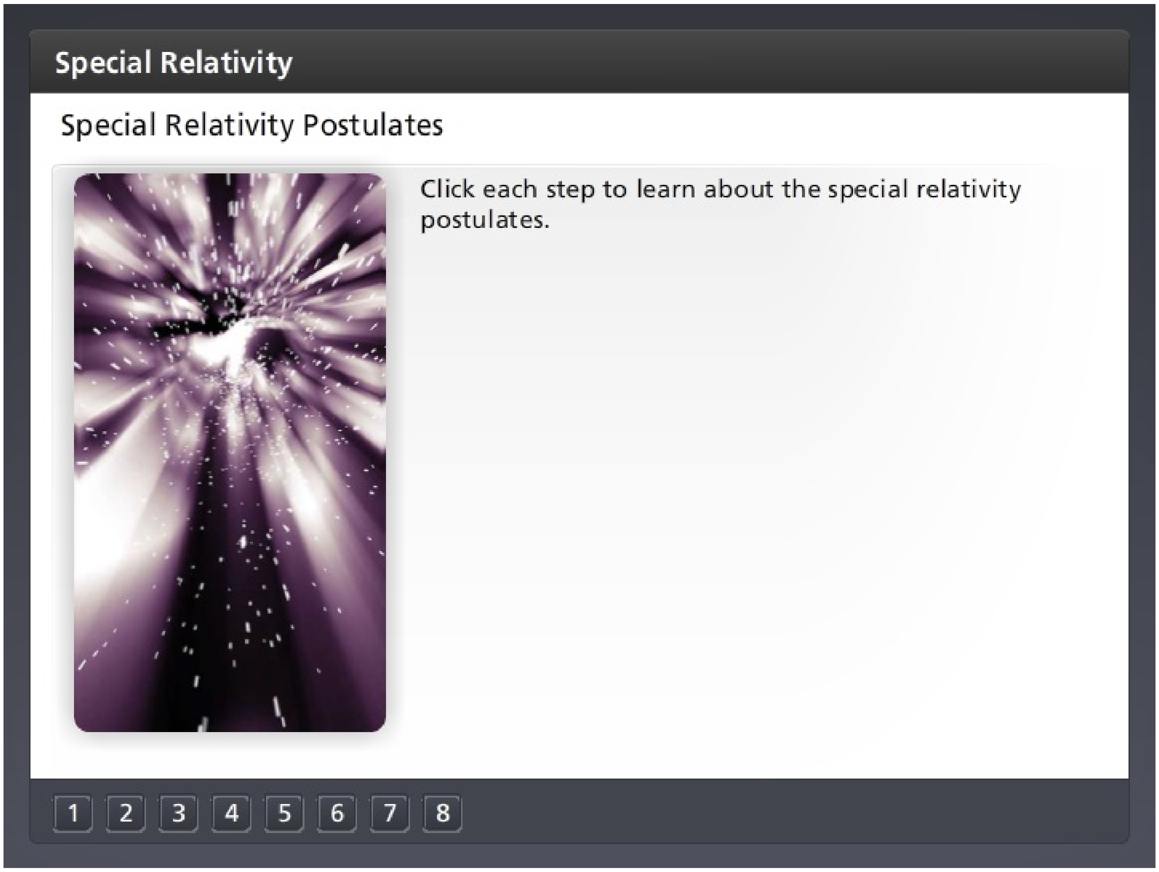
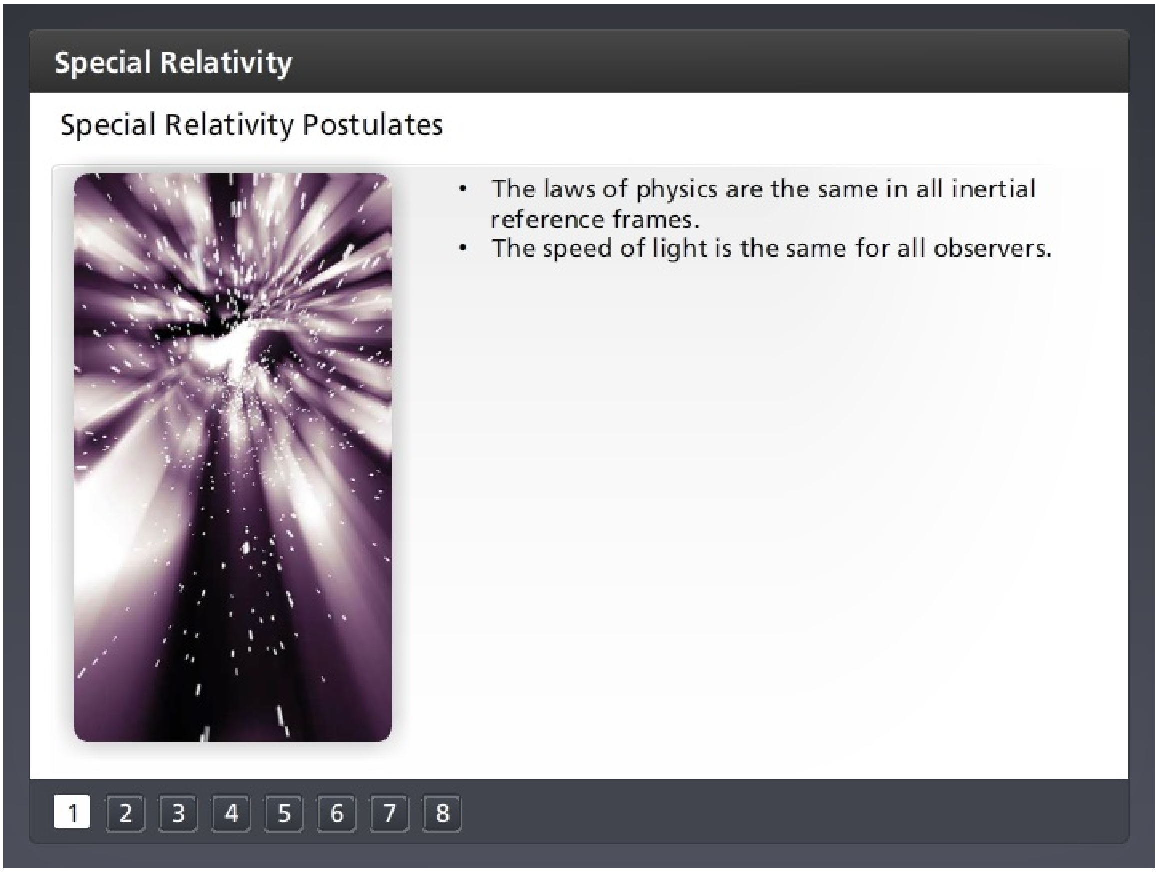
Module 8: 20th Century Physics
Topic 2 Content: Special Relativity

