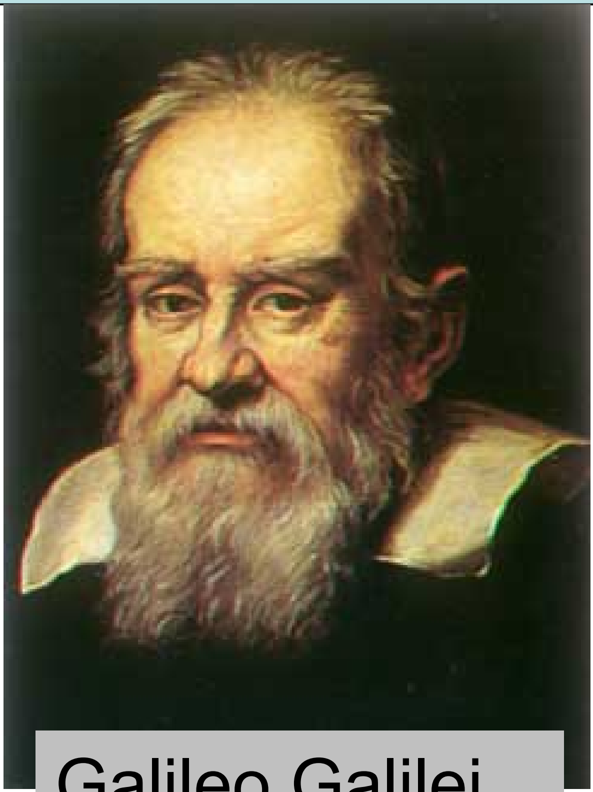
Galilean relativity

Announcements:

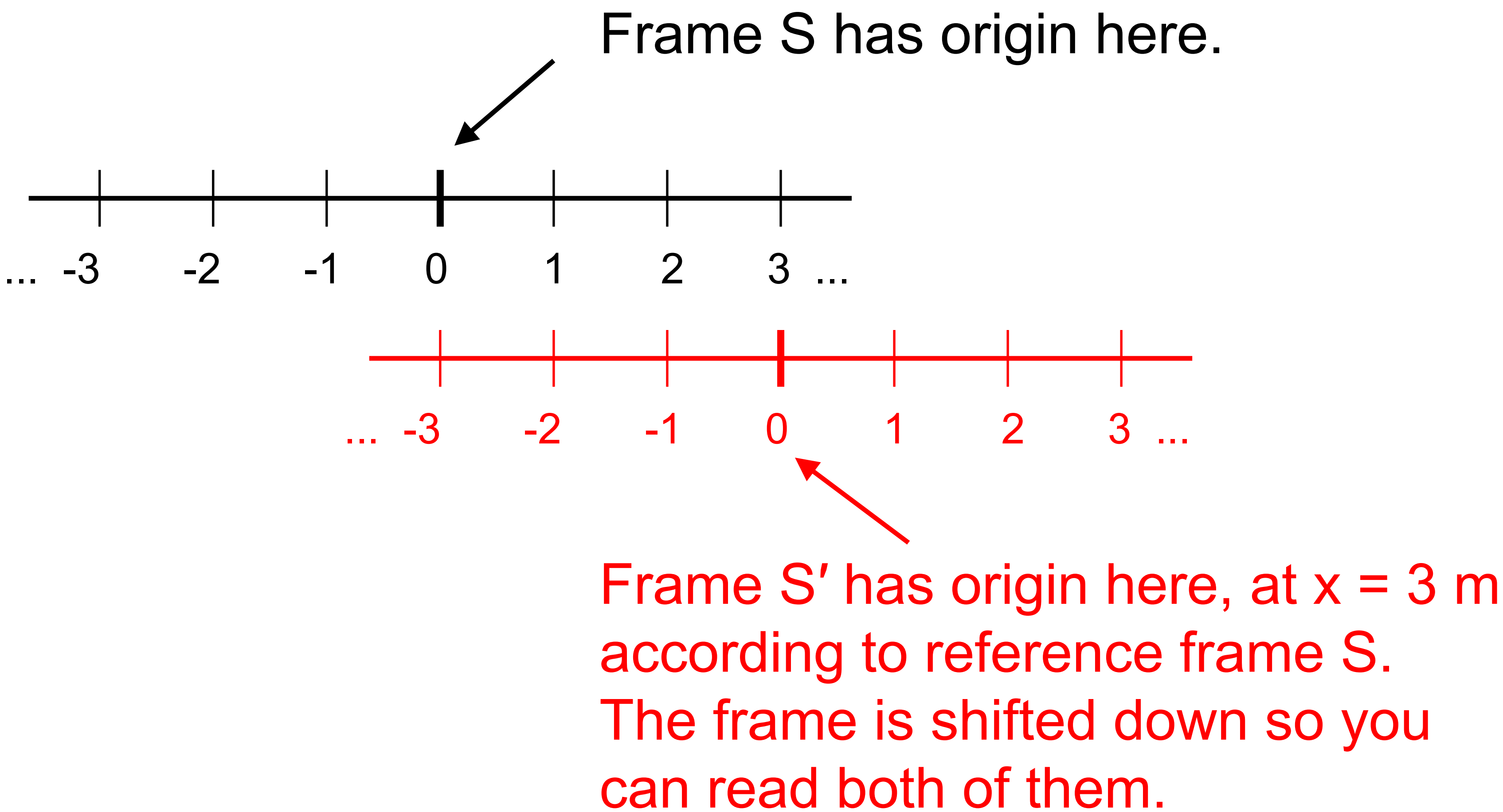
- Homework assignment will be posted on the web site by 5pm today.
- First problem solving session will be Tuesday 3-4 and 5-6.
- Homework is due next Wednesday at 12:50pm in wood box inside physics help room (G2B90).
- Web site www.colorado.edu/physics/phys2170/ contains lots of info, e.g. the course calendar has reading assignments and lecture notes.



