# PHY293 Lecture #2

October 27, 2017

1. Einstein's Postulates for Special Relativity
    1. Light moves at the same speed relative to all observers (independent of the motion of the source of light)
    2. All physical laws (as they pertain to light, but also other phenomena) are the **same** in all *inertial* reference frames. (ie. non-accelerating reference frames).

    (a) Relative velocity
2. Relative velocities (classical mechanics)
    - If you run along a moving train (100 km/hr) at 15 km/hr then you are moving (relative to the ground) at 115 km/hr (or 85 km/hr) (depending on whether you run in the same direction as the train is travelling or the opposite).
    - In our everyday experience velocities add and the laws of physical mechanics are the same for all observers.
    - This is not the case for light
        - If you shine the headlight of a car at an observer it appears to arrive at $v = c$
        - If car moving towards observer at $v = 0.5c$ light still appears to arrive at $v = c$ ... not $v = 1.5c$
        - Similarly if car backs away from observer at $v = -0.5c$ light **still** appears to arrive at $v = c$ ... again, not $v = 0.5c$.
        - The velocity of light, relative to any (non-accelerating) observer is independent of the velocity of the source
    - This was Einstein's first postulate
    - Our intuition about how velocities add fails us.
    - Velocity is still just "distance"/"time" so measurements of time and/or distance must be altered in different reference frames.
3. The second postulate says that you cannot make any physical measurement in different inertial reference frame that depends on the details of another internal reference frame. The velocities can be different but the physics remains the same
    - If you are juggling balls on a moving train, it doesn't take any different forces to keep the balls in the air, than if you were standing stationary on the platform next to the moving train – despite the fact that the balls are all moving 100 km/hr past the station platform. From the perspective of the juggler all the laws of physics stay the same, whether in motion or stationary.
4. Inertial Reference frames
    - View the same physics process from different reference frames
    - An "inertial frame" is one that is not accelerating (an object at rest, remains at rest in such a frame).
    - Two inertial frames differ by a constant velocity – will always make sure the x-axes line up with relative velocity...
    - Einstein postulated: Laws of physics must be identical in any two such frames.
5. Galilean Transformations
    - Define and 'event' as something that happens at some point in space $(x, y, z)$ at a particular time $t$ – measured in frame $S$.
    - The coordinates can be transformed to the frame $S'$ using, so-called, Galilean transformations:

    $$x' = x - vt, \quad y' = y, \quad z' = z, \quad t' = t, \quad u' = u - v$$

    - Use convention (of text) that $v$ is the relative velocity between $S$ and $S'$, and $u(u')$ is the velocity measured in frame $S$ $(S')$
    - Note in classical physics (for Galileo) time is **absolute** (the same in both reference frames).
    - Can also define an event in $S'$ at $(x', y', z')$ that occurs at a time $t'$ and then transfer to the coordinates of $S$:

    $$x = x' + vt, \quad y' = y, \quad z' = z, \quad t' = t, \quad u = u' + v$$

    - Differs only by the sign of $v$ from the transformation above.
    - This was how we concluded that runner was moving at 115 km/hr = $v_{run} + v_{train}$ relative to the ground
    - Typically we will take $S$ to be stationary (the ground) and $S'$ to be in motion, but relative velocity is all that matters.
    - Events occurring simultaneously at $(x_1, y_1, z_1)$ and $(x_2, y_2, z_2)$ will be simultaneous in $S'$ the same distance apart

- Since time is absolute ($t = t'$) if they happen at same $t$, they will happen at same $t'$.
- This will turn out not to be true in special relativity
  - Keeping the speed of light the same in all frames will lead to distortions of space and time in the moving frame

6. Consequences of Special Relativity:
   - Simultaneity: Events that happen at the same time in one reference frame are not necessarily simultaneous other frames.
     - Time is no longer absolute. Now it is also "relative" to the observers reference frame
   - Time Dilation: A clock (ie. time) in a moving reference frame runs more slowly that one at rest (by the same factor $\gamma$).

$$\gamma = \frac{1}{\sqrt{1 - v^2/c^2}}$$

     - This is seen in 'everyday' particle physics when particles that decay are moving close to the speed of light
     - Also leads to the "Twin paradox" – though that is not just a consequence of time dilation (will come back to this)
     - Length Contraction: Objects in motion are shorter – along the direction of motion – than when at rest (by a factor $\gamma$)
       - $*$ Ladder through a barn, or plane in a hanger example (in text)
     - Note: even for the fastest space craft $v \approx 10^4$ m/s. Given $c = 3 \times 10^8$ m/s, $\gamma \approx 1.0000000006$

