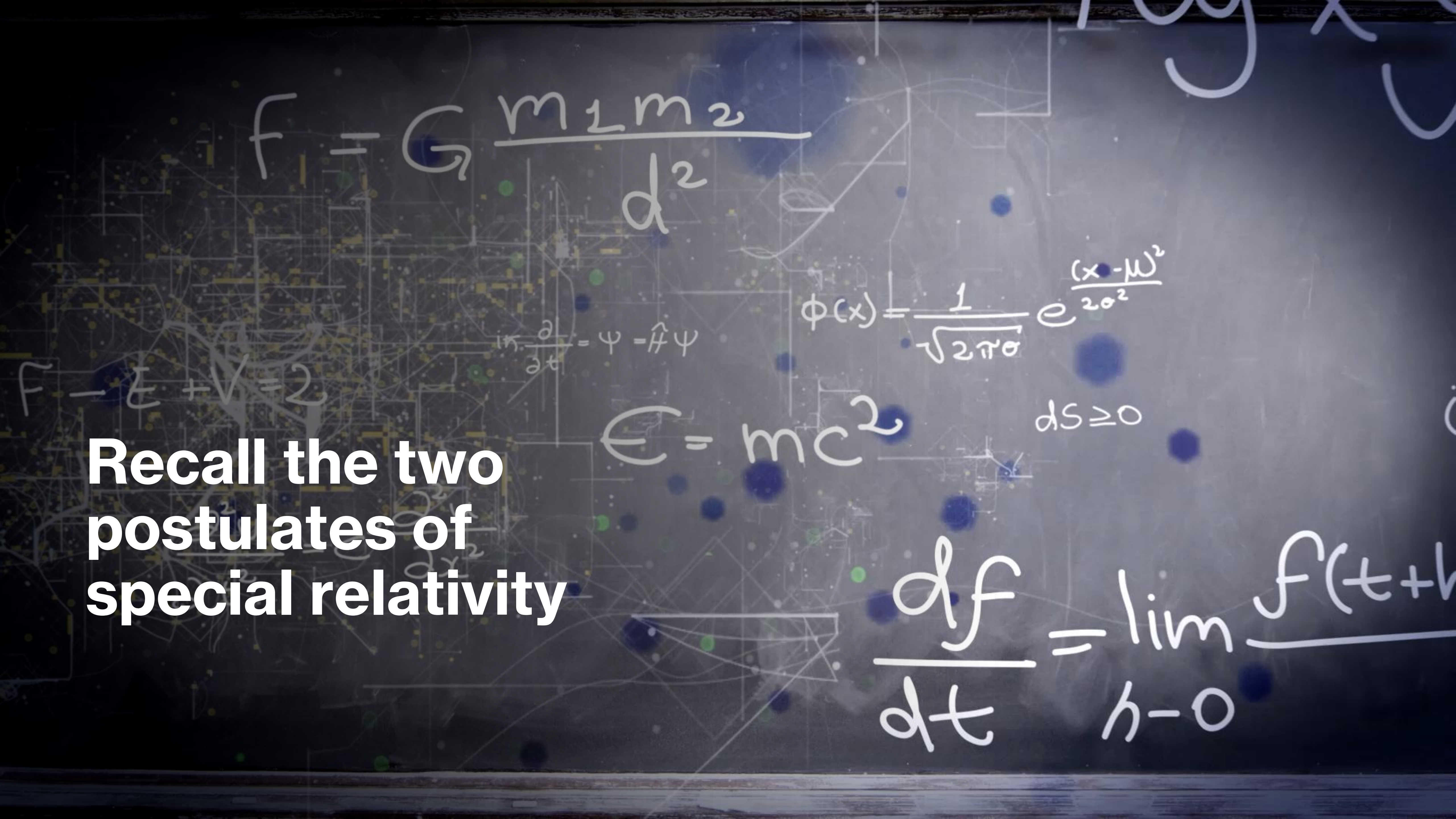
Special Relativity

Physics 12 – Mr. Harris

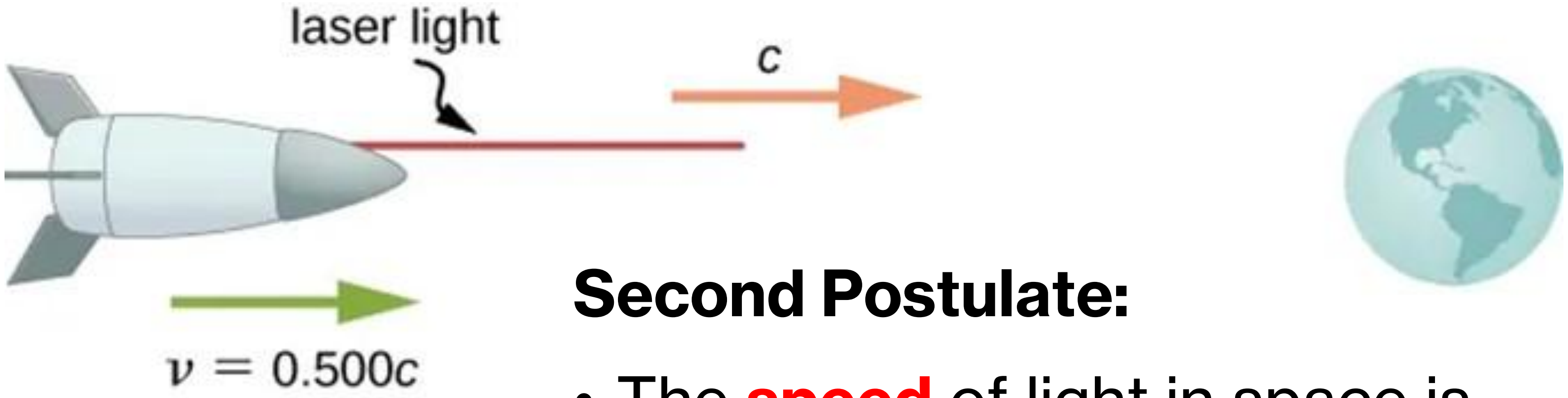


Recall the two postulates of special relativity

The first Postulate of relativity

- The first postulate is called the **Special Relativity Principle:**
  - If two frames of reference move with constant velocity relative to each other, then the laws of physics will be the same in both frames of reference.

