lecture 2

Relativity in nature

Announcements:

- lecture 1 is posted on the class website
- homework 1 is posted on CULearn
  - due Wed, Jan 19 in class
  - solutions will be posted on CULearn

- reading for this week is:
  - Ch 1 in TZD
  - course syllabus details

- remember to bring your clicker to every class
  - register it (once)
  - set it to frequency CB (once)

clicker question

Recognize non-inertial reference frame

Q: *Which of the following is not an inertial reference frame?*

a) A car traveling at 100mph down a straight road
b) A car traveling at 10mph around a corner
c) Earth
d) A car in a process of crashing into a concrete barrier
e) More than one of the above
f) None of the above

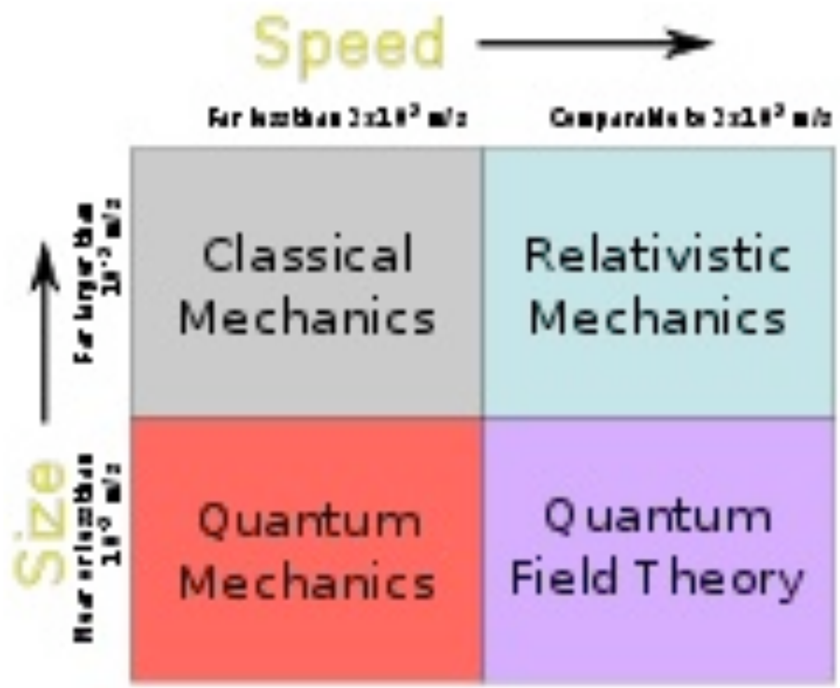
A: *In b),c) and d) there is centripetal and linear accelerations, velocity not constant -> if released objects will accelerate even without a force acting on them; remember Earth is revolving around the Sun, etc.; we will ignore latter effect.*

Last Time

recall lecture 1:

- course logistics: http://www.colorado.edu/physics/phys2170

- modern physics overview:



- Einstein's theory of relativity:

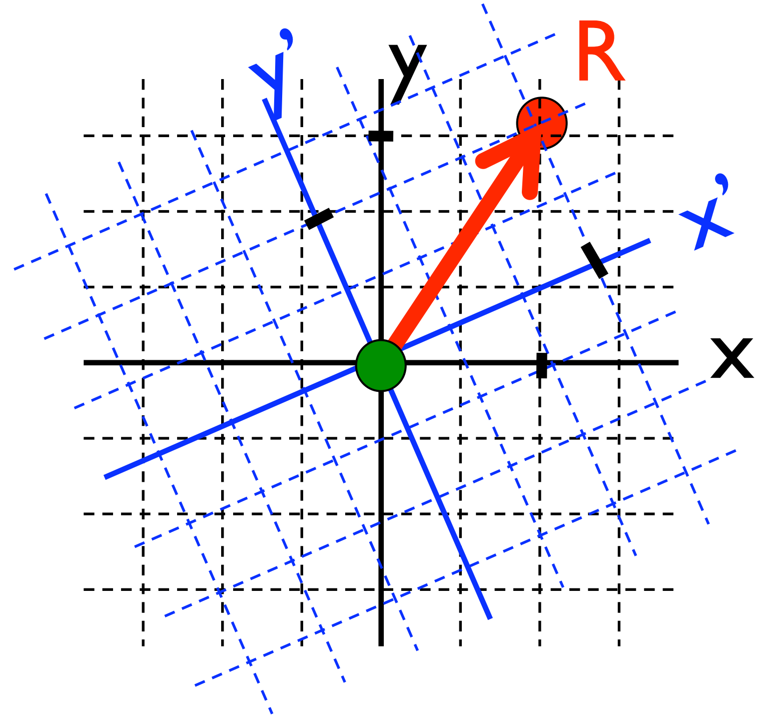
  description of fast (and slow) moving phenomena