Special Relativity Postulates



Click each step to learn about the special relativity postulates.

Special Relativity Postulates

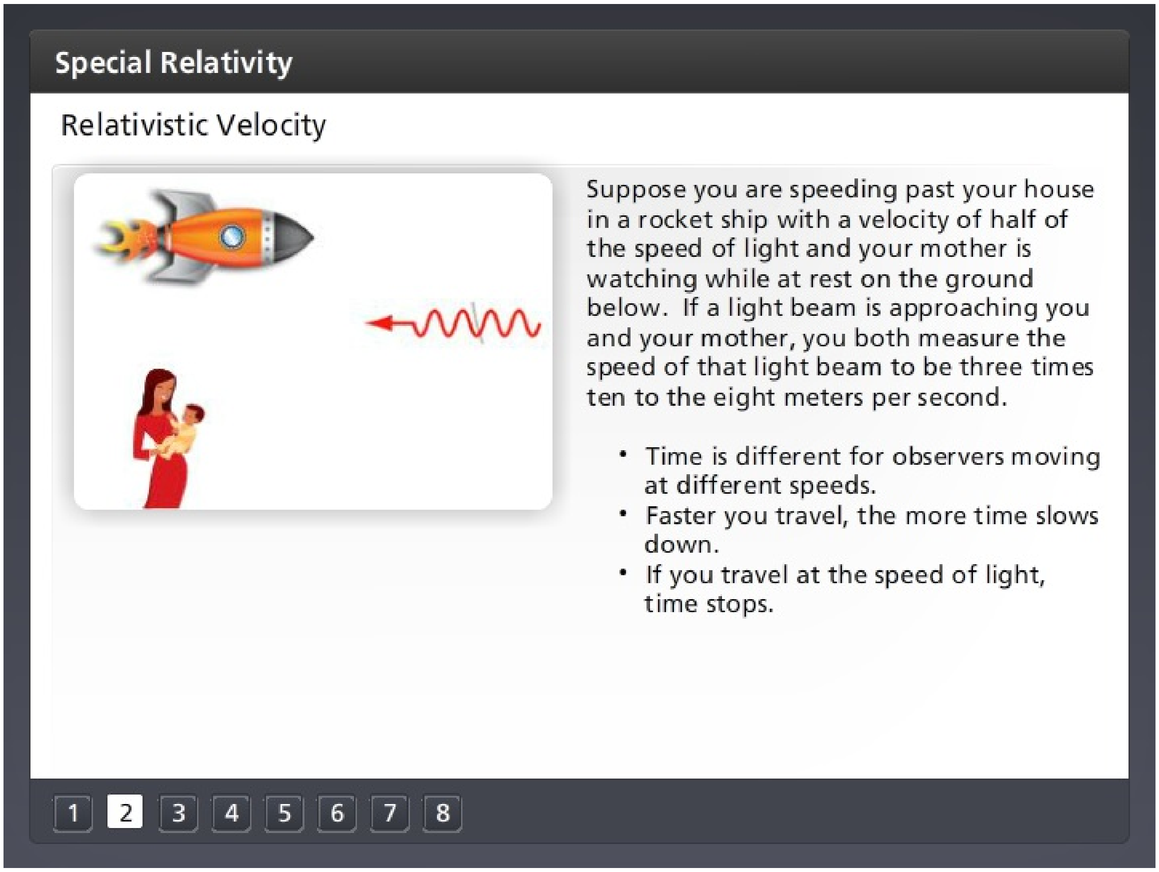


- The laws of physics are the same in all inertial reference frames.
- The speed of light is the same for all observers.

