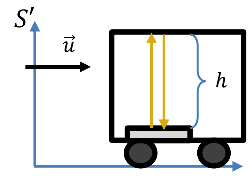
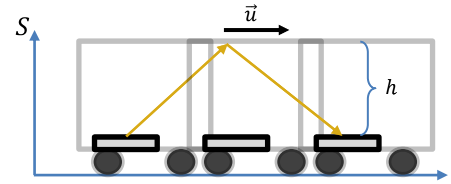
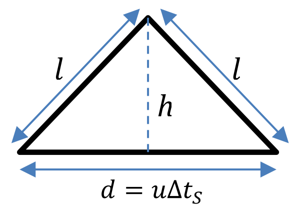
CONCEPT: TIME DILATION



- Consider the following experiment:
  - We will consider the S frame to be the lab frame and S' to be moving at u
  - An observer in S' then fires a laser upward from the floor of the train
  - This laser travels a height h before bouncing off the roof and returning
  - The total distance traveled was $2h$, and so the travel time $\Delta t_{S'} = 2h/c$



- Because the train is moving, an observer in S sees light travel along a triangle
  - The light travels a distance of l on the way up and the way down
  - During the time that the light takes, Δt_S, the train travels a distance $d = u\Delta t_S$
  - The height traveled by the light is still h, so $l^2 = h^2 + \frac{1}{4}u^2\Delta t_S^2$
  - So far, nothing strange about this result; this is just a geometry



- If we now apply the second postulate of Special Relativity, the light in S MUST travel at c, exactly as it does in S'
  - Remember! In Galilean relativity, we'd expect the speed of light in S to be $c + u$
  - This means that $l = c\Delta t_S$, and so $l^2 = c^2\Delta t_S^2 = h^2 + \frac{1}{4}u^2\Delta t_S^2$
  - Solving for Δt_S^2 gives us $\Delta t_S^2 = \frac{h^2}{c^2 - \frac{1}{4}u^2}$, which, after some algebra, becomes $\Delta t_S^2 = \frac{4h^2/c^2}{1-u^2/c^2}$
  - So, we find that in the frame S, the time taken by the light to travel up and down is $\Delta t_S = \frac{\Delta t_{S'}}{\sqrt{1-u^2/c^2}}$

- The time measured in S' is **different** than the time measured in S – this is known as TIME DILATION

  $\Delta t_S =$ ____________ where $\gamma =$ ________________ is called the LORENTZ FACTOR

  - The time in S is known as the ________________ time, and is ALWAYS ________________ than the time in S'
  - The time in S' is called the proper time, or the rest time because it is measured at rest with respect to the event
  - Typically, the dilated time will be given by $\Delta t'$ and the rest time by Δt_0

<u>EXAMPLE</u>: Spaceships have to launch at speeds larger than 11.2 km/s to escape Earth's gravity. If a spaceship launches at this speed, will astronauts on the ship experience any significant time dilation?

EXAMPLE: TIME DILATION FOR A MUON FROM THE ATMOSPHERE

Muons are very tiny, charged particles that are emitted from high up in our atmosphere when cosmic radiation enters our atmosphere and collides with atoms in the air. An emitted muon will typically travel at a speed of 90% the speed of light, towards the ground. Muons are unstable, though, and will decay after only about 2.2 μs in their rest frame. How long will a muon take to decay in a lab frame?

PRACTICE: TIME DILATION ON THE SPACE STATION

The international space station travels in orbit at a speed of 7.67 km/s. If an astronaut and his brother start a stop watch at the same time, on Earth, and then the astronaut spends 6 months on the space station, what is the difference in time on their stopwatches when the astronaut returns to Earth? Note that 6 months is about 1.577×10^7 s, and $c = 3 \times 10^8$ m/s.