Galileo Galilei (1564—1642):

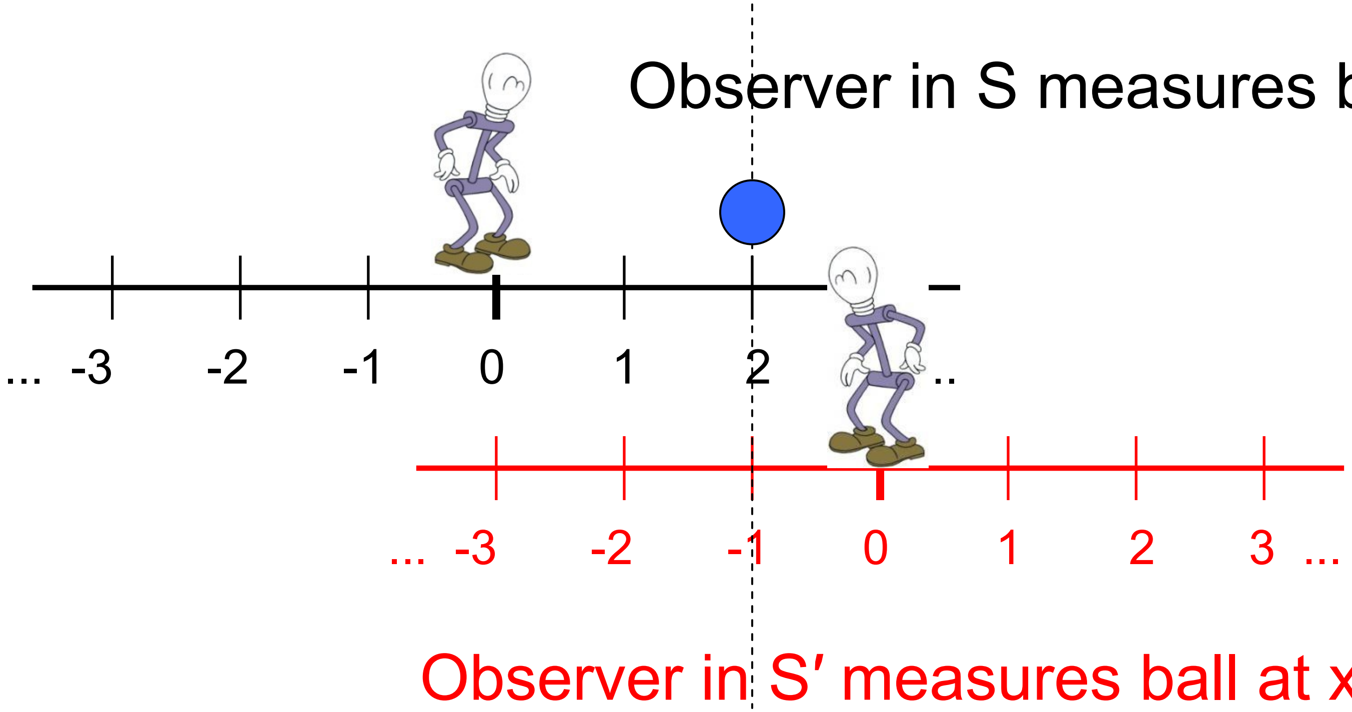
Today we will cover Galilean relativity and the special relativity postulates.

Compare two reference frames (in one-dimension)



Compare two reference frames (in one-dimension)

Observer in S measures ball at x = 2m.

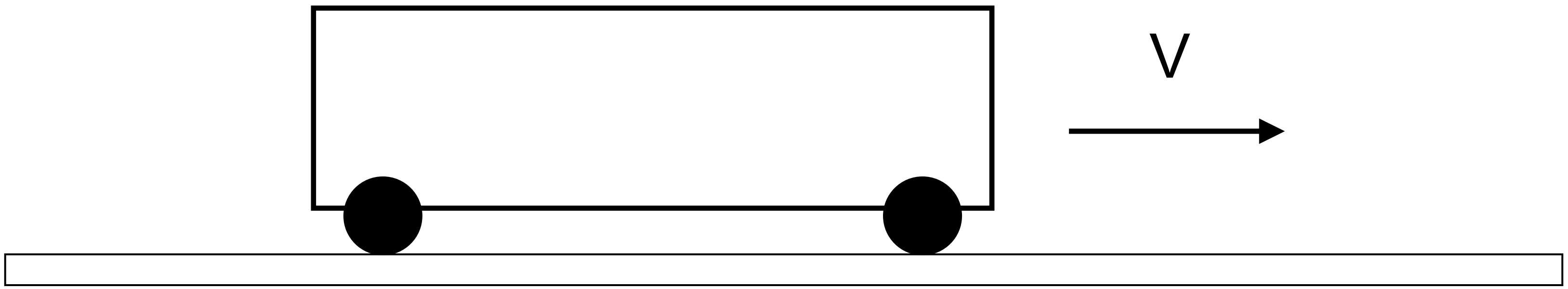


Observer in S′ measures ball at x′ = −1 m.