Einstein had two postulates for special relativity. First that the laws of physics are the same in all inertial reference frames. Second, that the speed of light is the same for all observers, regardless of their motion, or the motion of the object that emits the light.

These postulates were not immediately accepted by the scientific community. The idea of giving up time as a universal constant for all observers was difficult to accept. It took years to collect evidence to support Einstein's theory so that it would be accepted.

Relativistic Velocity



Suppose you are speeding past your house in a rocket ship with a velocity of half of the speed of light and your mother is watching while at rest on the ground below. If a light beam is approaching you and your mother, you both measure the speed of that light beam to be three times ten to the eight meters per second.

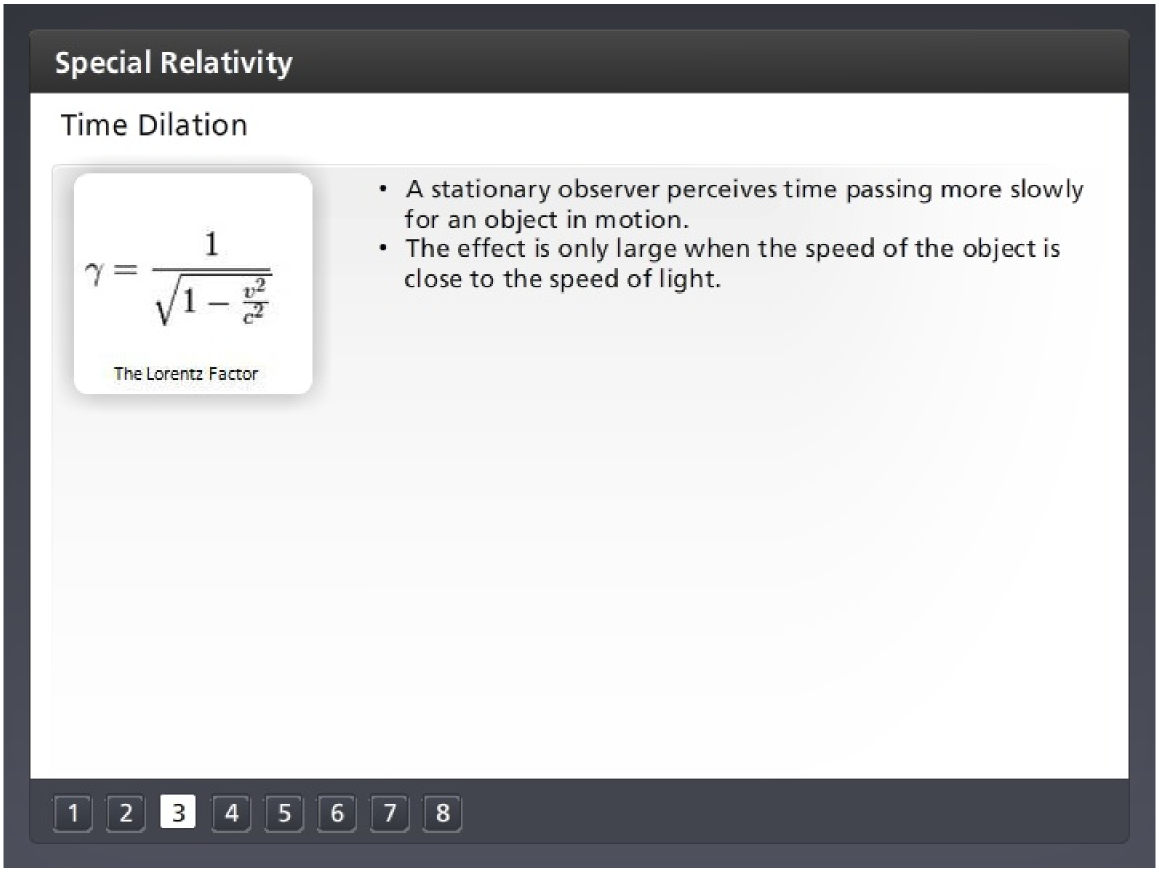
- Time is different for observers moving at different speeds.
- Faster you travel, the more time slows down.
- If you travel at the speed of light, time stops.

Suppose you are speeding past your house in a rocket ship with a velocity of half of the speed of light and your mother is watching while at rest on the ground below. If a light beam is approaching you and your mother, you both measure the speed of that light beam to be three times ten to the eight meters per second. This is a relativistic effect.

In our previous studies of motion we assumed that time is seen identically by all observers. However, keeping this assumption makes it impossible to explain how light can travel at the same speed according to both of the observers. The way that Einstein reconciled this was to say that time is different for observers moving at different speeds. The faster you travel, the more time slows down. If you travel at the speed of light, time stops.

Therefore, in our previous example, because you are moving at one half the speed of light, you see time as passing more slowly. The observer at rest sees time passing at the normal rate. This is how Einstein explained why light has the same speed in your reference frame as it has in the reference frame that is not moving.

