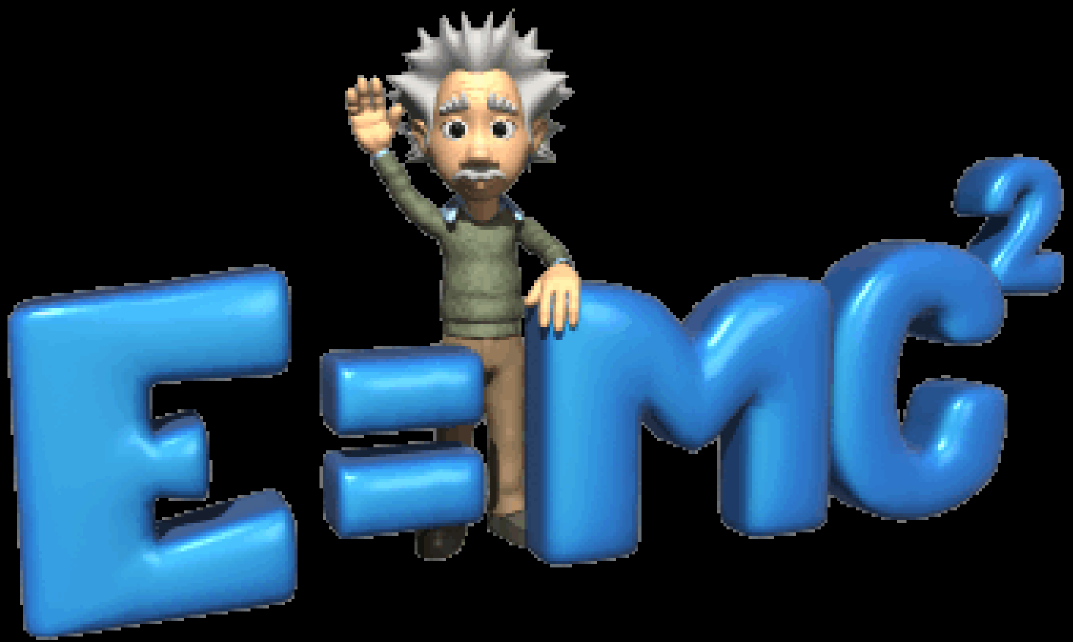
S-164

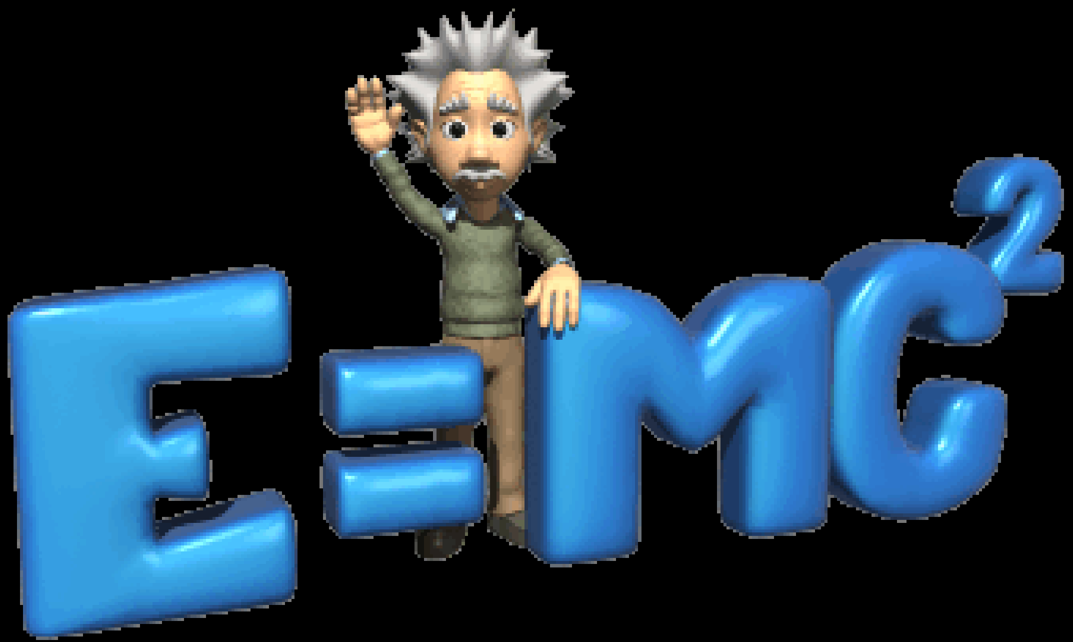
Countdown G minus 15 and counting

Relativity



AP Physics
Supplemental

Relativity



S.1 Introduction

S.1 Introduction

Electrons can be accelerated to 0.99c using a potential difference of 3.1 MV

According to Newtonia

Mechanics, if the

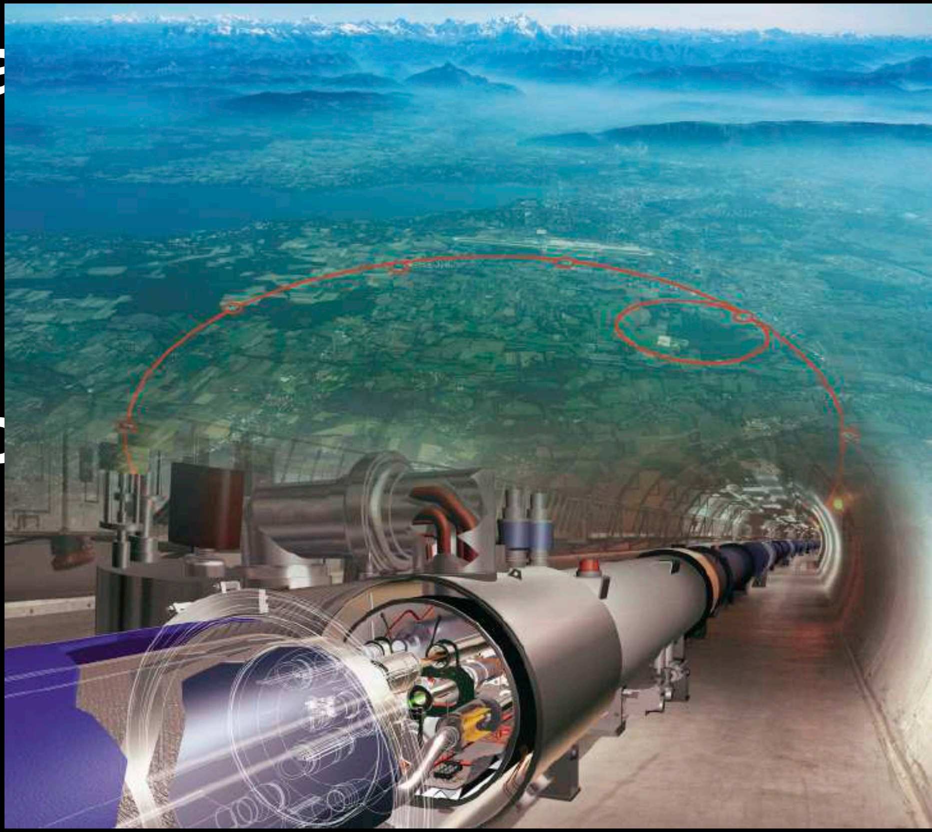