Two different observers measure two different results for the location of the ball

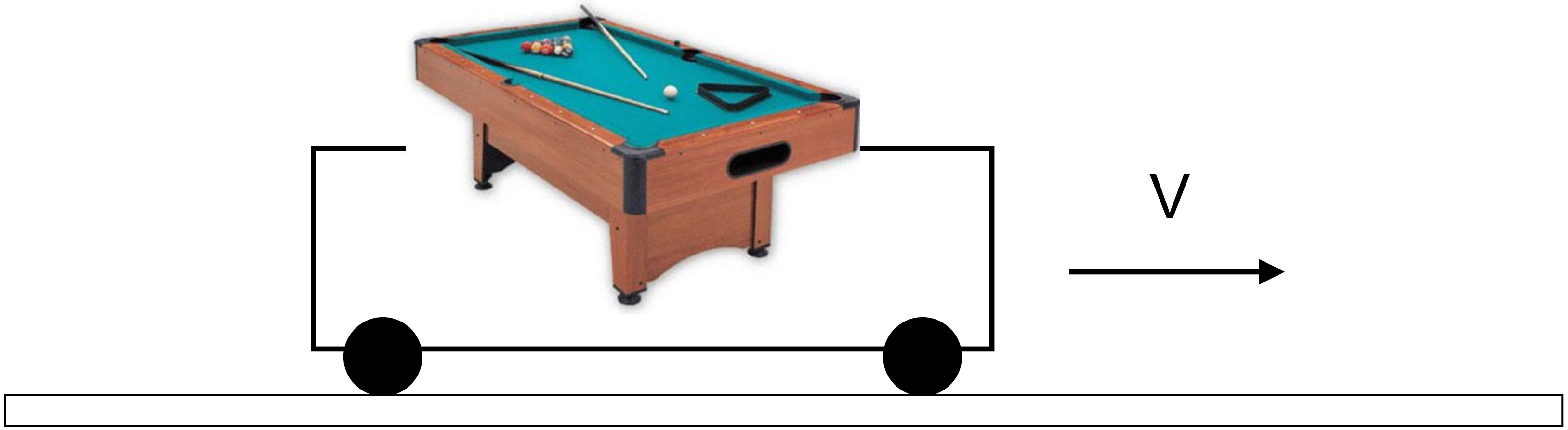
<u>And they are both correct!</u>

Inertial reference frames



Imagine a train car (it's always a train!) moving with constant velocity with respect to the ground. The train runs smoothly, so that you can't tell it's moving by feeling the bumps on the track.

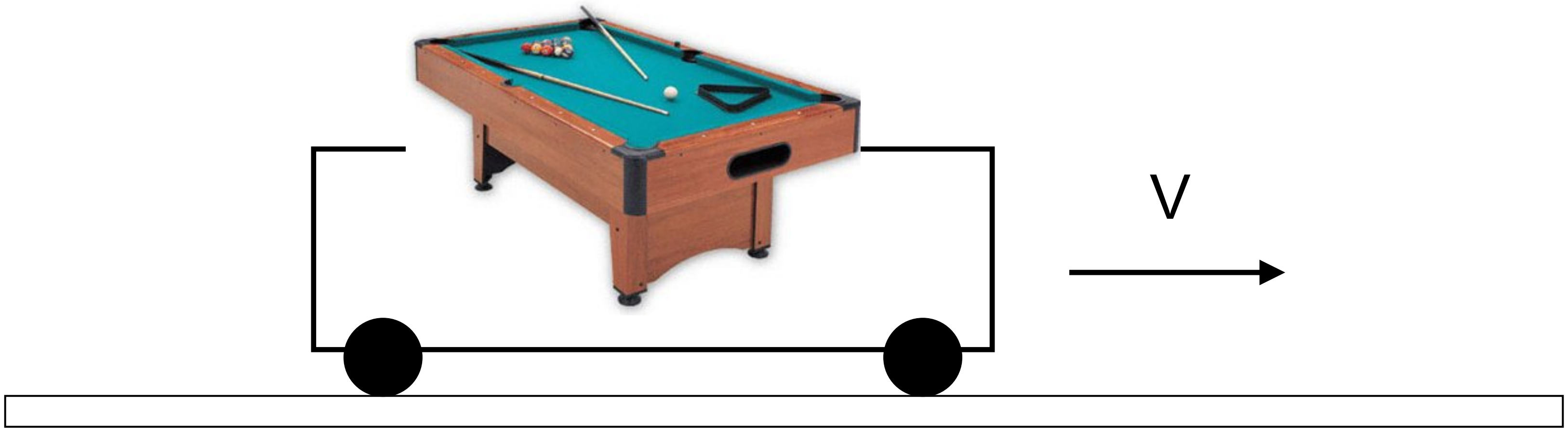
Inertial reference frames



Now, you're playing pool on the train. The balls roll in straight lines on the table (assuming you put no English on them). In other words, the usual Newtonian law of inertia still holds. The frame as a whole is not accelerating.