Today

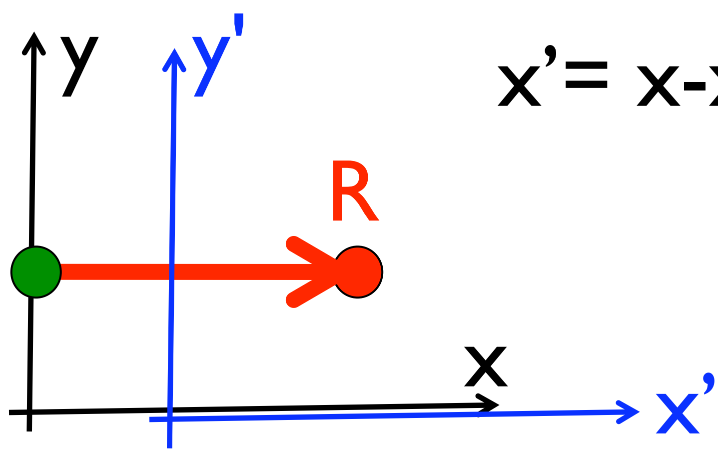
- relativity in nature
- inertial reference frame
- Galilean relativity
- space-time event

Looking at nature from different points of view

- changing coordinate systems:

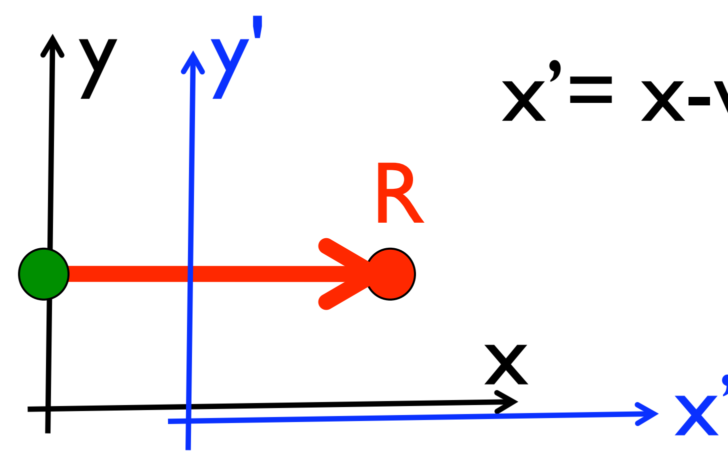


  - rotate around origin
  - translate the origin



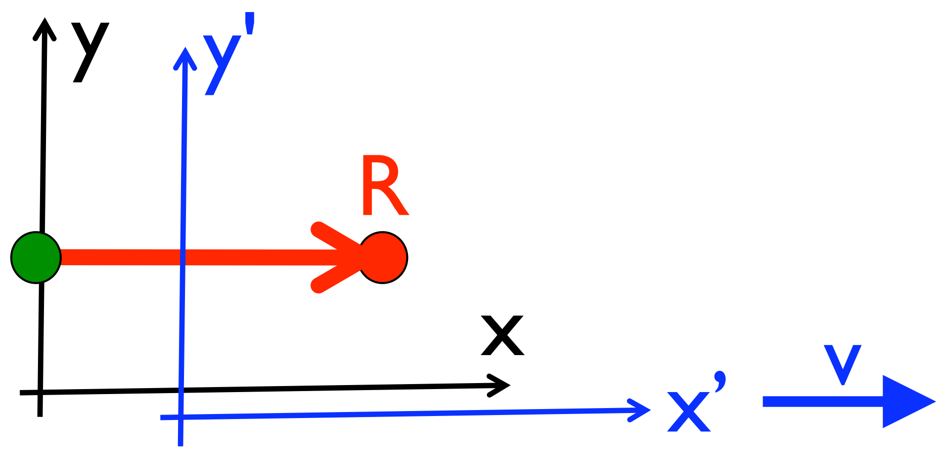
$$x' = x - x_0$$

- moving reference frames:



$$x' = x - vt$$

Inertial reference frame



- inertial reference frame -> frame:
  - reference frame moving with *constant velocity* (not accelerating)
  - cannot tell there is motion without looking out the window

- scope of Einstein's special (as opposed *general*) theory of relativity

