



Introduction

- Last Time: Time Dilation, Space Contraction, Speed Limit, "Paradoxes"
 - Moving Clocks run slow
 - · Moving objects shrink along the line of motion
 - Events in different places can happen in different order to different observers
 - Simultaneity and the "garage paradox" not really a paradox
 - Something different happens in the "twin paradox"
 - Real world: supports conclusion of "twin paradox"

Today: Mass is Energy, Energy is Mass

- Recall: Existence of speed limit from principle of relativity
- Enforcement of speed limit (relativistic mass)
- Mass is energy (E = mc²)
- · Einstein's own words:
- http://www.aip.org/history/einstein/voice1.htm

Review of the idea that nothing can travel faster than the speed of light . The example below shows directly, from the principle of relativity, that c is the ultimate speed limit. (This is a version of the example from the text, page 108.) <u>i</u> → B → O → A → E <u>i</u> → B Light pulses (A & B) are emitted at 0, travel to mirrors, are reflected and return to 0.

The Speed Limit

Now suppose O is moving (with respect to us) to the right at a speed which is greater than the speed of light. What do we see?
We see pulse B never returns to O!! After pulse reflects from the mirror, we see it move at the speed of light which would be less than the speed with which O is moving ⇒ B will never catch up to O!
Whether B returns to O or not cannot depend on the reference frame. Therefore, O cannot move at speeds greater than light!

How is the Speed Limit Enforced?

- We have now seen that if things could travel faster than the speed of light, the Principle of Relativity would be violated.
- Question: How is this speed limit enforced? Why can't we just keep adding energy to the object which will cause its velocity to keep increasing??
- Answer: As we add energy to the object, its mass increases also which makes it harder to accelerate!
- How can this be?? Isn't mass a property of the object, an absolute quantity? It is in classical physics, but























- Result of Einstein's Postulates: Mass and energy are equivalent!
- Completely different from Newtonian ideas!
- Now the ideas of mass and energy are unified -- two things which appeared to be completely unrelated in the old paradigm (classical physics) are the same in the new paradigm (special relativity)!





- How long would it take?
- If you body can withstand acceleration only up to around a ~ 10g ~ 100m/s², it will take about

Time ~ c/a ~ 3,000,000 s ~ 0.1 years

• Most of the energy must be supplied far from the earth - how to do this?????



Summary

Nothing can go faster than the speed of light.

- How is this speed limit enforced?
 - The faster you go, the more massive you become!
 - A force causes a body to accelerate: momentum changes
 As the speed inspectors, more and more of the the operative accelerate.
 - As the speed increases, more and more of the the energy goes into increased mass and less and less into increased velocity
 Never reach the speed of light!
- Energy and mass are equivalent: E = mc²
 - Unifies two concepts that were totally previously disconnected
 - Nevertheless, agrees with Newton's formulas for small v
 - Applies to ALL forms of energy and mass
 - Usually too small to be detected
 - Output of large power plant for 1 year ~ 1 Kg
 - Nuclear energy involves larger changes in energy
 - Rest mass of nuclei converted into kinetic energy
 - 1 gram of mass ~ energy released in an atomic bomb