particles energy is

increased by a factor o

4, the speed of the

particle should be

1.98c



S.1 Introduction

From experiments the speed of any particle is always less than 1.00c.

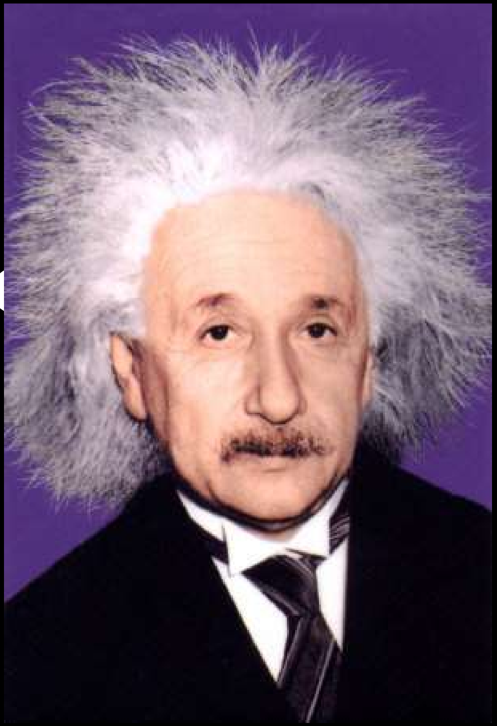
No matter what the movies say

S.1 Introduction

So Newtonian mechanics disagrees with modern experimental results.