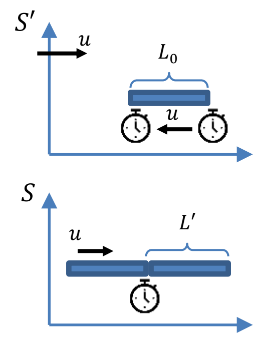
CONCEPT: LENGTH CONTRACTION

● Because time is measured differently in different inertial frames, distances should be measured differently, too

- This phenomenon is known as LENGTH CONTRACTION, and is another fundamental result of Special Relativity

● Imagine a rod of some length L_0, when measured AT REST, moving at u in the lab frame

- Define S as the lab frame, containing a clock at rest (measuring proper time)
- Define S' as the moving frame, moving at u (this is the rod's rest frame)
- In S', as the clock passes the rod, it travels a length L_0, and measures a time $\Delta t'$
- This means that the distance traveled is $L_0 = u\Delta t'$
- In S, the rod passes the clock, and travels a distance L', while the clock measures Δt_0
- The means that the distance traveled is $L' = u\Delta t_0$
- This means that $u = L'/\Delta t_0 = L/\Delta t'$, or, $L = (\Delta t_0/\Delta t')L_0$



● The length measured in S' is **different** than the length measured in S – this is known as LENGTH CONTRACTION

$L' =$ __________

- Recall that $\Delta t' = \gamma\Delta t_0$

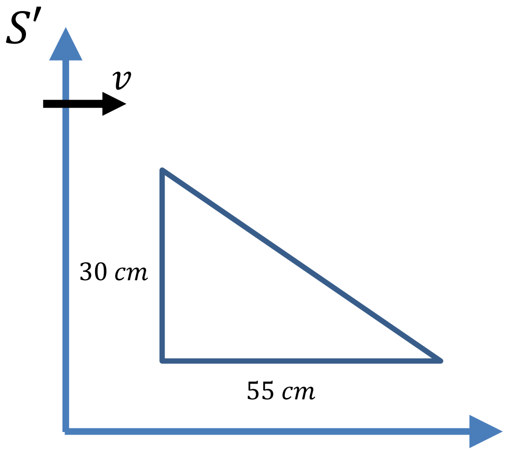
EXAMPLE: A spaceship is measured to be 100 m while being built on Earth. If the spaceship were flying past the Earth at 10% the speed of light, how long would it be measured by an observer at rest on Earth?

<u>EXAMPLE: LENGTH CONTRACTION FOR A MUON FROM THE ATMOSPHERE</u>

Muons are very tiny, charged particles that are emitted from high up in our atmosphere when cosmic radiation enters our atmosphere and collides with atoms in the air. An emitted muon will typically travel at a speed of 90% the speed of light, towards the ground. Muons are unstable, though, and will decay after only about 2.2 μs in their rest frame. How far will a muon travel in a lab frame?

PRACITCE: LENGTH CONTRACTION OF A RIGHT TRIANGLE

In the following figure, a right triangle is shown in its rest frame, S'. In the lab frame, S, the triangle moves with a speed v. How fast must the triangle move in the lab frame so that it becomes an isosceles triangle?



CONCEPT: PROPER FRAMES AND MEASUREMENTS

● It's really important to be absolutely clear about the meaning of a "proper" frame, or a "proper" measurement

- A "proper" frame is a frame that is at rest with respect to ______________________________

- Sometimes the proper frame is the lab frame, and sometimes it's the moving frame

● For length contraction, the proper frame is easy to find – it's the one at rest with respect to the object

- You are interested in the length of an object, so you need to be at rest to measure its length
- If the object is moving relative to you, the length you'll measure will be contracted

EXAMPLE 1: A ship passed Sally, who is standing on the Earth's surface watching the ship fly by. If Sally measures the length of the ship to be 100 m, is this the proper length or the contracted length?

● For time dilation, finding the proper frame is often times more tricky than for length contraction

- No matter what, though, the problem is going to impart some sort of significance on one time vs another
- Typically, you'll be interested in some sort of "event" happening in a problem
- The proper frame is going to be the one at rest with respect to ______________________

EXAMPLE 2: An astronaut is leaving home on a long trip, but before he goes he synchronizes a watch with his brother, allowing them to compare the amount of time that passes when he returns. During the astronaut's trip, he measures himself to be 5 years older, while his brother will measure a different amount of time passing. Which of the two is measuring the proper time?