- constant with respect to what?
  - philosophy: very subtle...with respect to distance stars (?)
  - pragmatic: frames in which juggling, playing pool, etc...requires no adjustments, Newton's laws satisfied,...

Intuition for inertial reference frame

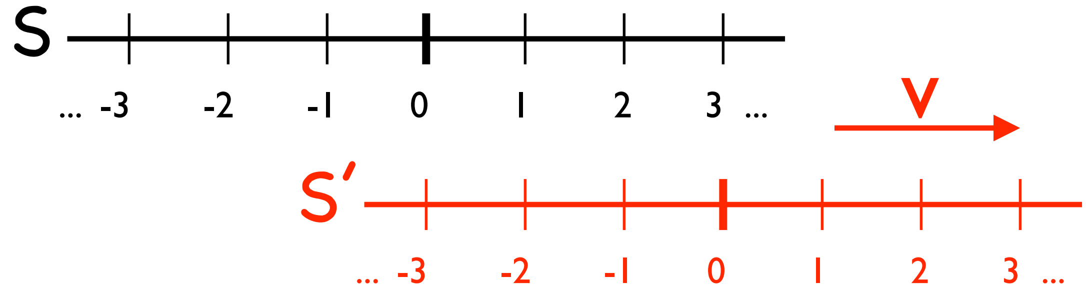
You are playing pool on a train moving with velocity v

- balls roll in straight lines on the table (assuming you put no English on them)
- usual Newtonian law of inertia still holds

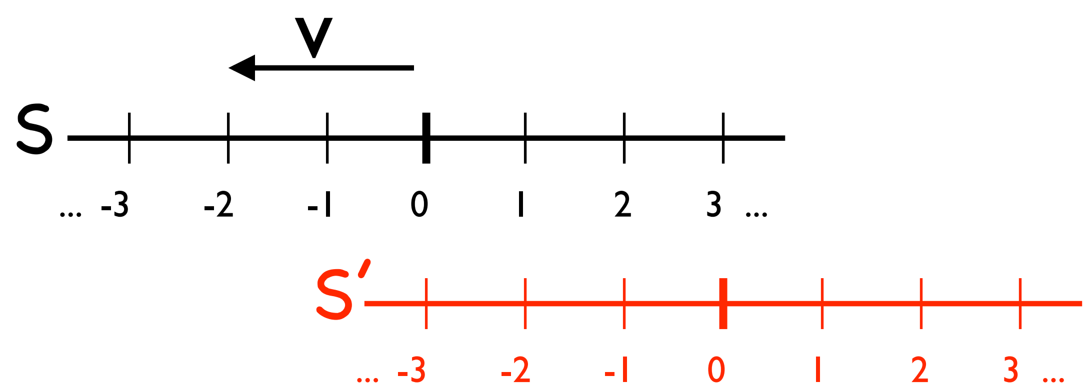
The frame as a whole is not accelerating

Comparing inertial frames

- Two inertial reference frames, moving with respect to one another:



- According to S, S′ is moving to the right, with $v = 1$ m/s



- According to S′, S is moving to the right, with $v = -1$ m/s
  (i.e., S is moving to the left, with $v = 1$ m/s)

<u>Both S′ and S are correct</u>: *it's a matter of reference frames*

Principle of relativity

… even though *description* from different observers may be different

Laws of nature are the same in all reference frames

- *special* relativity: only *inertial* frames
- *general* relativity: *any* (e.g., accelerating) frames

- Galilean relativity:
  - *satisfied* by *Newton's laws* of mechanics F = ma
  - *violated* by *Maxwell's laws* description of light (E&M)
- Choices:

(a) change laws of light (Maxwell's equations)

(b) change transformation rules between frames

→ *Lorentz transformations…later…*

clicker question

Key ideas

Q: *Which of the following is a key idea from last lecture?*

a) Relativity in nature:

- *physical phenomena are coordinate- and frame-invariant*

b) Inertial reference frames:

- *non-accelerating … constant velocity (including zero)*

c) Galilean relativity:

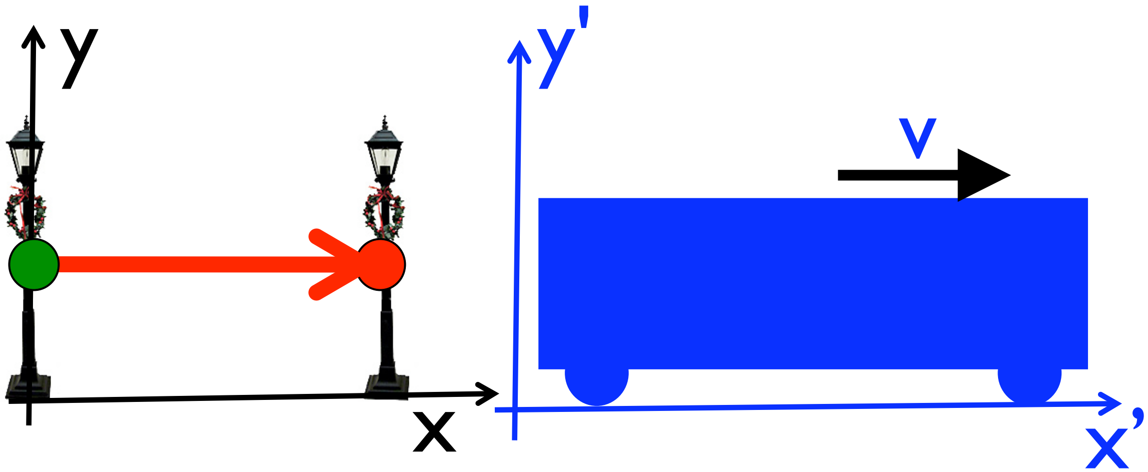
- *Newton's laws (mechanics, Phys 1110) are invariant*
- *Maxwell's laws (E&M, light, Phys 1120) are not invariant*

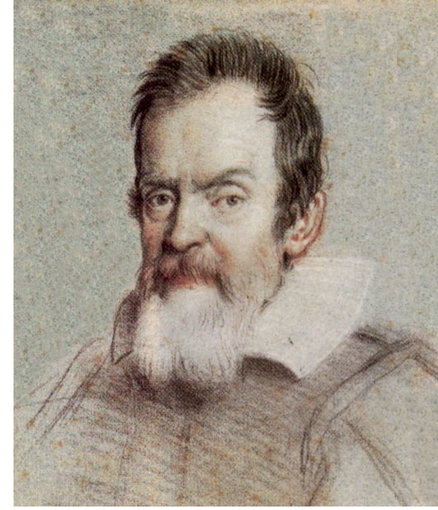
d) All of the above

A: *(d) all of the above.*

…before Einstein

Galilean ("old") relativity





Galileo Galilei (1564—1642)