Clicker question 1

Set frequency to DA

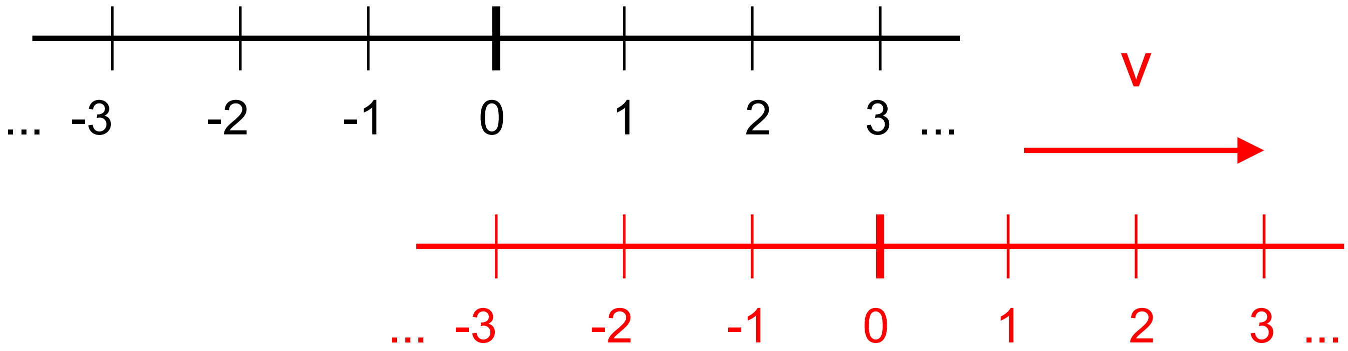


As I'm lining up my shot, the train slows and approaches the station. I have not touched the cue ball. What does it do?

A. Rolls to the front of the train
B. Rolls to the back of the train
C. Remains motionless
D. Grows legs and runs around the pool table

This frame is no longer inertial. It is a non-inertial frame.

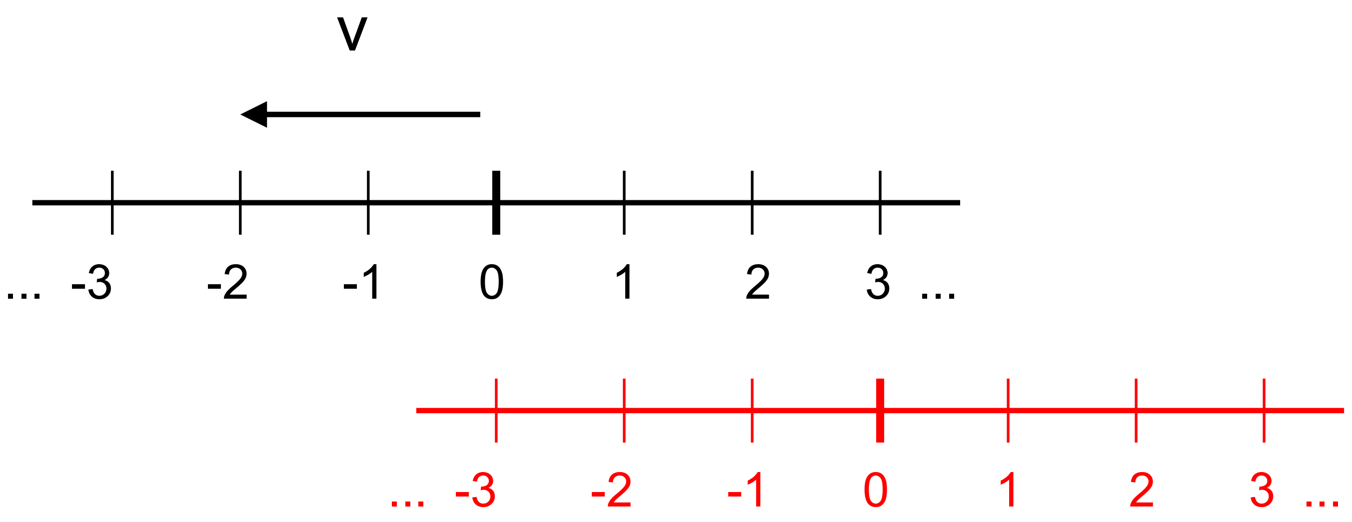
Comparing inertial frames



Here are two inertial reference frames, moving with respect to one another.

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

Comparing inertial frames



Here are two inertial reference frames, moving with respect to one another.

According to S′, S is moving to the left, with v = −1 m/s.