7. Four simple examples (3 this time and 4th next time)

   I Simultaneity from the perspective of two observers moving at a constant velocity
   - Label lengths and times in the different frames $_t$ for moving observer (on train) and $_g$ for stationary observer (on ground)
   - Consider light-bulb hanging at centre of train car. At $t = 0$ it emits a light pulse that goes off in all directions at $c$
   - If there is a detector at each end of the train car: Which one records the light pulse arrival first?
   - For Anna (observer in train) the pulses arrive at same time. Light travels the same distance to get to each detector
   - For Bob (stationary on the ground), the train moves forward (slightly) a distance $vt_g$, while light pulse is propagating.
     - Since light travels at the same speed for Bob
     - The 'rear' detector (that has moved towards where the light pulse was emitted) detects the light **first**
     - The 'forward' detector (that has moved away) detects the light **later**
   - Two events that were simultaneous for Anna (moving observer) are **not** simultaneous for Bob (stationary observer)

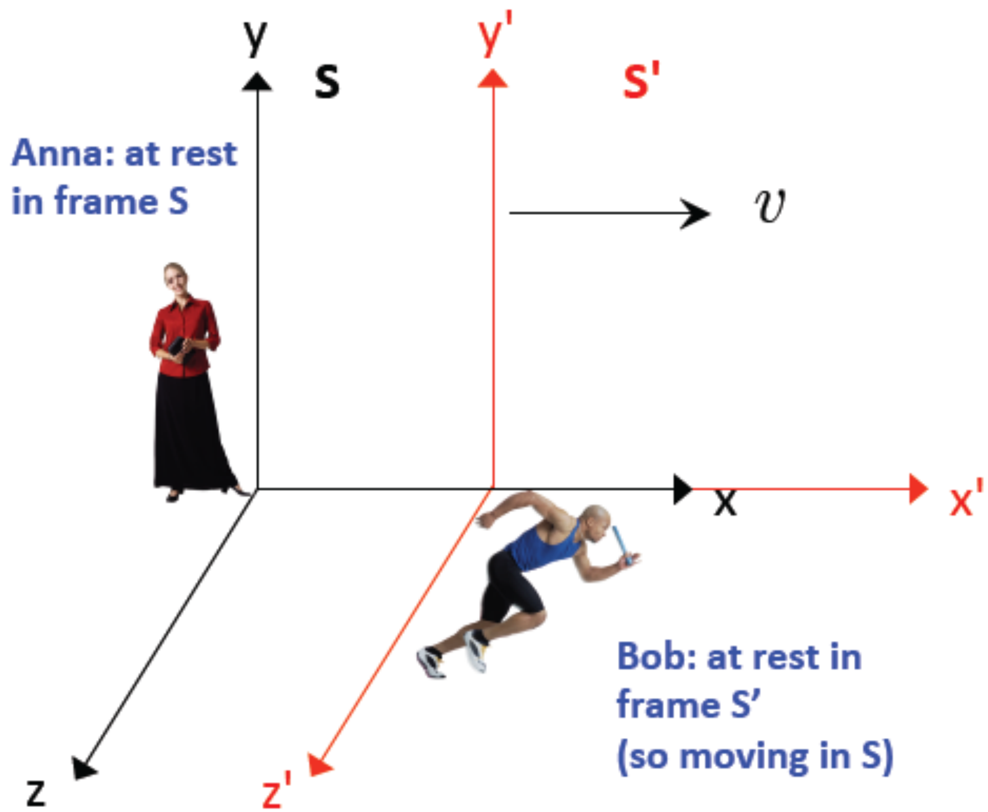
   II Textbooks example of (non-)Simultaneity
   - Consider instead two light sources (one at either end of the train car) with a detector in the centre
   - Lights are switched on simultaneously and detector measures time difference between arrival from the two sources
   - What does the moving observer (Anna) see?
   - What does the stationary observer (Bob) see?
   - Work through this for yourself and see if you can see how the result leads to the same conclusions as my example.