If an object has velocity *u* in frame S, and its position, *x(t)*, changes with time, *t*. <u>And</u> if frame S′ is moving with velocity *v* relative to frame S, then:

positions and time:

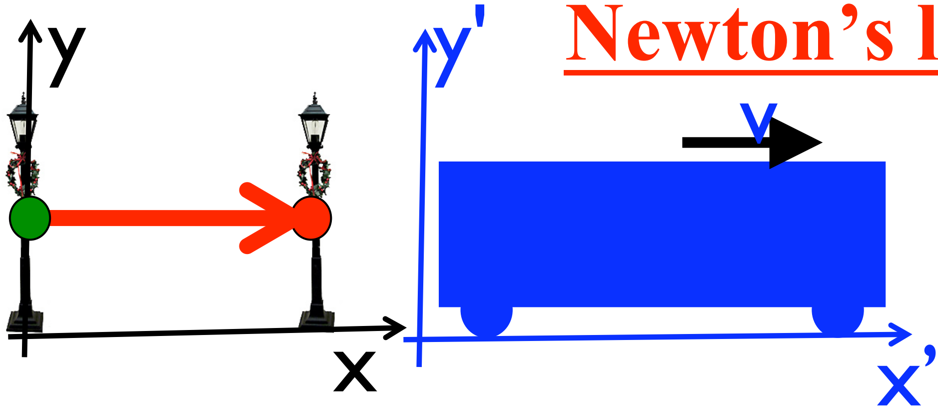
$$x' = x - vt$$
$$y' = y$$
$$z' = z$$
$$t' = t$$

$$\boxed{\begin{aligned} \vec{r}\,' &= \vec{r} - \vec{v}t \\ t' &= t \end{aligned}}$$

velocity (add):

$$u' = \frac{dx'}{dt'} = \frac{d}{dt}\left(x - vt\right) = \frac{dx}{dt} - v = u - v$$

eg: think about a car with velocity u relative to the ground and velocity u′= u – v relative to another car moving with v



Newton's law dynamics

Galileo Galilei (1564—1642)

If an object has velocity *u* in frame S, and its position, *x(t)*, changes with time, *t*. And if frame S′ is moving with velocity *v* relative to frame S, then:

positions:

$$x' = x(t) - vt$$

velocity add:

$$u' = \frac{dx'}{dt'} = \frac{d}{dt}(x - vt) = \frac{dx}{dt} - v = u - v$$

acceleration *unchanged*:

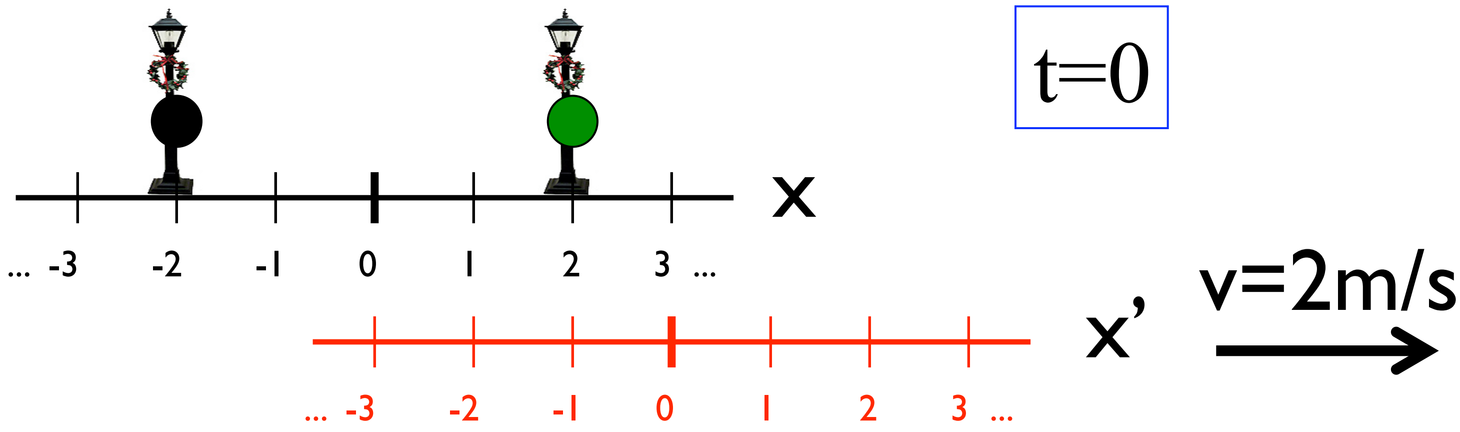
$$a' = \frac{du'}{dt'} = \frac{d}{dt}(u - v) = \frac{du}{dt} = a$$