Both S′ and S are correct. It's a question of reference frames

Q. What is an inertial reference frame?

A. Objects in inertial frames obey the law of inertia
A. Inertial frames travel at constant velocity (can be 0)

Equivalent statements

Clicker question 2

Set frequency to DA

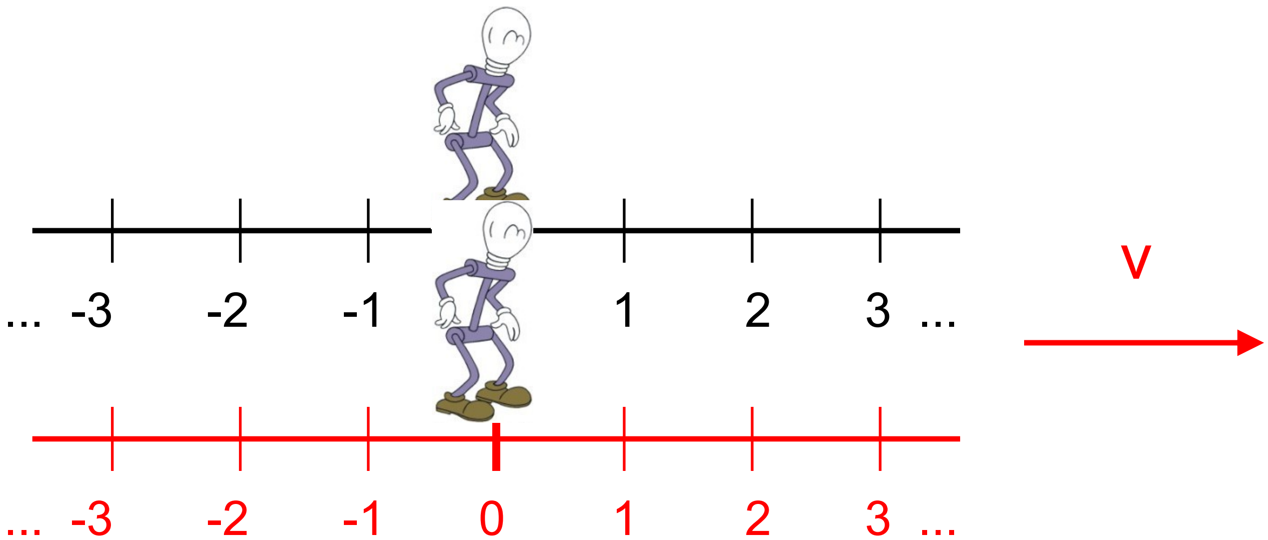
Q. Which of the following is not an inertial reference frame?

A. A car traveling at 100 mph down a straight road
B. A car traveling at 20 mph around a corner
C. A car in the process of crashing into a concrete barricade
D. More than one of the above
E. None of the above

In A objects at rest stay at rest and reference frame velocity is constant

In B and C objects at rest will move because reference frame velocity is not constant: centripetal acceleration in B and linear acceleration in C.

Comparing inertial frames

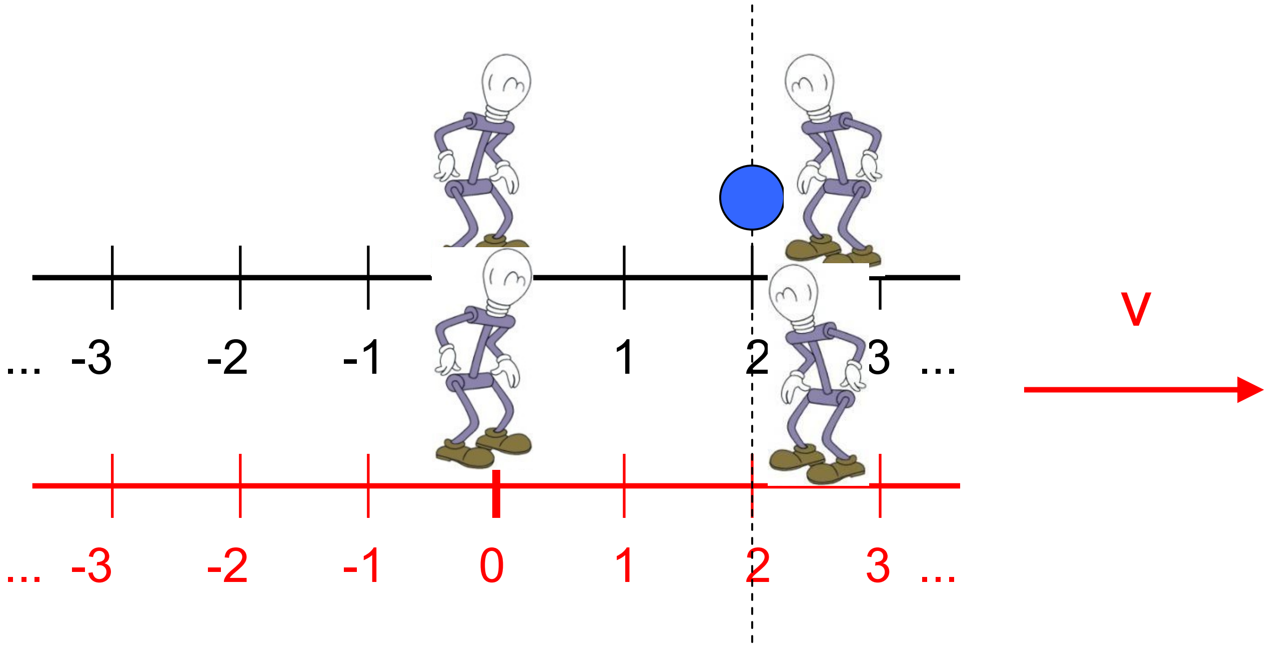


Think about two frames that coincide at t=0.

How do we know??

<u>Answer</u>: Two local observers are there to measure the facts.