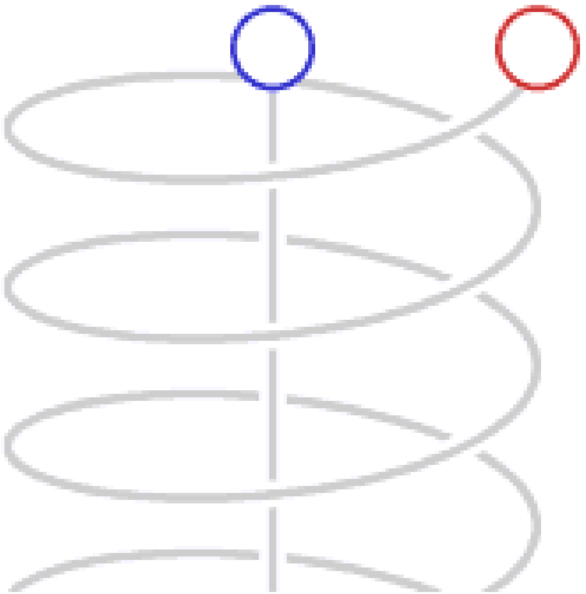
Second Postulate of Relativity

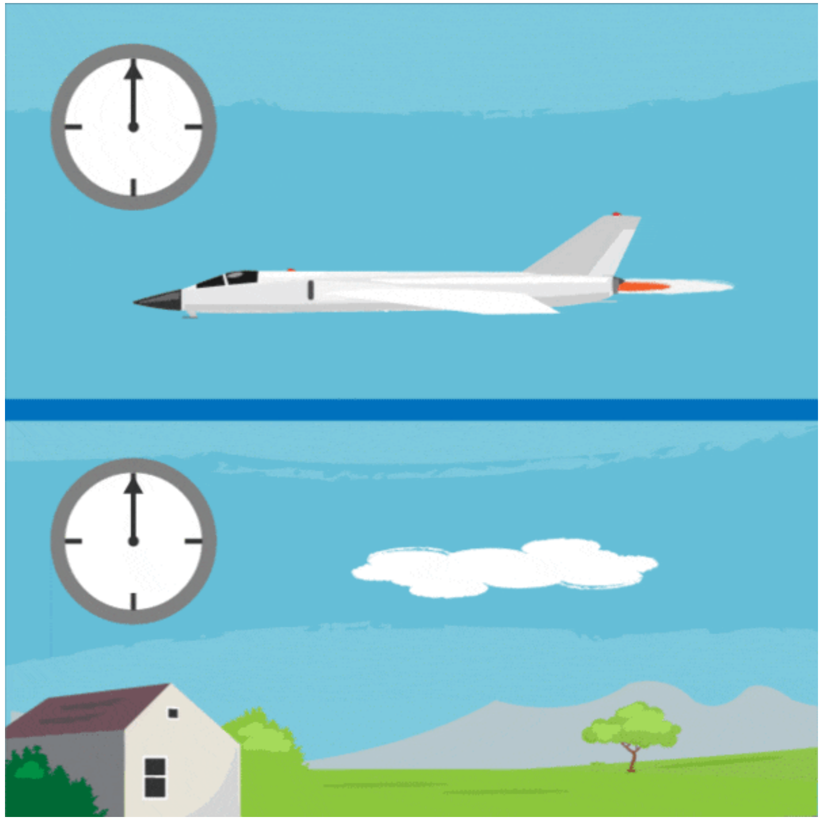


Second Postulate:

- The **speed** of light in space is the same for any **observer** no matter what the velocity of the observer's frame of reference is, and no matter what the velocity of the source of **light** is.

Time Dilation





- According to Einstein's theory of Special Relativity, a lock that is moving will run **slow**.
- The "stretching" of time for a moving object relative to a stationary observer is called **time dilation**

Time Dilation Cont'd

- Einstein imagines a clock where a light beam bounces between two **mirrors**

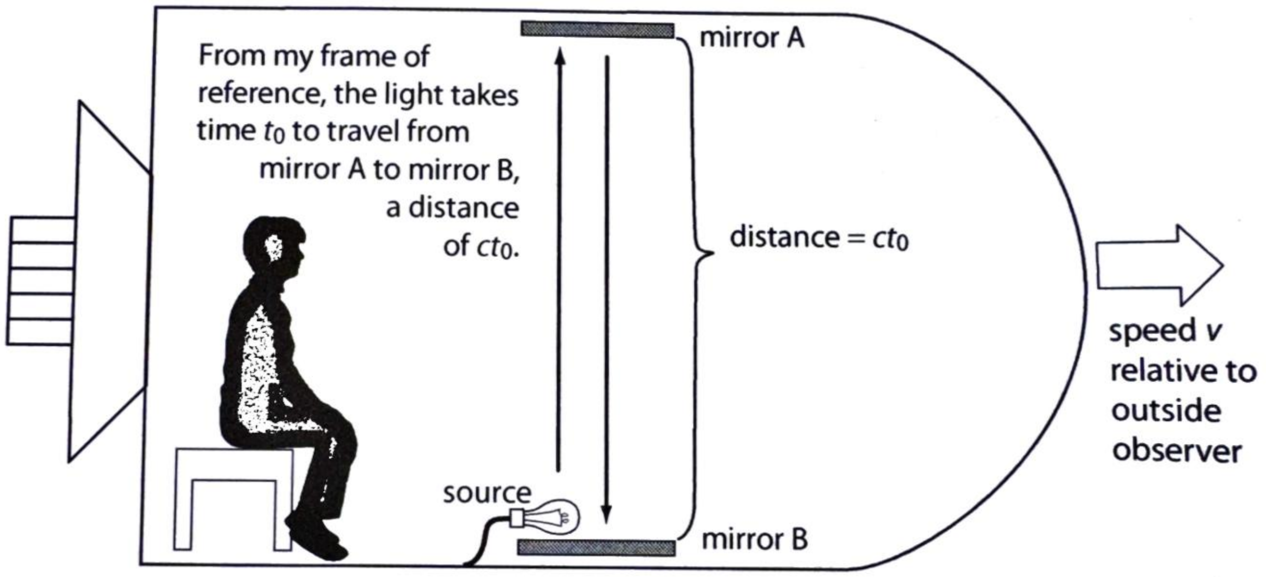
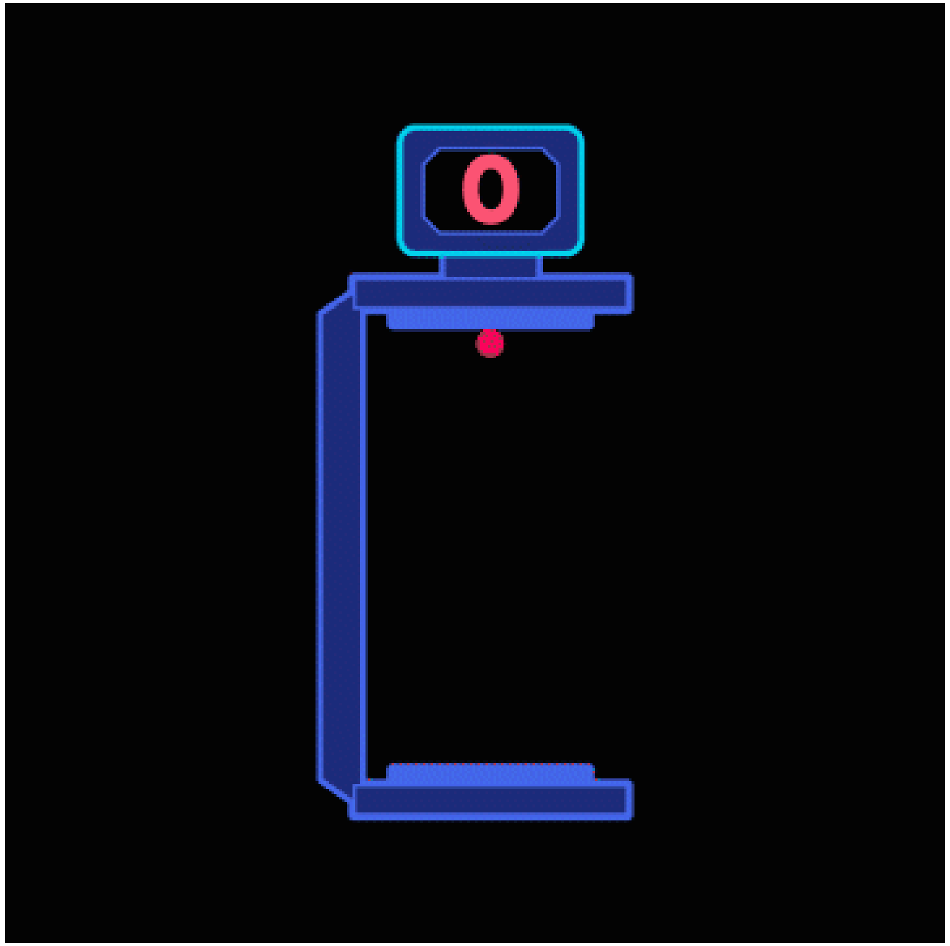