Time Dilation



- A stationary observer perceives time passing more slowly for an object in motion.
- The effect is only large when the speed of the object is close to the speed of light.

According to Einstein, if we start with two synchronized clocks and then one clock stays put while the other one is sent on a journey, the clock that travels will have measured less time than the one that stayed put. A stationary observer perceives time passing more slowly for an object in motion

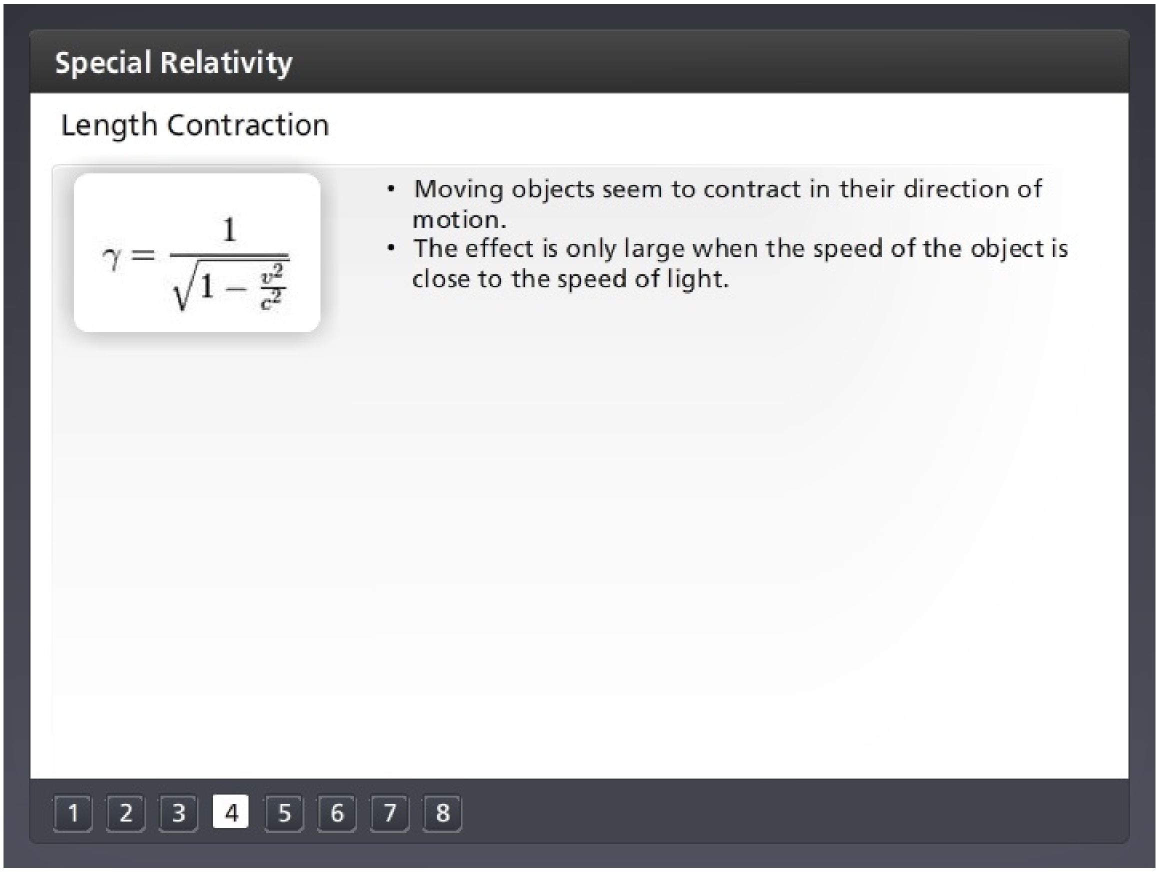
The factor that describes the size of this effect is called the Lorentz factor. One divided by the square root of the quantity one minus v squared over c squared gives the value of the Lorentz factor. Notice that when v is small, v squared over c squared is going to be very close to zero, and the denominator of this equation will be very close to one. V must be very large to have appreciable slowing of time. The closer v gets to c, the smaller the denominator gets and the larger the Lorentz factor gets. The time in the moving reference frame will be the time in the rest frame multiplied by the Lorentz factor.

For the change to be significant, the speed, v, must be close to the speed of light, c, or three times ten to the eight meters per second. At normal speeds, the effect of time dilation is negligible. If an object could reach the speed of light, or if v could equal c, a stationary observer would perceive that time had stopped for that object.

So if you had a twin brother and you sent him off in a space ship to travel at ninety percent of the speed of light, one year for him would be like 2.29 years for you.

Another consequence of time dilation is that events that occur simultaneously in the reference frame of an observer at rest may not occur simultaneously for an observer in a moving reference frame.