Comparing inertial frames



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

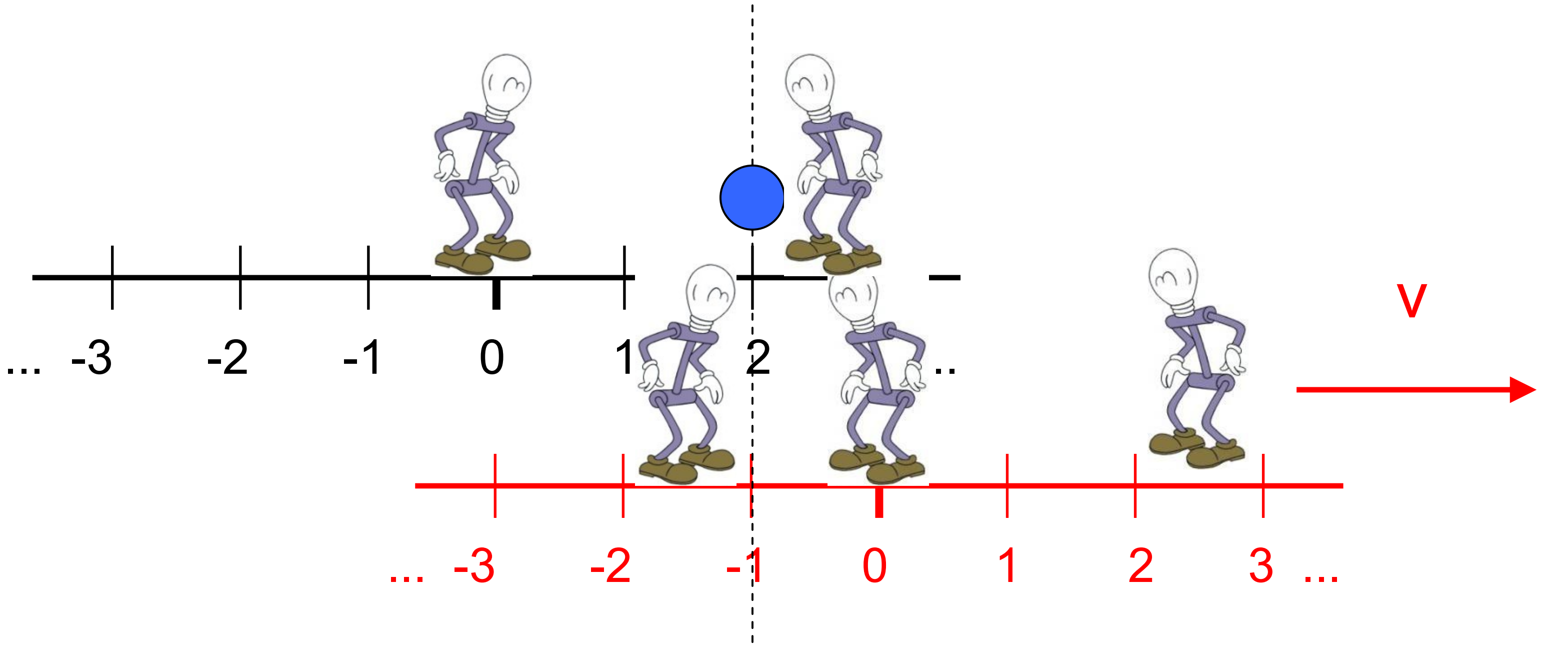
- x = 2 m in S
- x′ = 2 m in S′

How do we know??

Two more local observers:

- One in S
- One in S′

Comparing inertial frames



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 in S
- x′ = −1 m in S’

How do we know??   YUP!