   III Time Dilation
   - Consider same train car, but now with light detector on floor directly below light source (distance $h$).
   - How long does it take for light to reach this detector
     - For observer on the train (Anna) this is simple: $t_t = h/c$ – just the time for light travel from roof to floor of the car
     - For observer on the ground (Bob) the path the light takes is slightly more complicated.
     - By the time the light reaches the detector on the floor, the car will have moved forward a distance $vt_g$
     - So the total path of the light is $\sqrt{h^2 + (vt_g)^2}$ and thus the time is $t_g = \frac{1}{c}\sqrt{h^2 + (vt_g)^2}$
     - Which gives $t_g = \frac{h}{c}\frac{1}{\sqrt{1-v^2/c^2}} = \gamma t_t$ where $\gamma = \frac{1}{\sqrt{1-v^2/c^2}}$
     - So time intervals for the fixed observer (Bob) are longer than for the moving observer (Anna) by a factor $\gamma$.

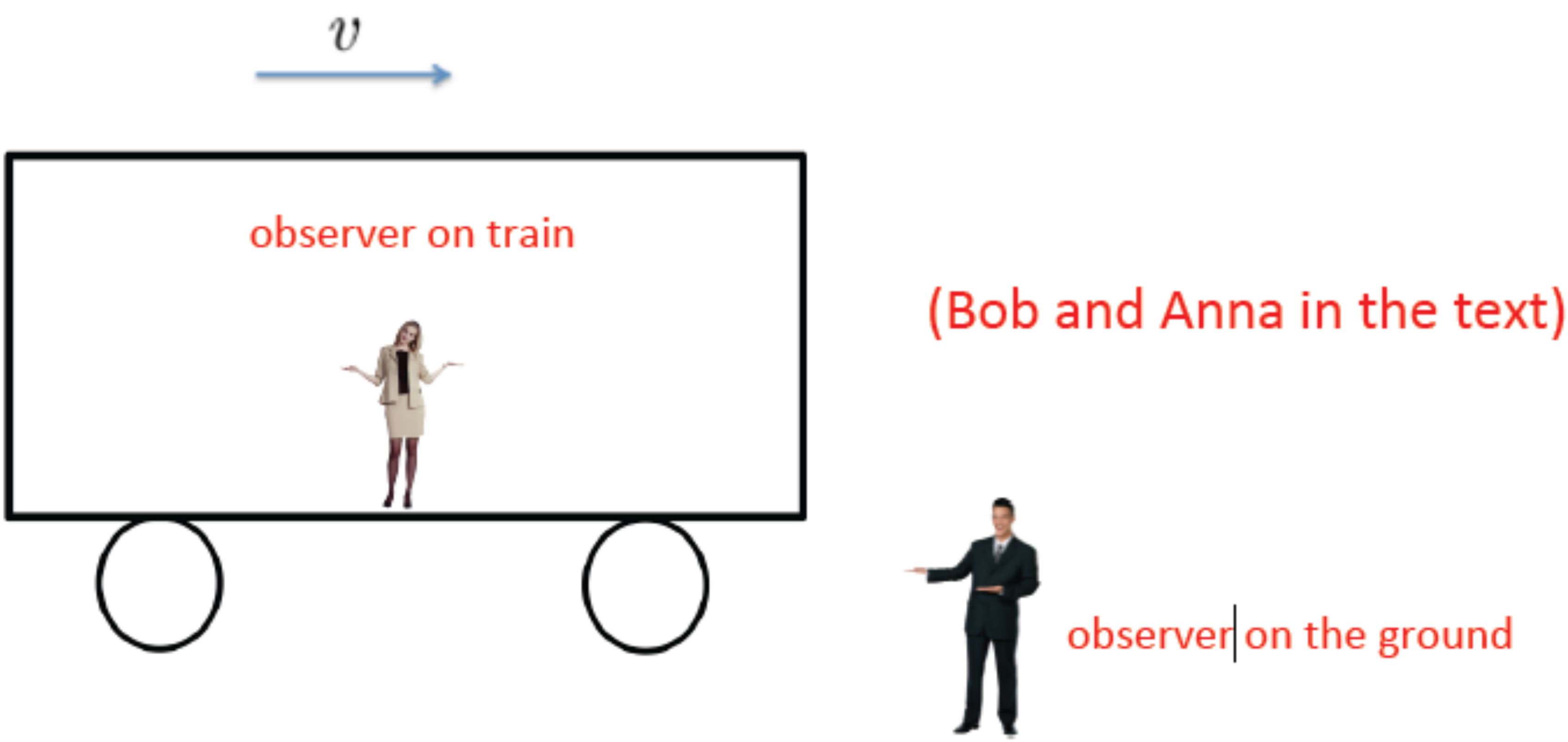
- Have seen that time intervals grow by a factor $\gamma$ from moving to stationary frame
- Distance intervals shrink by a factor $\gamma$ from moving to stationary – actually start of lecture 3
- Next time see how the actual coordinates transform to achieve these two – very real – effects