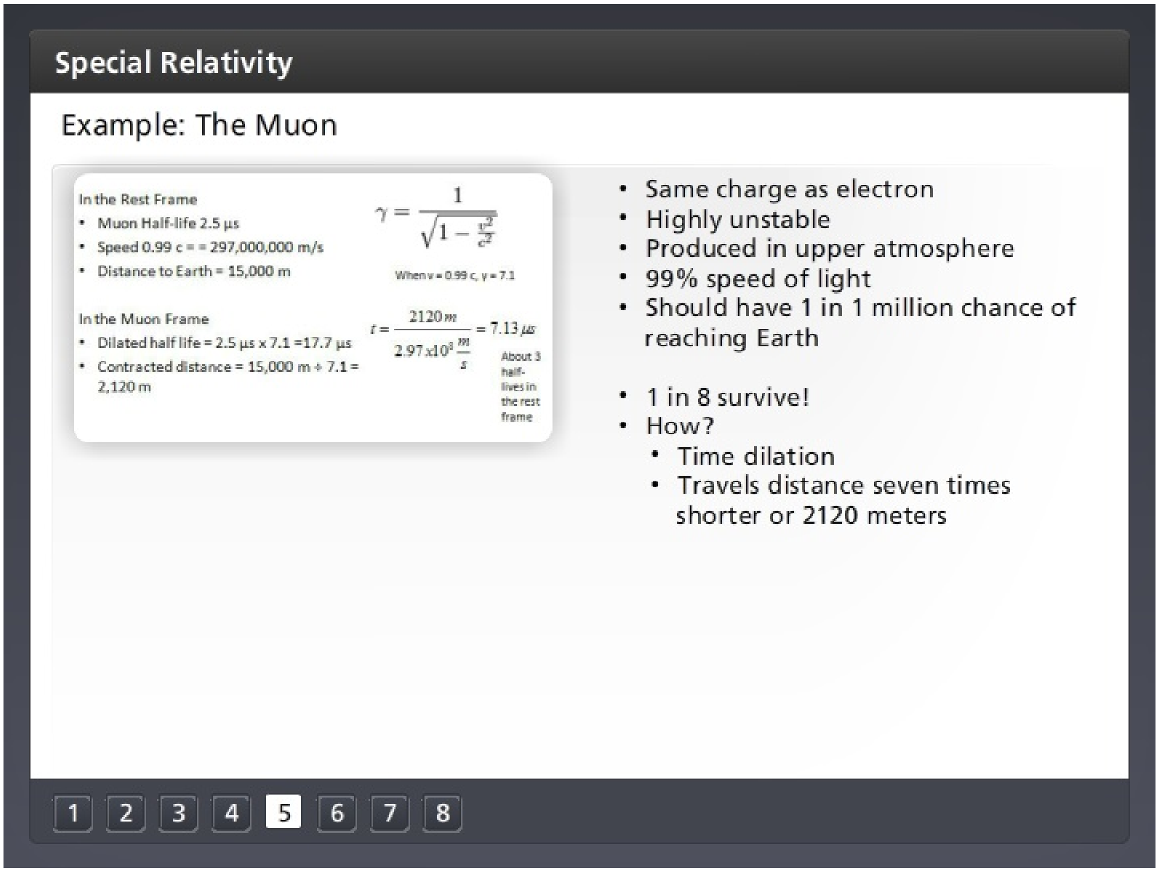
Length Contraction



- Moving objects seem to contract in their direction of motion.
- The effect is only large when the speed of the object is close to the speed of light.

Another result of special relativity is moving objects seem to contract in their direction of motion. The length in the moving reference frame is the rest length divided by the Lorentz factor.

Example: The Muon



- Same charge as electron
- Highly unstable
- Produced in upper atmosphere
- 99% speed of light
- Should have 1 in 1 million chance of reaching Earth