Newton's law (F=ma) is therefore unchanged, i.e., Galilean invariant

(all that you learned in Physics 1110 holds in S and S′)

clicker question

Galilean transformation coordinates



What is the coordinate of the green ball in two frames after one second, i.e., at time t = 1?

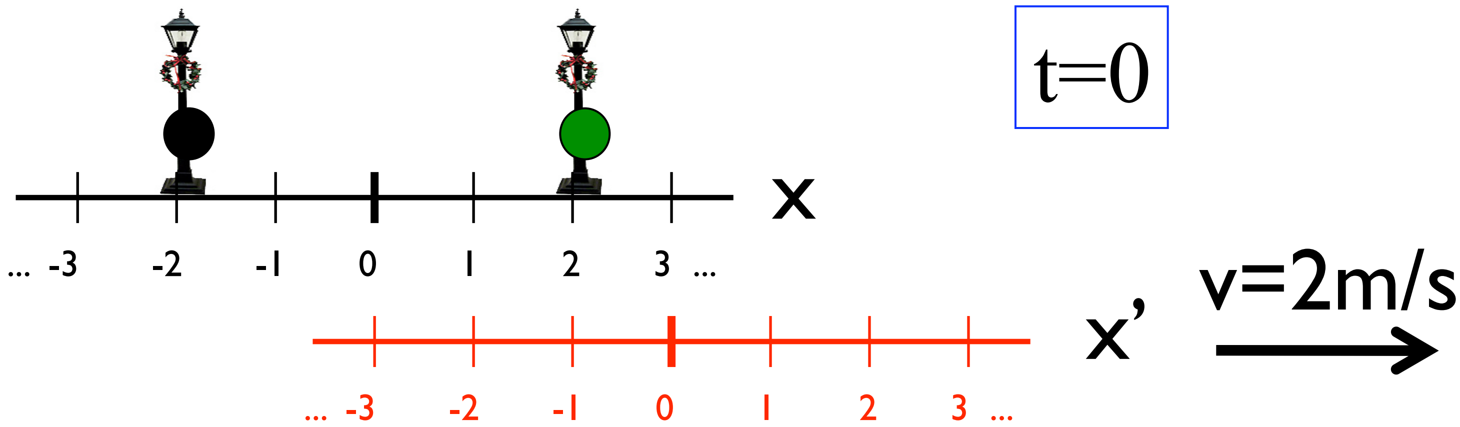
a) 2 m in S and 2 m in S′
b) 2 m in S and –1 m in S′
c) 2 m in S and –3 m in S′
d) 4 m in S and 4 m in S′

Two different observers measure two different coordinates for the same location of the ball

And they are both correct!

clicker question

Galilean transformation



What is the distance between the green and black balls in two frames at time t = 1 second?

a) 2 m in S and 2 m in S′
b) 2 m in S and -1 m in S′
c) 2 m in S and -3 m in S′
d) 4 m in S and 4 m in S′