# Classical Relative Speed

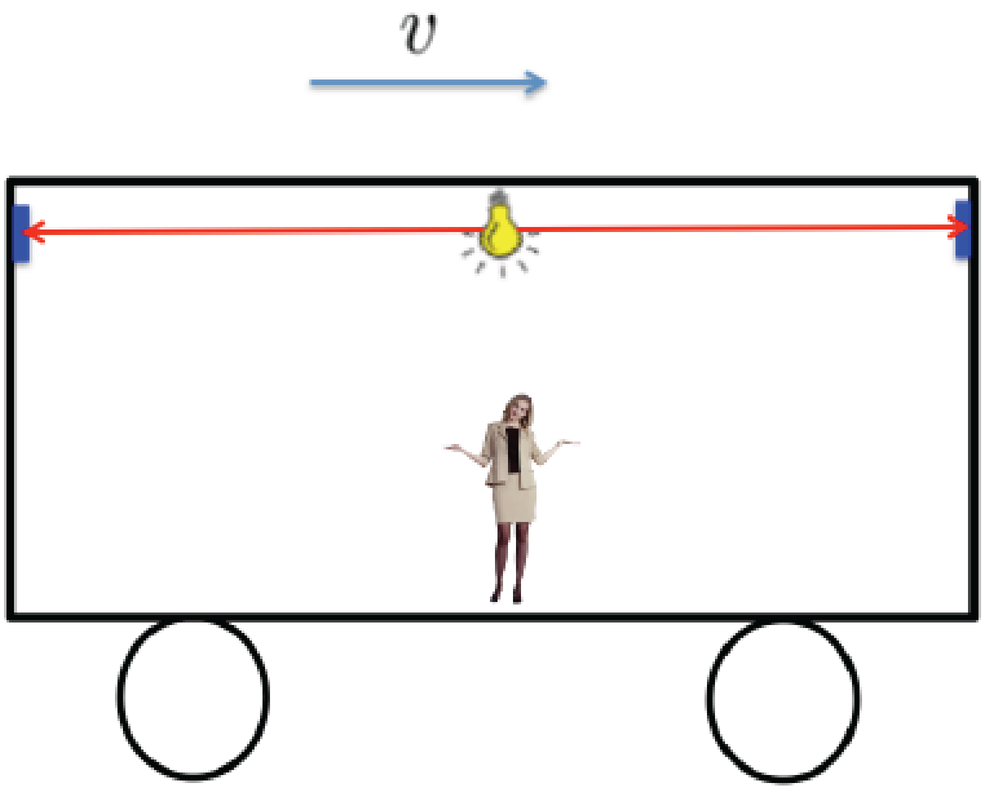
# Defining a Pair of Inertial Reference frames



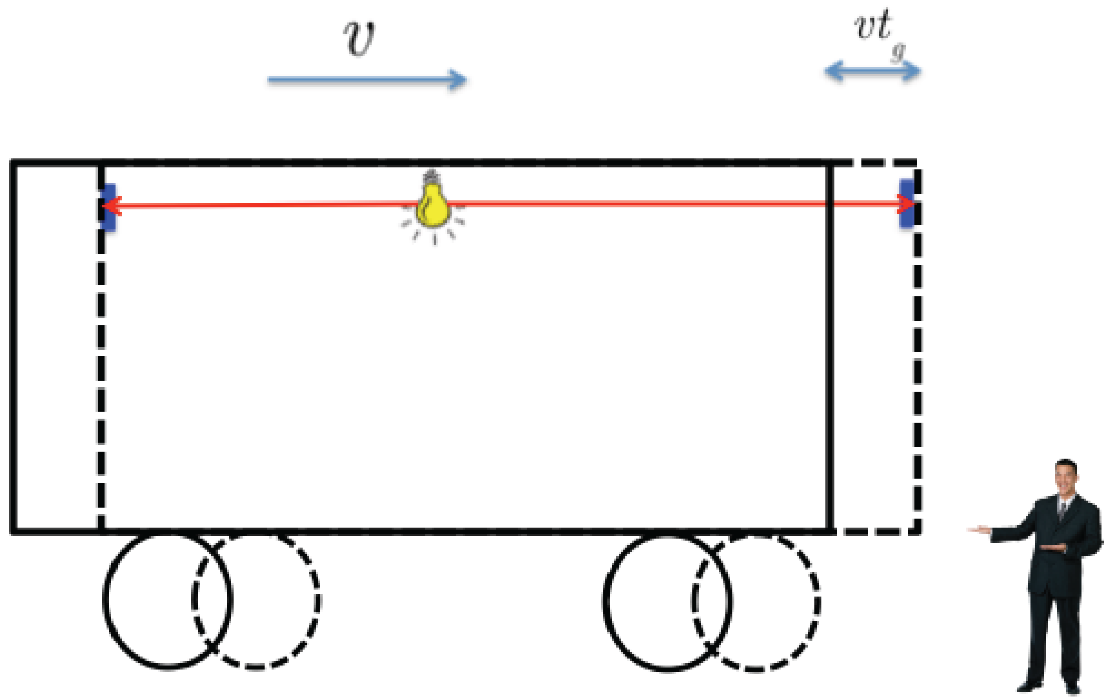
# Thought Experiments (i)