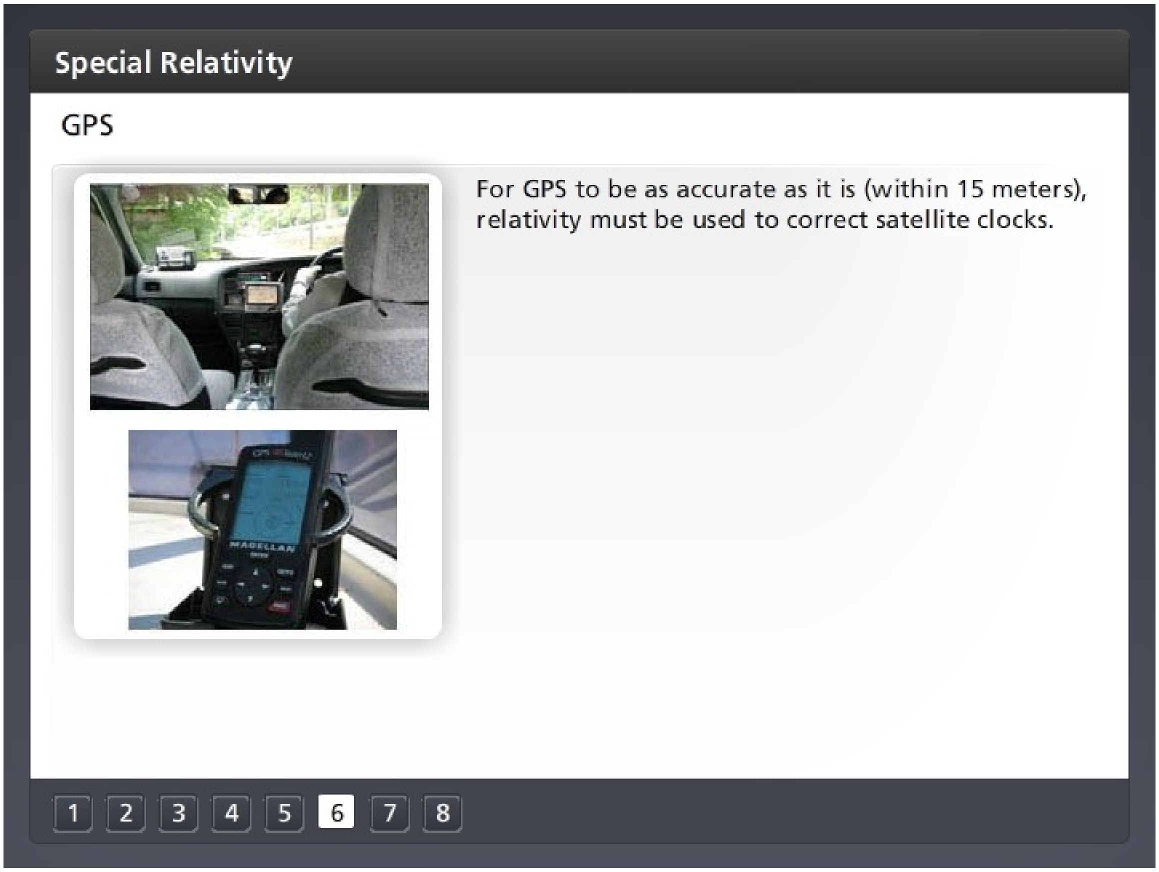
- 1 in 8 survive!
- How?
  - Time dilation
  - Travels distance seven times shorter or 2120 meters

A muon is a sub-atomic particle with the same charge as an electron, and a mass about 200 times as big as an electron. Muons are highly unstable particles with a half life of about two point five times ten to the negative six seconds, or two point five micro seconds. Typical muons are produced in the upper atmosphere with a speed of about 99% of the speed of light. They are produced at an altitude of about 15,000 meters. By these numbers, muons should have pretty slim chances of making it to Earth. It should take the muon about 50 micro seconds to get to Earth, this is about twenty half lives. Given these times, a muon should have about a one in a million chance of reaching Earth before it decays. However, the actual survival rate is about one in eight. Why is there such a difference?

Two effects contribute to this difference. First, the muon experiences time dilation. At 99% of the speed of light, time is seven times slower. The dilated half-life is seventeen point seven micro seconds. And the distance the muon travels is seven times shorter, or 2120 meters. Traveling at 99 percent of the speed of light, muons reach the Earth in less than three half-lives, as measured in the moving reference frame. One-half to the third power is one eighth.

Therefore, the unexpectedly higher survival rate for muons can be explained using the relativistic ideas of time dilation and length contraction.