Good thing it’s a big universe…

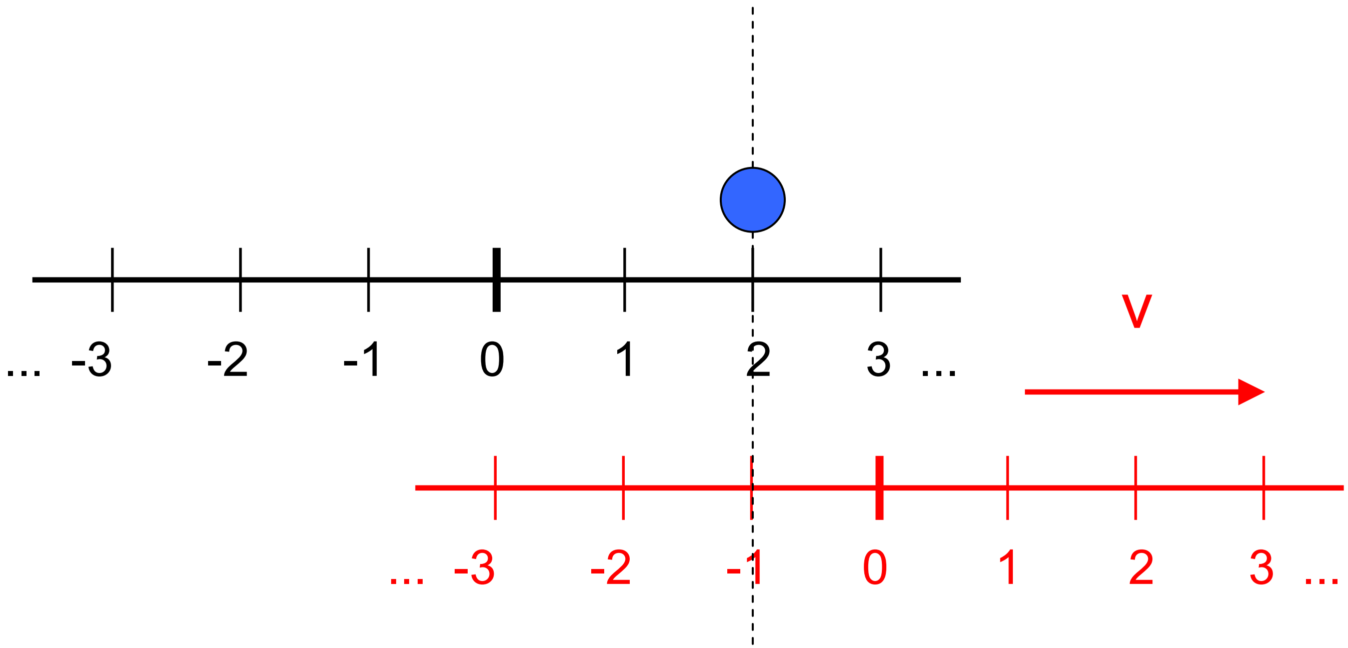
Definition of event

- *Where* something is depends on *when* you check on it (and on the movement of your own reference frame).
- Definition: an event is a measurement of where something is and when it is there.

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

Events are measurements in 4D space-time made by local observers on the scene.

Comparing inertial frames



Clicker question 3

Set frequency to DA

Q. At time 0, the ball was at $x = x'$. At time t later, the ball is still at x in S. Where is it in S′?

A) $x' = x$ B) $x' = x + vt$ C) $x' = x - vt$

Galilean transformations

If S′ is moving with speed v in the positive x direction relative to S, then an object's coordinates in S′ are

$$x' = x - vt$$

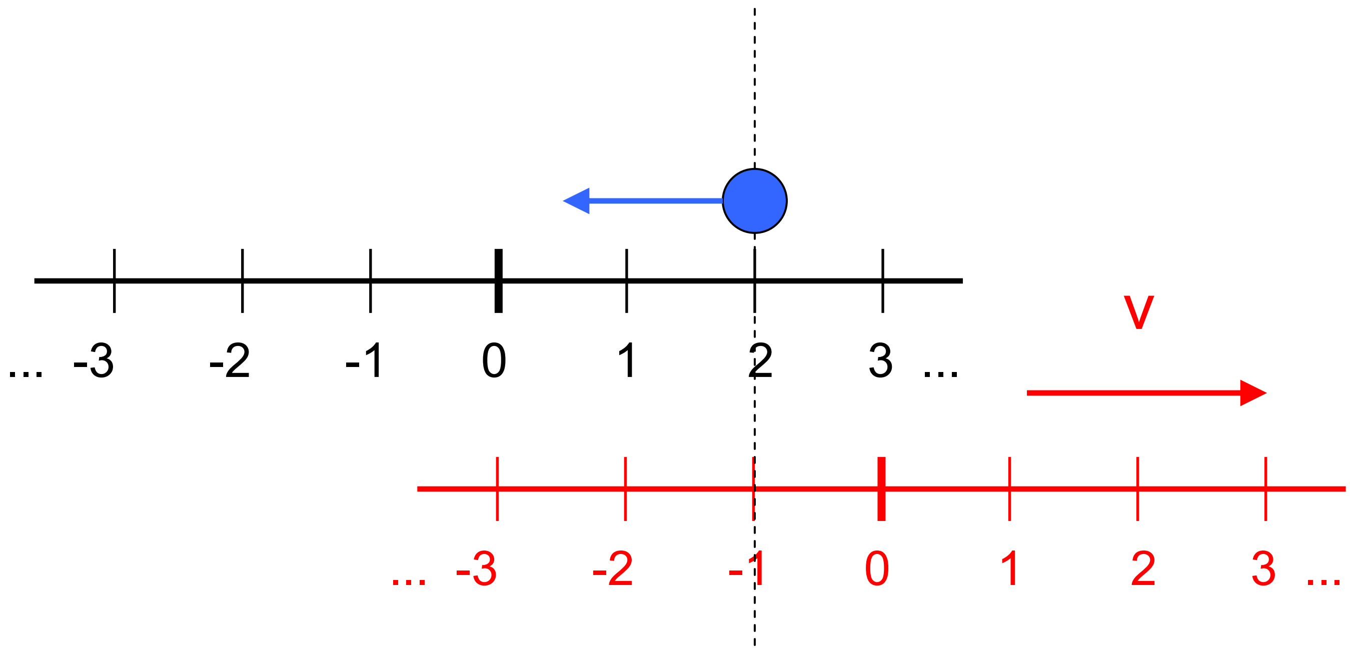
$$y' = y$$

$$z' = z$$

$$t' = t$$

Note: in Galilean relativity, time is measured the same in both reference frames.

More Galilean relativity



Same thing, but now the ball is moving in S, too, with a velocity of –2 m/s.

Clicker question 4 Set frequency to DA

Q. Is the ball faster or slower, as measured in Frame S′?

A) faster B) slower C) same speed

Galilean velocity transformation

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

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

Velocity of object in S′ is therefore:

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

This is the classical velocity-addition formula which is simply vector addition

Two observers in different reference frames can give a *different description* of the same physical fact, in this case the velocity and position of the ball. And they're both right!

Dynamics

We still have an object moving with velocity *u* in inertial frame S and an inertial frame S′ which moves at a constant velocity *v* with respect to frame S.