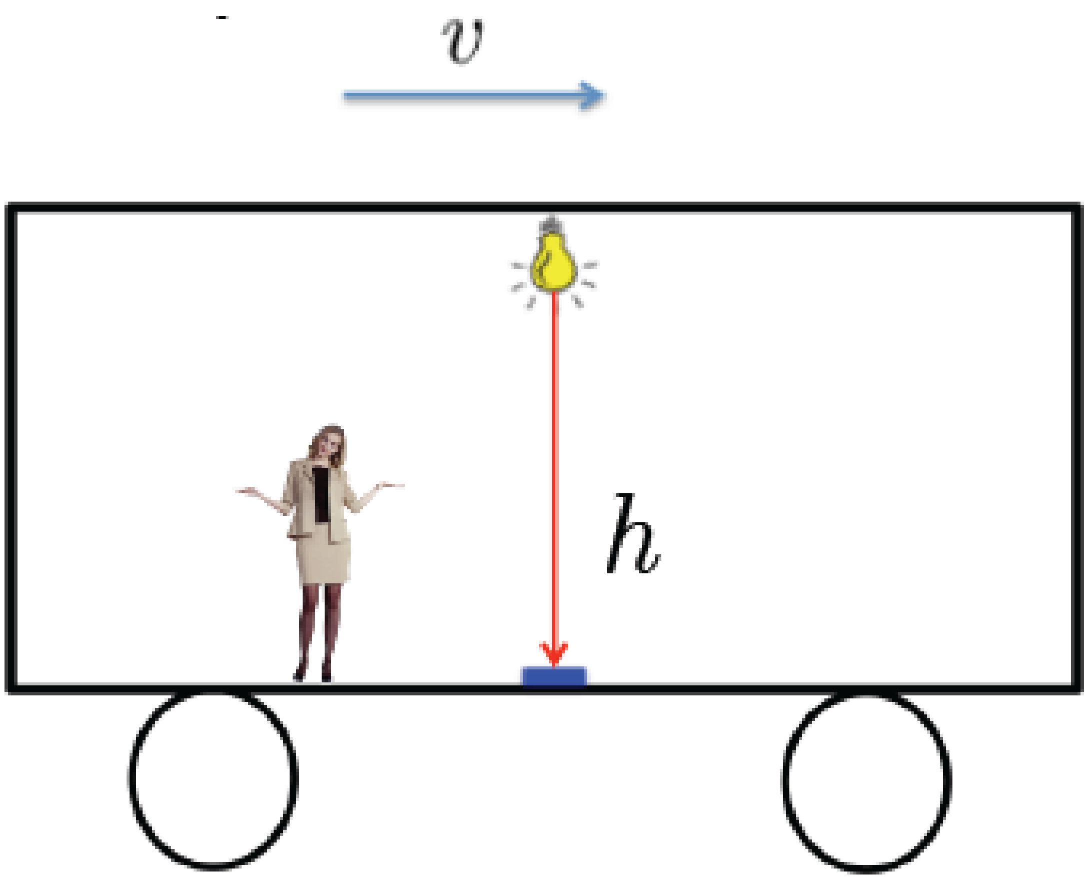
# Moving Observer: Simultaneity



# Stationary Observer: Simultaneity



# Time Interval for Moving Observer



# Time Interval for Stationary Observer