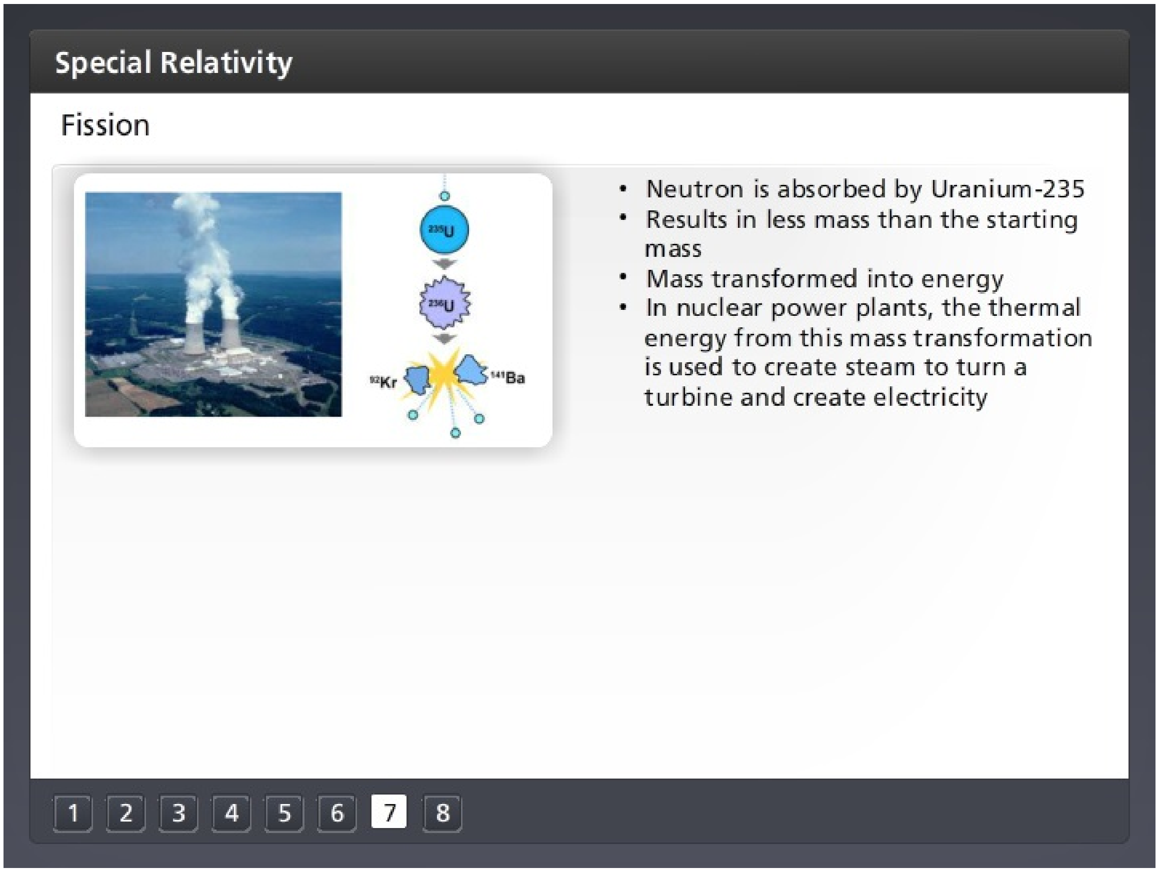
GPS



For GPS to be as accurate as it is (within 15 meters), relativity must be used to correct satellite clocks.

Now, you might be thinking "When am I ever going to travel at the speed of light?" How is this relevant? Well, if you have GPS in your car or on your phone, the satellite clocks must be corrected using relativity to ensure an accuracy of within fifteen meters.

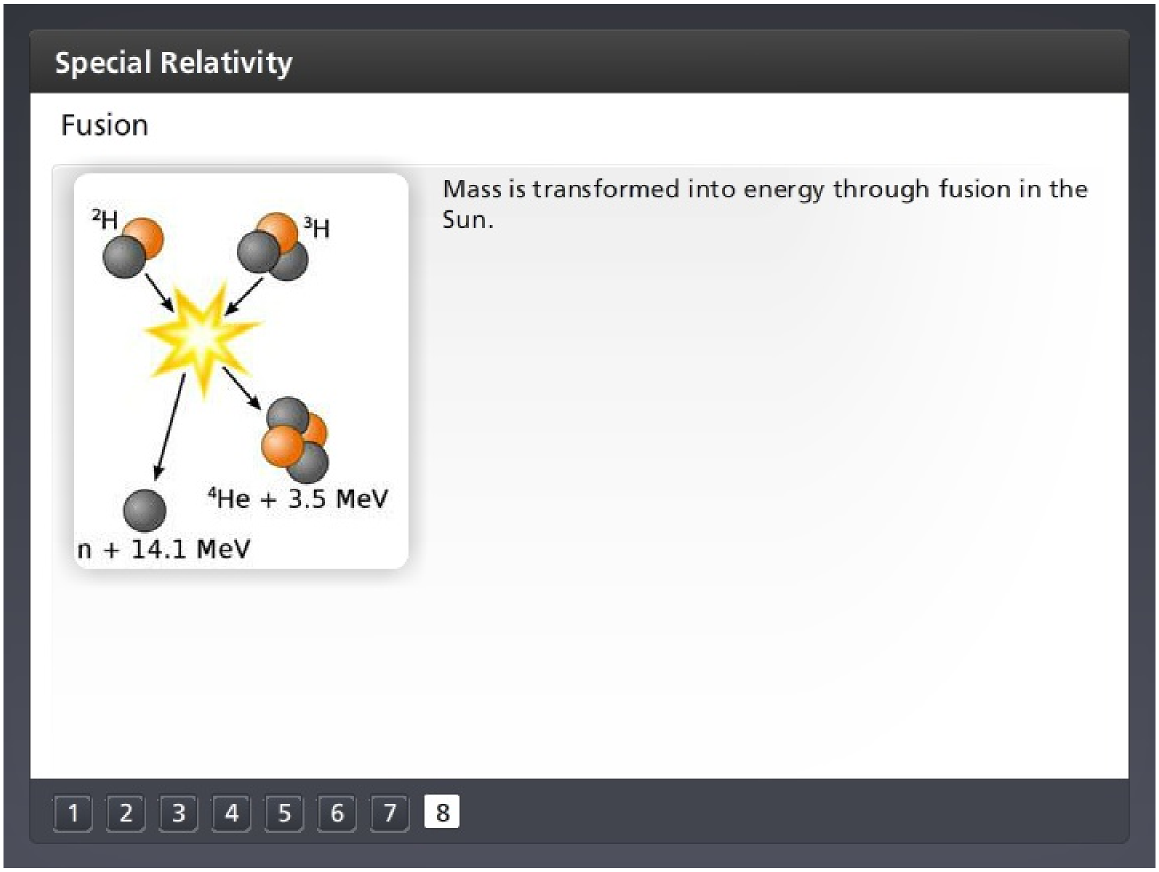
Fission



- Neutron is absorbed by Uranium-235
- Results in less mass than the starting mass
- Mass transformed into energy
- In nuclear power plants, the thermal energy from this mass transformation is used to create steam to turn a turbine and create electricity

One application of E equals m c squared is in nuclear fission. In a fission reaction, a neutron is absorbed by Uranium two thirty five. In this sample fission reaction, the Uranium atom divides into two fission fragments, Krypton ninety two and Barium one forty one, plus three neutrons. Now if we do a little book keeping and add up all of the masses of the fission fragments and the neutrons we will see that there is less mass than the mass that we started with. This mass has been transformed into energy. In a nuclear power plant, the thermal energy from this mass transformation is used to create steam to turn a turbine and create electricity.