Figure 4.1.6 *This observer is inside a glass-walled spaceship watching a light beam.*



Time Dilation Cont'd

- He then asks us to imagine what it would look like to you, the **stationary** observer, if the clock was moving across the classroom (or in a spacecraft).
- Maxwells equations imply that we must take the speed of light as a **constant** seriously. So what?

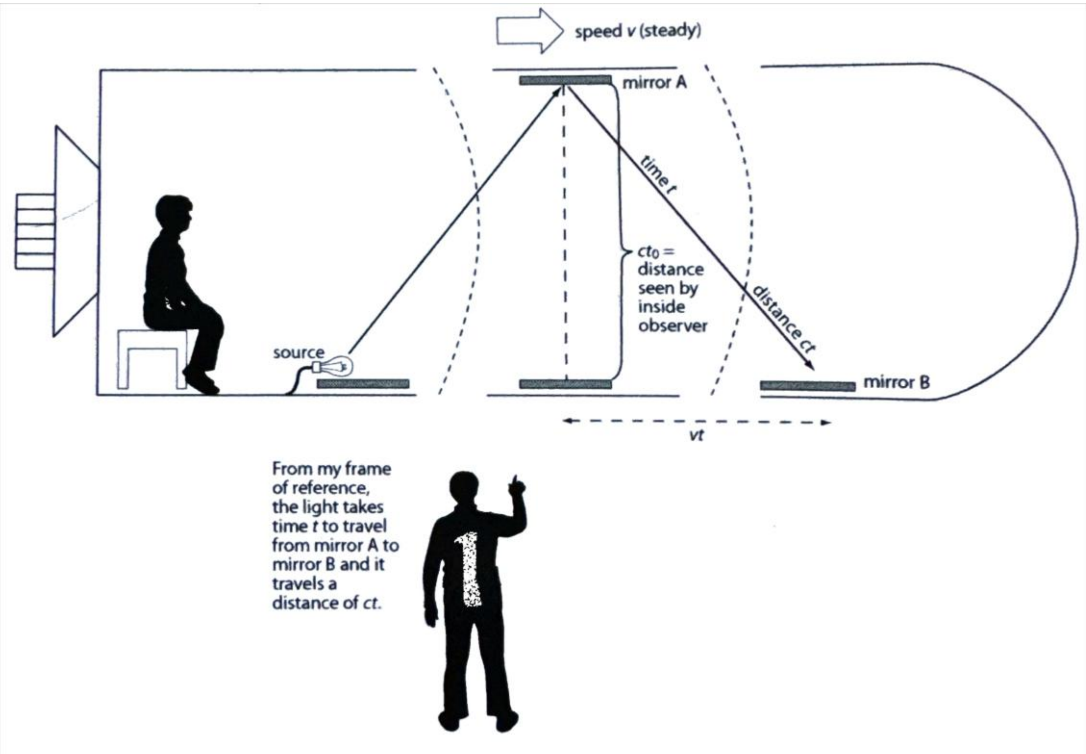
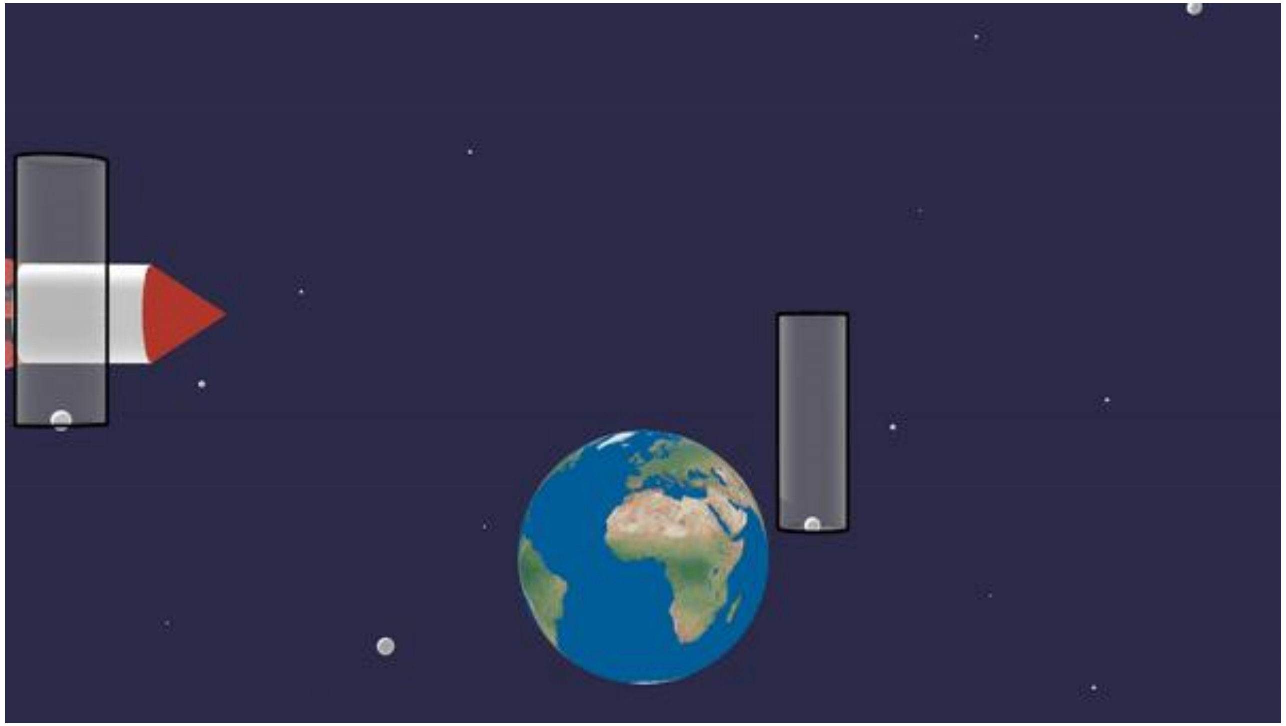
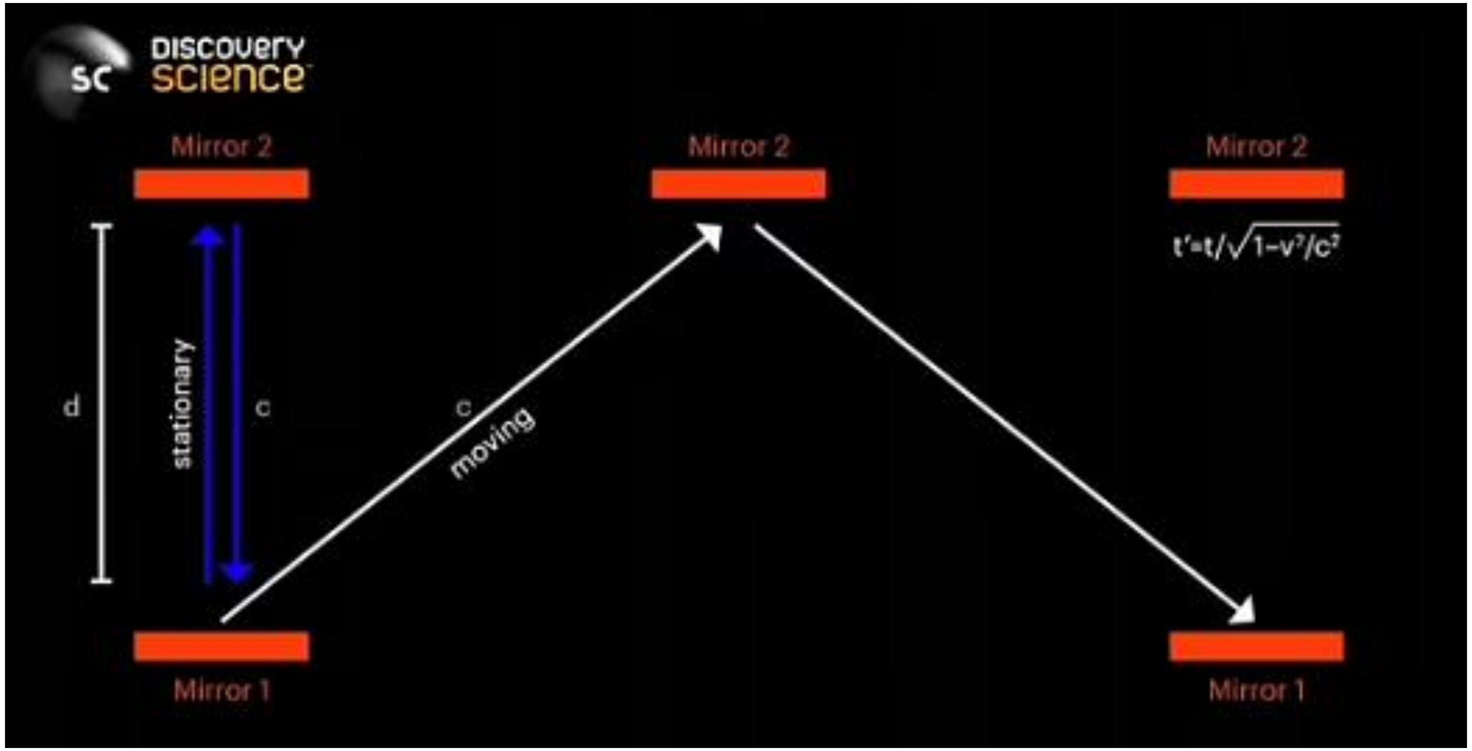


Figure 4.1.7 *The observer is outside the glass-walled spaceship watching a light beam.*



Time Dilation Cont'd

- It is self-evident that the path of the stationary clock is **shorter** than the path of the moving clock.
- Since we agree that the speed of light is constant, it must take **longer** for the light beam to travel the longer path.



- Simulation

Calculating Time Dilation

$$t = \frac{t_o}{\sqrt{1 - \frac{v^2}{c^2}}}$$

***t* = *Dilated Time*:** The time measured by an observer watching something moving fast (appears longer/slower).

***t_o* = *Proper Time*:** The time measured by someone moving with the object (the "actual" time for that event).

***v* = *velocity*:** the speed of the moving object relative to the observer

***c* = *Speed of light*:** 3.00×10^8 m/s

Example 1: An astronaut travels in an ultra-fast spacecraft at 0.90c (90% the speed of light). They make a round trip from Earth to the edge of the solar system and back, taking 10 years as measured on Earth.

How much time passes for the astronaut on the spacecraft?

