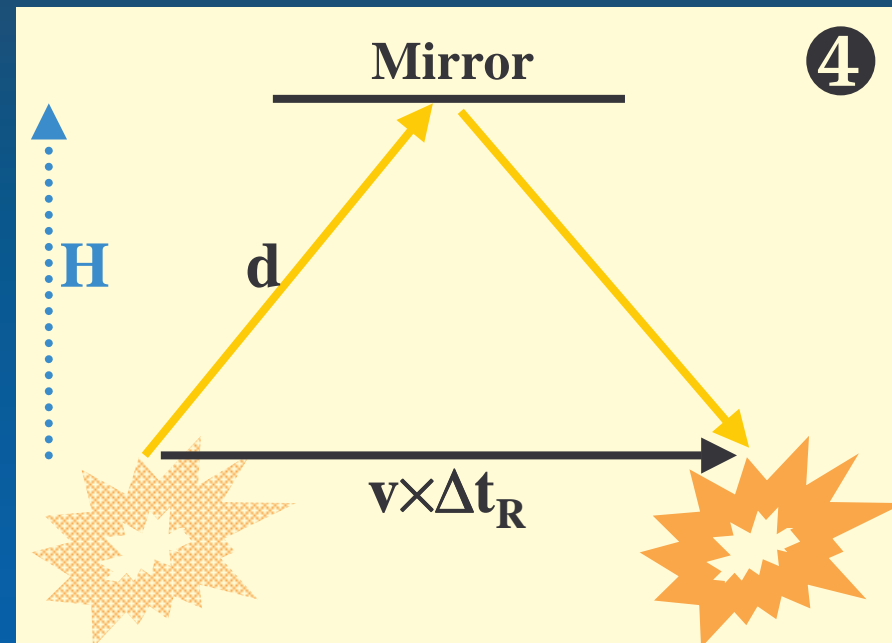
⇒ simultaneity is relative

Consequence II: time dilation

- Observer comoving with the space ship



- Outside observer



⇒ moving clock must go slower !!

Consequence II: time dilation

- Time measured by passenger in the ship:

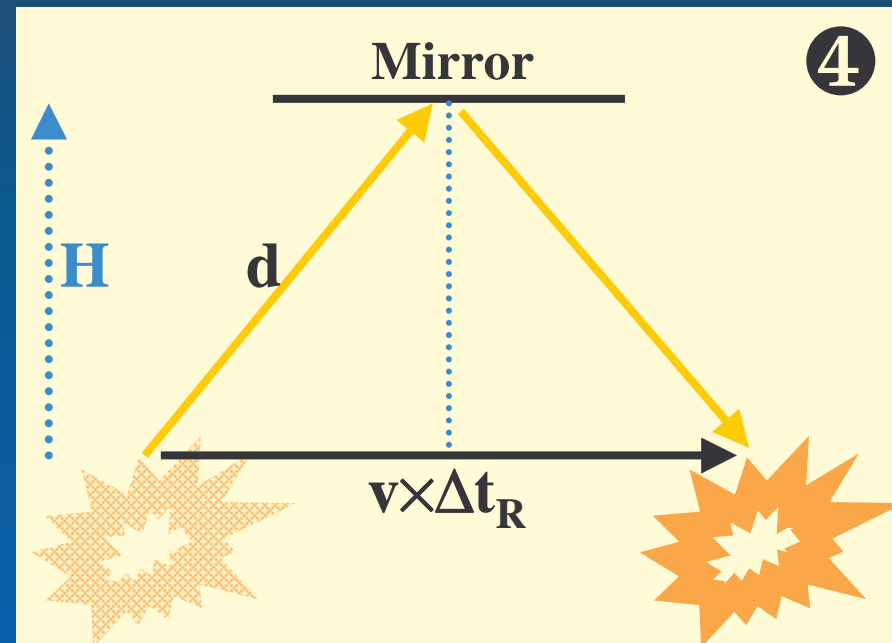
$$\Delta t_p = 2H/c$$

- Distance traveled by light in rest frame:

$$d^2 = H^2 + (0.5v \times \Delta t_R)^2$$

- relation between Δt_p and Δt_R :

$$\Delta t_R = \frac{\Delta t_p}{\sqrt{1 - \frac{v^2}{c^2}}}$$



How can we test this ?

- **Proposal A:**

take two atomic clocks, put one in an airplane and have the airplane fly once around the Earth. Compare the clock with the other one that stayed at rest.

⇒ Result: the traveling clock is indeed somewhat behind.

How can we test this ?

- **Proposal B:**

There exist an elementary particle, the muon, which is created when cosmic rays hit the upper levels of the atmosphere. Their lifetime is so short, that they should decay before they reach the surface of the Earth. Nevertheless they are detected. **Solution:** muons move at speeds close to the speed of light, “life” proceeds much slower.

What don't we see it in daily life ?

- Effect is too small since v is usually much smaller than the speed of light

- Example:

Fly daily and for one year with the Concorde from JFK to Paris and back.

Speed: 700 m/sec Travel time: 6 hours

⇒ time difference: 1/50 000 sec

Consequence III: length contraction

- Consider distance between two space stations, measured using travel time of a space ship moving at speed v
 - Observer in one of the stations: space ship moves with velocity v , travel time is Δt_R
 \Rightarrow distance: $d = v \times \Delta t_R$
 - Observer in the ship: space ship moves with velocity v , travel time is Δt_P
 \Rightarrow distance:

$$d_P = v \times \Delta t_P = d_R \sqrt{1 - \frac{v^2}{c^2}}$$