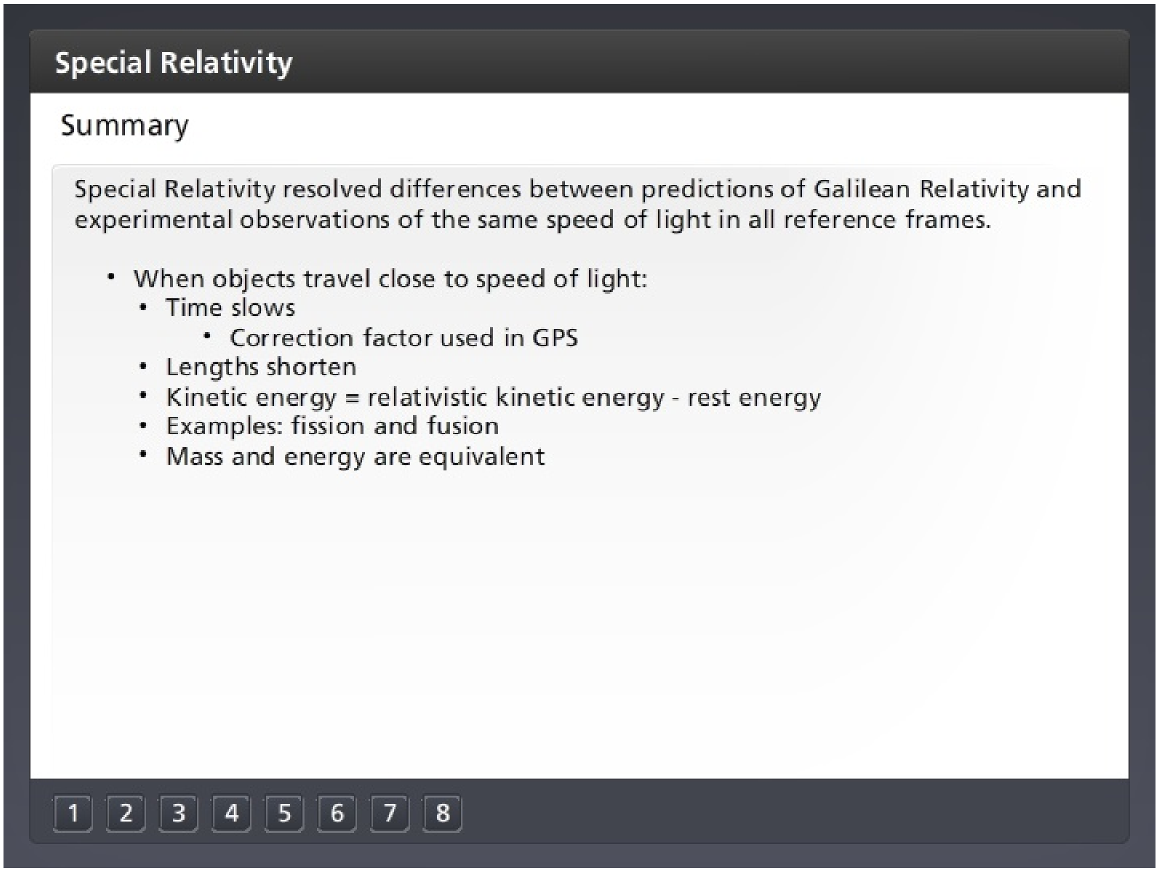
Fusion



Mass is transformed into energy through fusion in the Sun.

The Sun transforms mass into energy by nuclear fusion. In fusion, two smaller atoms combine to make one larger atom. In this process, some mass is transformed into energy. The diagram illustrates two isotopes of hydrogen, deuterium and tritium combining to form helium.

Summary



Special Relativity resolved differences between predictions of Galilean Relativity and experimental observations of the same speed of light in all reference frames.

- When objects travel close to speed of light:
  - Time slows
    - Correction factor used in GPS
  - Lengths shorten
  - Kinetic energy = relativistic kinetic energy - rest energy
  - Examples: fission and fusion
  - Mass and energy are equivalent

In summary, Special Relativity resolved differences between predictions of Galilean Relativity and experimental observations of the same speed of light in all reference frames. When objects travel close to the speed of light, time slows down, the correction factor is used in GPS, and the lengths get shorter.

When objects travel at speeds close to the speed of light, the kinetic energy is equal to the relativistic kinetic energy minus the rest energy. Examples are fission and fusion. Mass and energy are equivalent.