$t = 10\,a$ or $10\,yr.$

$V = 0.90c$

$t_0 = ?$

$$t = \frac{t_0}{\sqrt{1 - \frac{v^2}{c^2}}}$$

$$t_0 = t\sqrt{1 - \frac{v^2}{c^2}}$$

$$t_0 = 10\sqrt{1 - \frac{(0.90\cancel{c})^2}{\cancel{c^2}}}$$

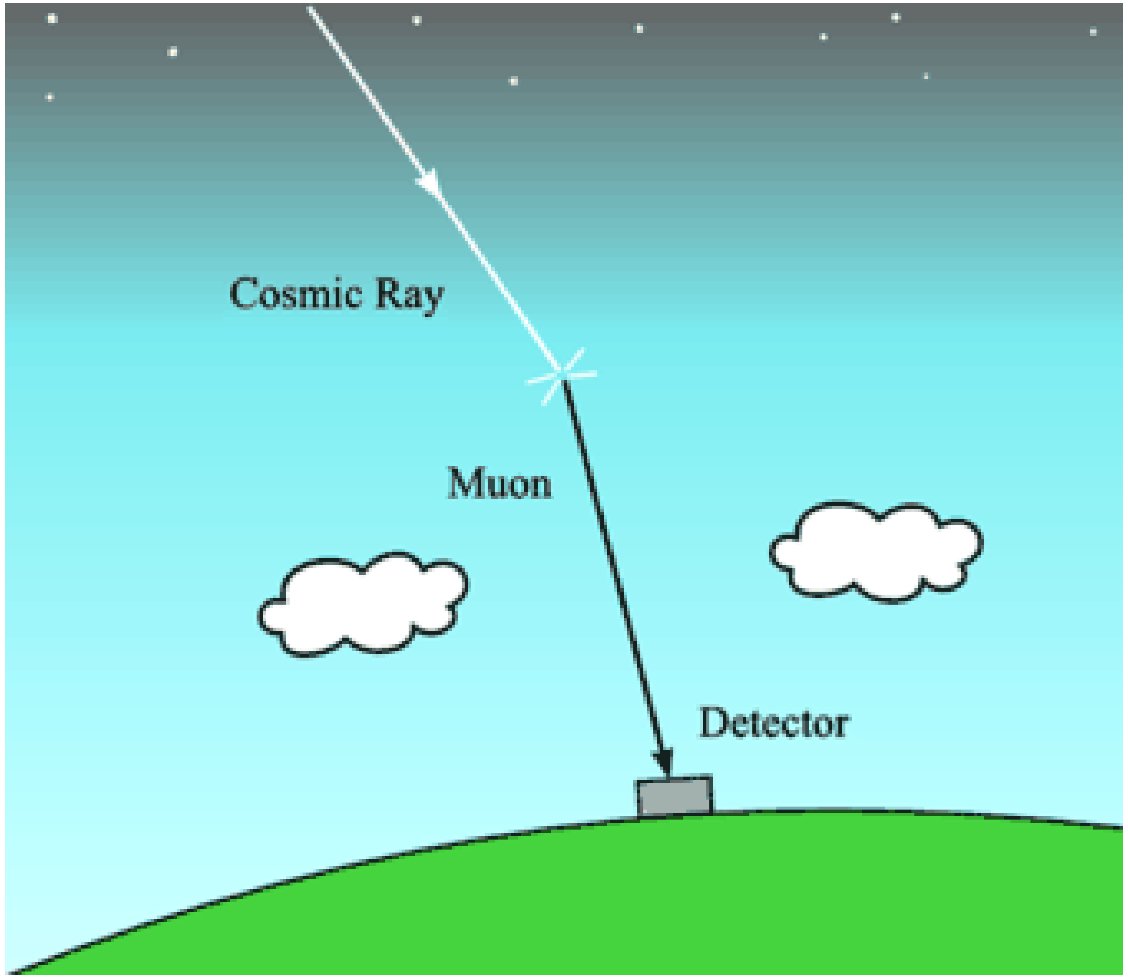
$$t_0 = 10\sqrt{1 - 0.81}$$

$$\boxed{= 4.36 \text{ years}}$$

* 10 years on Earth
* 4.36 years for astronaut.

Experimental Evidence for Time Dilation

- Muons (an elementary particle) have half-lives of **2.0×10^{-6} s**
- Created **6-8 km** above Earth during collisions between cosmic rays and atmospheric atoms
- High speed particles – **0.988c**



How far will muons travel during their lifetime?

Here we consider the muon's reference frame

- $\mathrm{t} = 2.0\ x\ 10^{-6}\ s$
- $v = 0.998c$
- $c = 3.0 \times 10^{8}\ m/s$

Calculate using Newtonian Physics

$$d = vt$$

$$d = (0.988)(3.0 \times 10^{8}\ m/s)(2.0\ x\ 10^{-6}\ s)$$

$$d = 600\ m = 0.6\ km$$

Using Newtonian physics, a muon should only travel 0.6 km before decaying. However, we can detect them on Earth's surface 8 km below. How can this be?

How far will muons travel during their lifetime?

Consider the muon's time of travel as an observer on Earth.

- $t_o = 2.0 \; x \; 10^{-6} \; s$
- $v = 0.998c$
- $c = 3.0 \times 10^8 \; m/s$

$d = vt$

$d = 0.998(3 \times 10^8)(3.2 \times 10^{-5})$

$d = 9600m$

or 9.6km

Calculate using Time Dilation

$$t = \frac{t_o}{\sqrt{1 - \frac{v^2}{c^2}}}$$

$$t = \frac{2.0 \times 10^{-6}}{\sqrt{1 - \frac{(0.998\cancel{c})^2}{\cancel{c^2}}}}$$

$$t = \frac{2.0 \times 10^{-6}}{\sqrt{0.004}} = 3.2 \times 10^{-5} s$$

Thought Experiment:

Imagine it's 2038 and you just turned 30 years old. You have a 6-year-old daughter who you love, but you've been given an opportunity to board a new, near light-speed, spaceship that will take you on a journey for the next 5.0 a at a speed of 0.99c. How old will you be compared to your daughter when you get home?

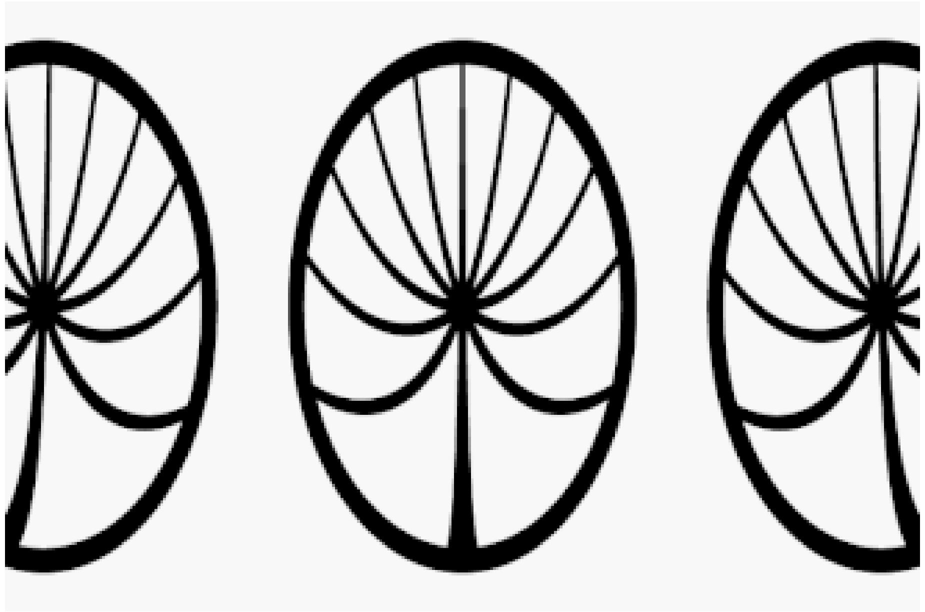
$$t = \frac{t_0}{\sqrt{1 - \frac{(0.99\cancel{c})^2}{\cancel{c^2}}}}$$