Now let's apply a force to the object in frame S.

From Newton's 2nd law ($F = ma$) this means the object accelerates in frame S.

What is the acceleration in frame S′?

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

So, although the positions and velocities can be different in different inertial frames, the acceleration and forces are the same

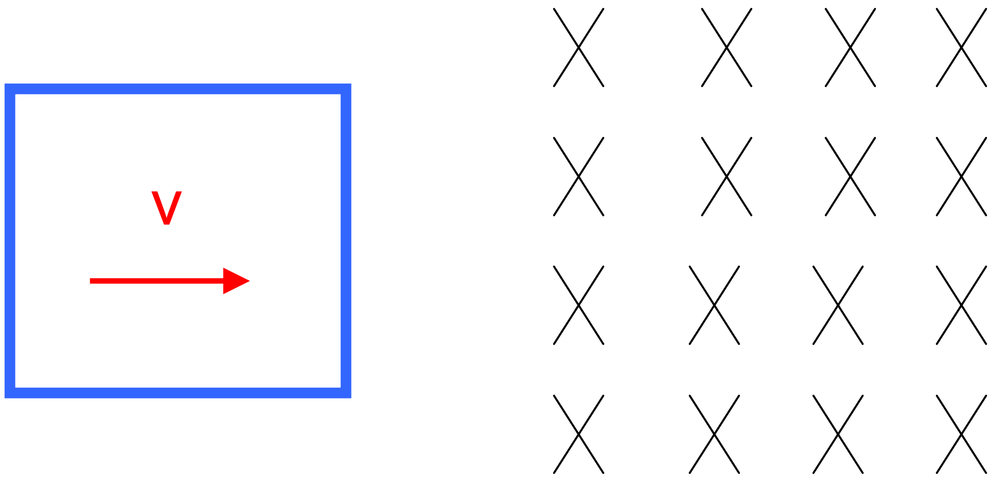
Galilean relativity

In Galilean relativity, the laws of mechanics (good old $F=ma$ and everything else in Physics 1110) are the same in any inertial frame of reference.

What about the physics of electromagnetism?
Does E&M depend on which inertial frame you are in?

Clicker question 5

Set frequency to DA



Q. A magnetic field points into the board. A wire loop moves into the field with velocity *v*. An electron in the wire feels a Lorentz force $\vec{F} = q\vec{v}\times\vec{B}$. What happens in the wire?

A. nothing

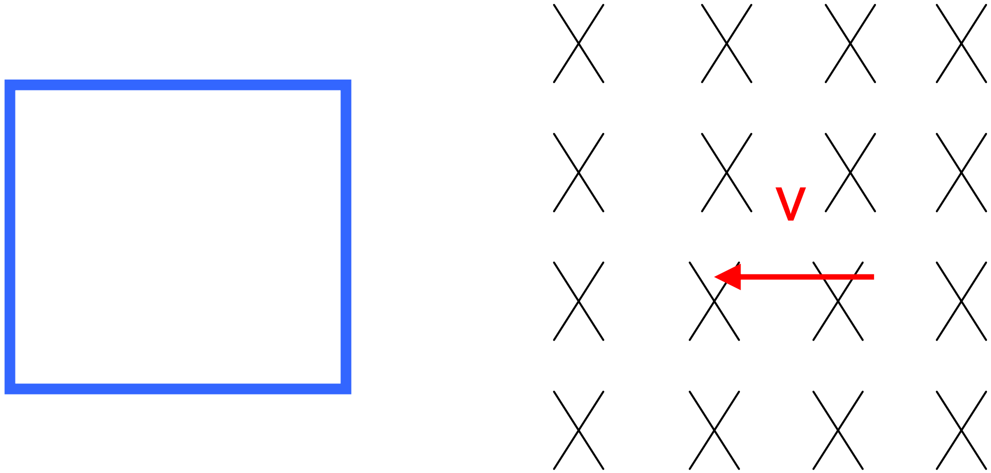
B. a current flows clockwise

C. a current flows counterclockwise

Remember the right hand rule and that current is the direction a positive charge would move

Clicker question 6

Set frequency to DA



Q. Now the loop is stationary and the magnetic field moves into the loop. What happens in the wire?

A. nothing
B. a current flows clockwise
C. a current flows counterclockwise

Faraday's law states:

$$\oint \vec{E} \cdot d\vec{\ell} = -\frac{d\Phi_B}{dt}$$

The magnetic flux through the loop is changing which induces an electric field and thereby drives a current.

OK, so which is correct?

- In the reference frame of the magnetic field, an observer thinks the electron feels a magnetic force.
- In the reference frame of the electron, an observer thinks the electron feels an (induced) electric force.
- And they're both right!

Einstein's first postulate for special relativity is:

> Postulate 1: All the laws of physics are the same in all inertial reference frames.

Not just mechanics but all physics laws

From Maxwell's equations, light is an electromagnetic wave with speed:

$$c = \frac{1}{\sqrt{\mu_0 \varepsilon_0}} = 299792458 \text{ m/s}$$

Conventional wisdom: Waves must have a medium to travel in – sound in air, tsunami in water, etc.

Therefore it was believed light traveled in stationary ether where the speed was 299792458 m/s.

If the ether exists, it is an incompressible, invisible, and non-viscous medium which permeates the universe (like The Force).