Both observers measure the same *distance* between two balls

coordinates change but *distance* is a frame-invariant quantity

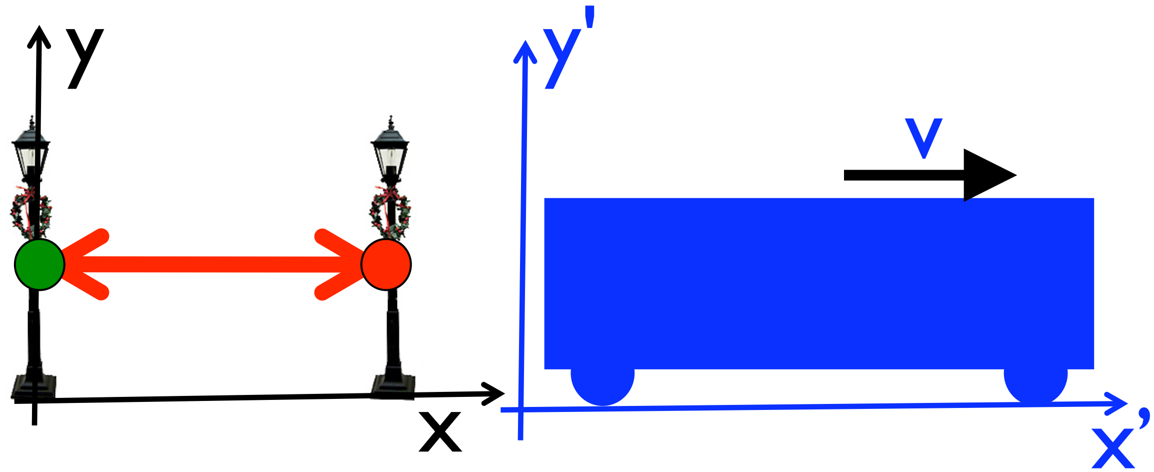
Galilean invariants

$x' = x - vt$

$y' = y$

$z' = z$

$t' = t$

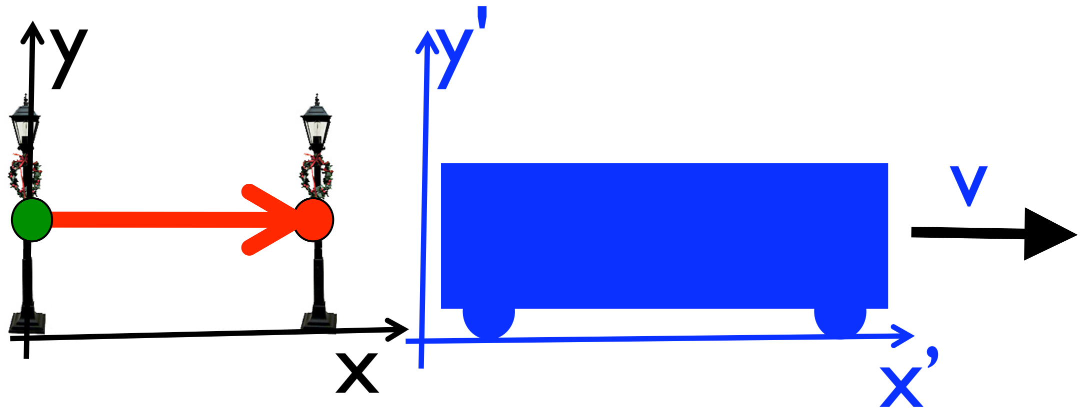


distance (*length* of a vector) is an *invariant*
i.e., independent of Galilean reference frame
(many other quantities: mass, force,...)

$$\left.\begin{array}{l} x'_1 = x_1 - vt_1 \\ t'_1 = t_1 \\ x'_2 = x_2 - vt_2 \\ t'_2 = t_2 \end{array}\right] \Longrightarrow \begin{array}{l} d' = x'_2 - x'_1 = (x_2 - \cancel{vt_1}) - (x_1 - \cancel{vt_2}) \\ \quad = d \end{array}$$

why?

Invariance under Galilean transformation



Galileo Galilei (1564—1642)

Newton's law (F=ma, mechanics) is therefore unchanged, i.e., Galilean invariant (all that you learned in Physics 1110 holds in S and S')

What about the physics of Electromagnetism?

Does Electromagnetism depend on which inertial frame you are in ?

YES according to Galileo! → "*trouble*" → Einstein's relativity