$$t = \frac{5.0a}{\sqrt{(1 - 0.980)}}$$

$$= 36 \text{ years}$$

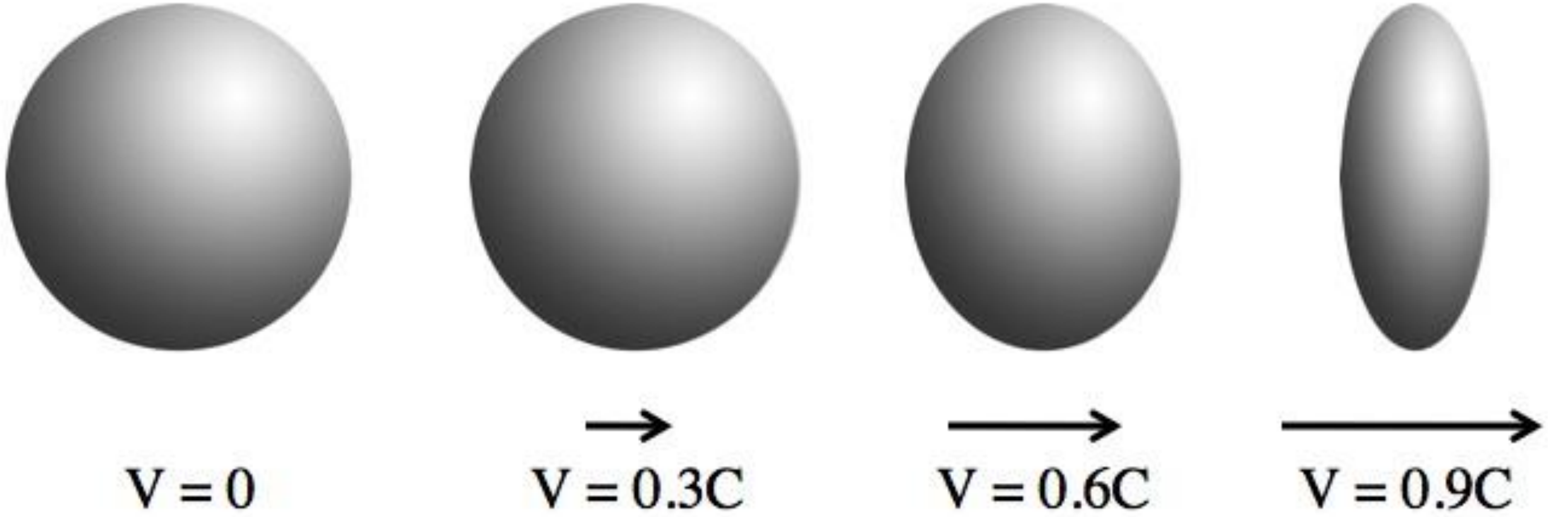
You will be 30yr + 5yr = 35yr.

Your daughter will be 6yr + 36yr = 42yrs.



Lorentz (Lenth) Contraction

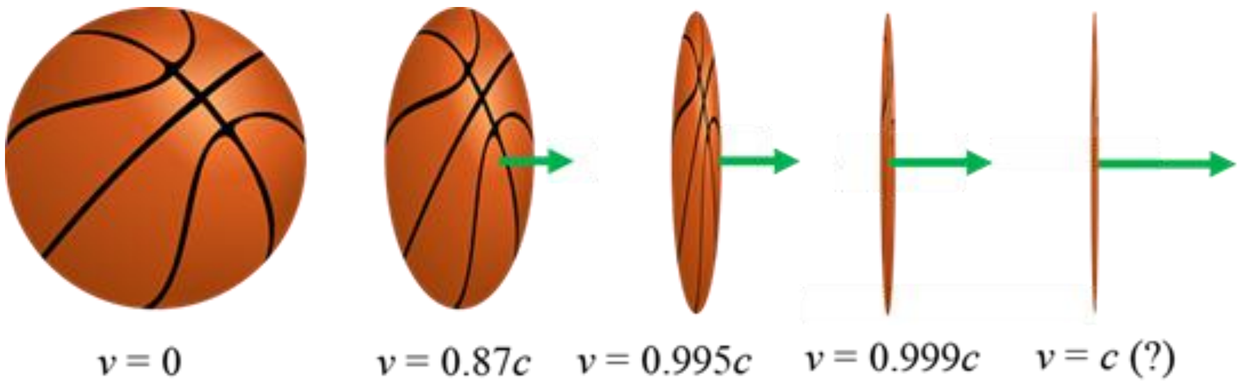
- The length of an object is measured to be **shorter** when it is moving than when it is at rest. This shortening is only seen in the **dimension** of its motion.



The Length Contraction Equation

$$l = l_o\sqrt{1-\frac{v^2}{c^2}}$$

- L_o = *length of object at rest*
- L = *length of object measured when moving*
- *v = velocity of the moving object*
- *c = speed of light: 3.0 x 10^8 m/s*



Example 2: How long would a metre stick appear to be if it was moving past you with a speed of 0.995c?

$$l = l_0 \sqrt{1 - \frac{v^2}{c^2}}$$

$$l = 1.00\,\text{m} \sqrt{1 - \frac{(0.995\cancel{c})^2}{\cancel{c^2}}}$$

$$l = 1.00\,\text{m} \sqrt{0.010}$$

$$l = 0.10\,\text{m} \text{ or } 10\,\text{cm}$$

Relativistic Momentum

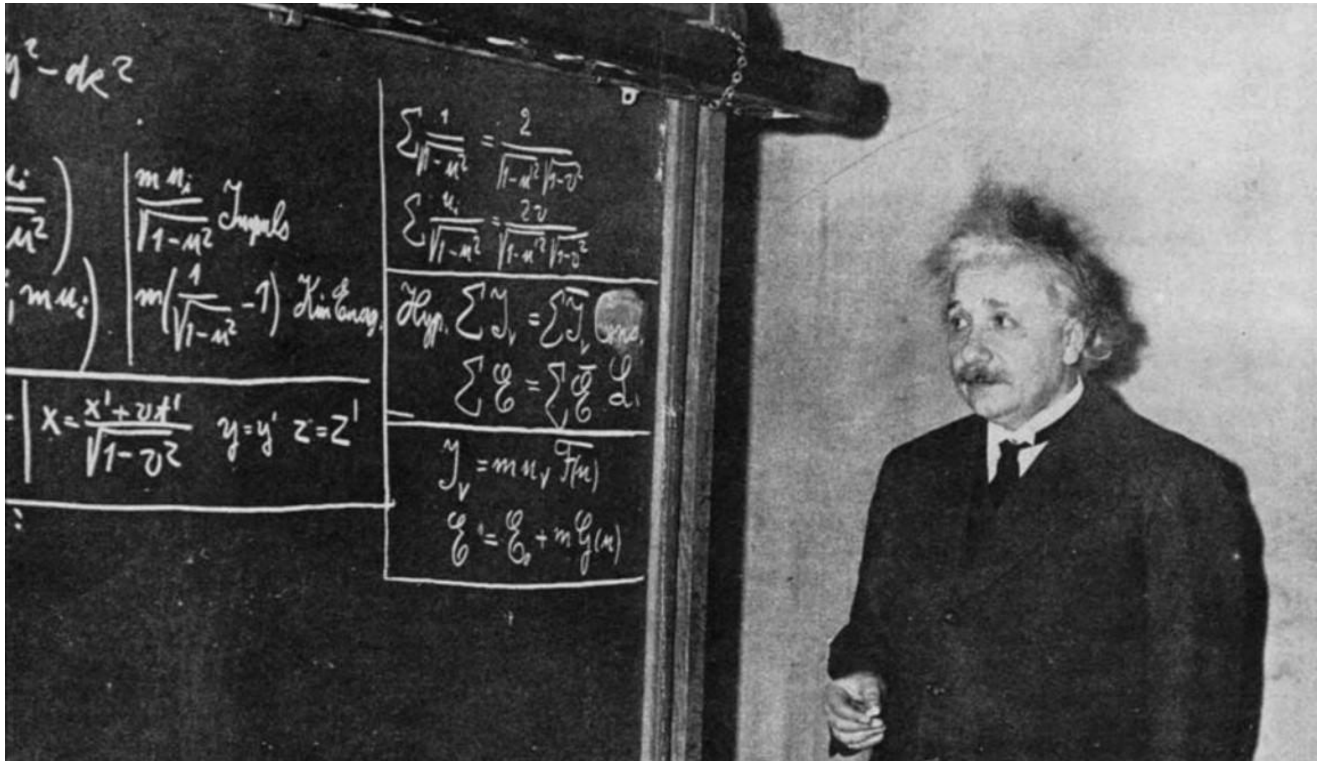
- Newtonian definition of momentum was ***p = mv***
- Only works when ***v→0***

$$p = \frac{mv}{\sqrt{1 - \frac{v^2}{c^2}}}$$

Mass-Energy Equivalence

- Einstein showed that mass and energy are **equivalent**
- Experimentally shown in 1932 when a gamma photon converted to an **electron** and **positron** (C.D. Anderson)
- A small amount of mass releases a huge amount of energy

1 kg → 9.0 × 10^{16} J



$$E = \frac{mc^2}{\sqrt{1 - \frac{v^2}{c^2}}} \xrightarrow{v \to 0} E = mc^2$$

$$t = \frac{t_o}{\sqrt{1 - \frac{v^2}{c^2}}}$$

$$l = l_o \sqrt{1 - \frac{v^2}{c^2}}$$

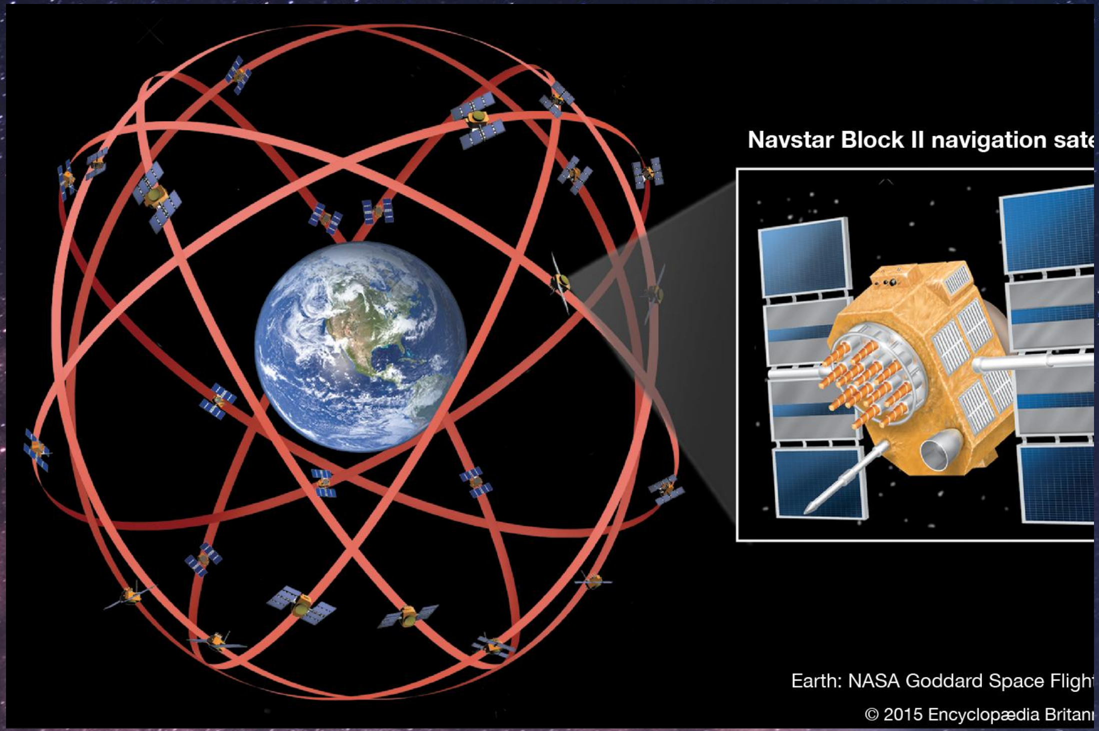
$$p = \frac{mv}{\sqrt{1 - \frac{v^2}{c^2}}}$$

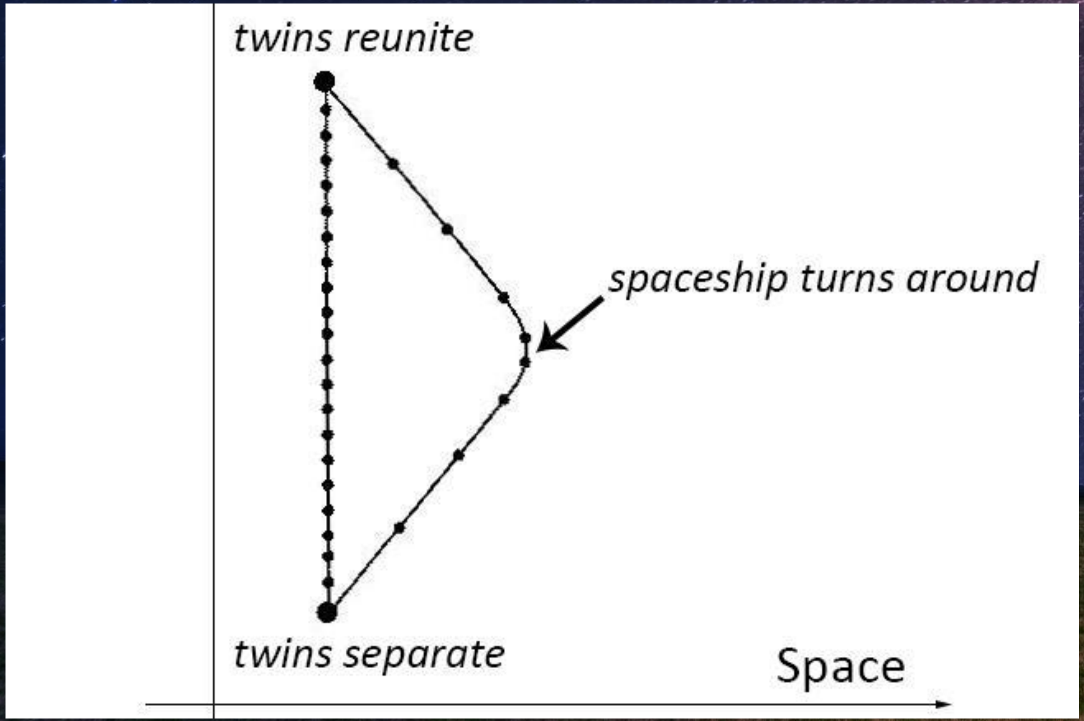
$$E = \frac{mc^2}{\sqrt{1 - \frac{v^2}{c^2}}}$$

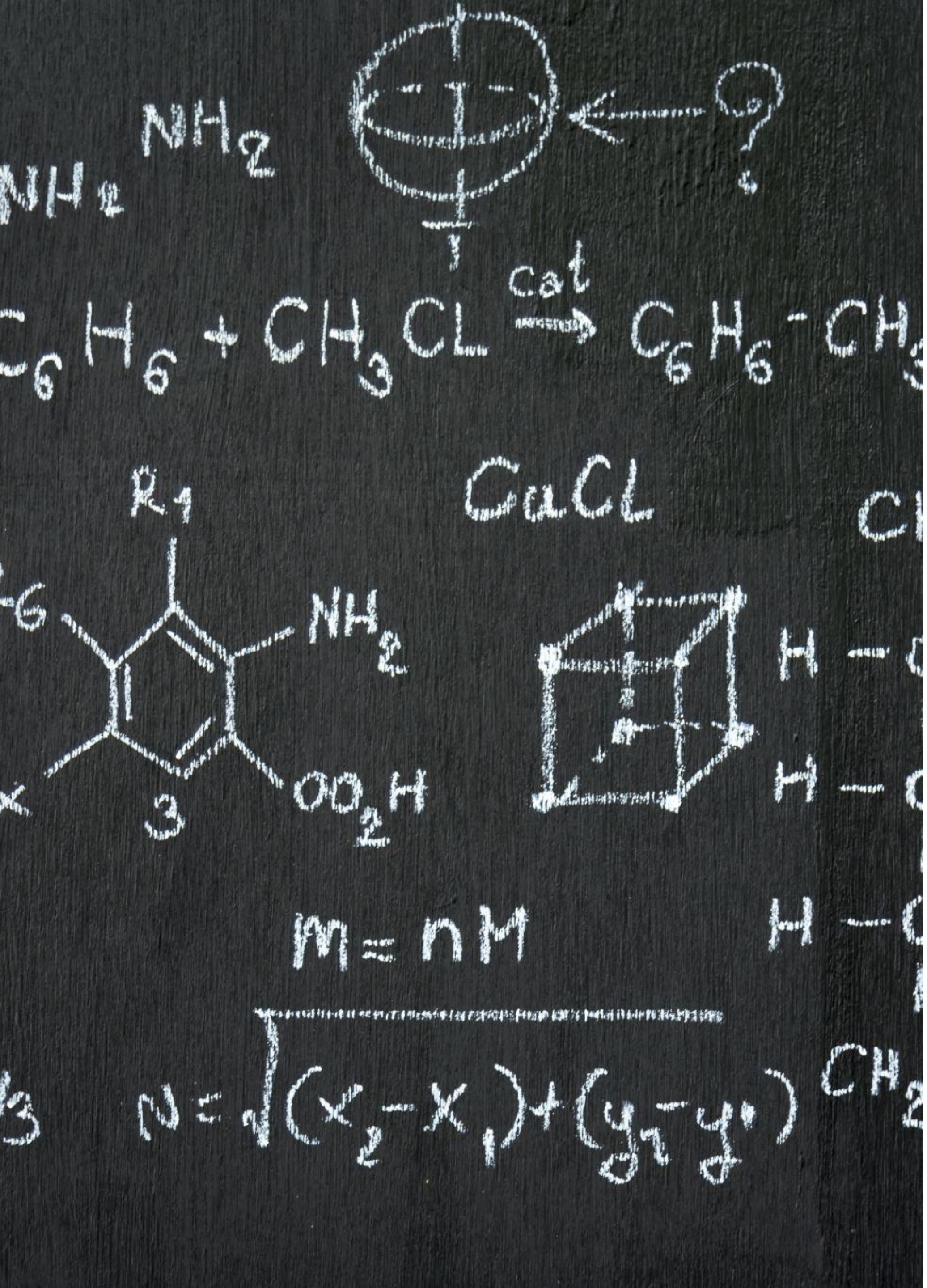
Considering the Universal Speed Limit

Consider the following equations. What happens to each as velocity $v \rightarrow c$?

- The Twin Paradox?
- GPS
- Time Travel







Assignment:

Sandner Gore BC Physics 12:

- Review Questions Pages 111-114 #1-11
- Try the Quick Checks on pages 106, 108, and 110