1905 – Albert Einstein

Special Theory of Relativity – two postulates



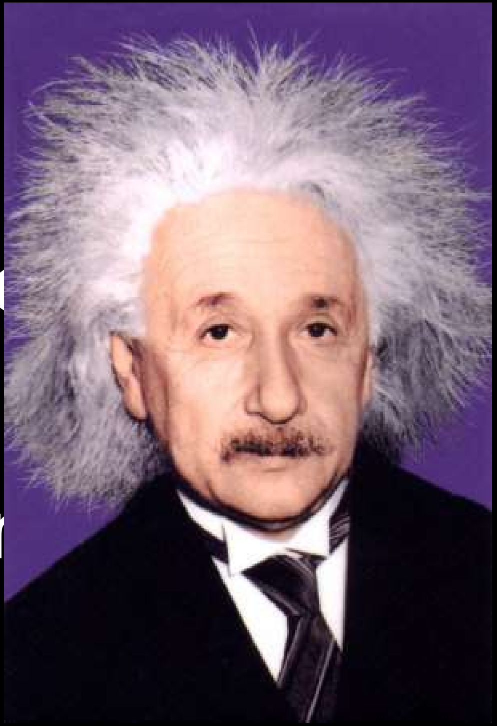
1. The laws of physics are the same in all coordinate systems either at rest or moving at constant velocity with respect to one another

S.1 Introduction

So Newtonian mechanics disagrees with modern experimental results.

1905 – Albert Einstein

Special Theory of Relativity – two postulates



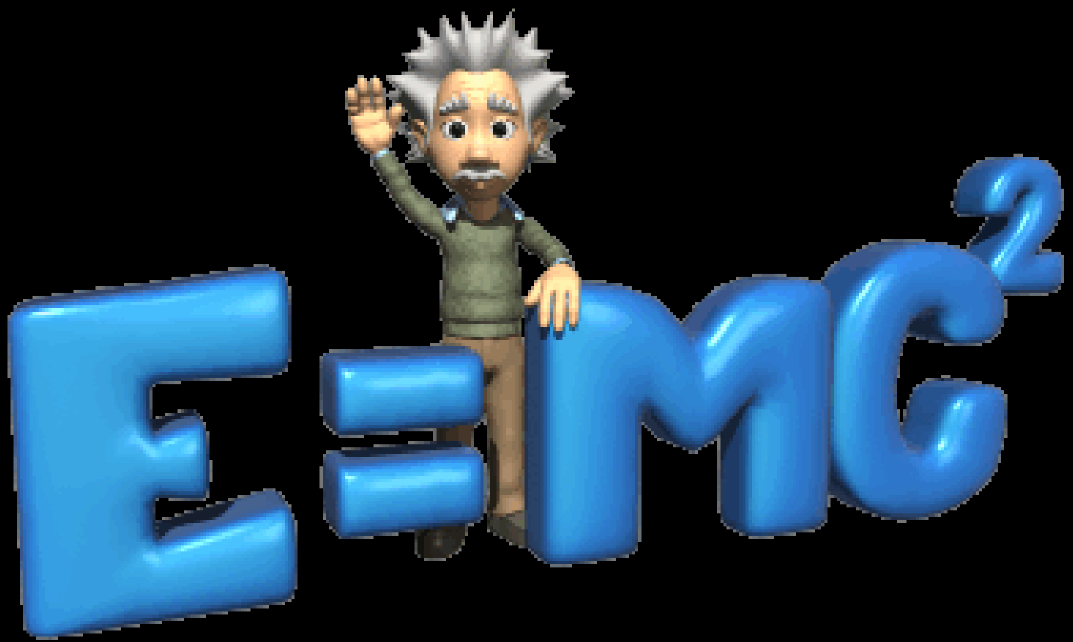
2. The speed of light in a vacuum has the same value,

300,000,000 m/s, regardless of the velocity of the observer or the velocity of the source emitting the light.

S.1 Introduction

Newton Mechanics is a special case of Einstein's theory

Nuclear Physics and Radioactivity



S.2 The Principle of Galilean Relativity

S.2 The Principle of Galilean Relativity

Review – to describe motion we need a frame of reference

Galilean relativity – the laws of mechanics must be the same in all inertial frames of reference

Galilean Relativity

Inertial frames of reference – Newton's Laws are valid

There is no preferred frame of reference for describing the laws of mechanics

S.2 The Principle of Galilean Relativity

Non-Inertial Frames (Examples)

a frame undergoing translational acceleration

a frame rapidly rotating with respect to two inertial frames

Nuclear Physics and Radioactivity

S.3 The Speed of Light

S.3 The Speed of Light

Galilean relativity produces a paradox when related to the speed of light.

The value of the speed of light is always 299,792,458 m/s in free space

Lecture

If an arrow is shot form a moving

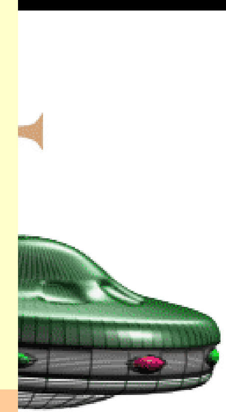
obj

wo

to a

obs

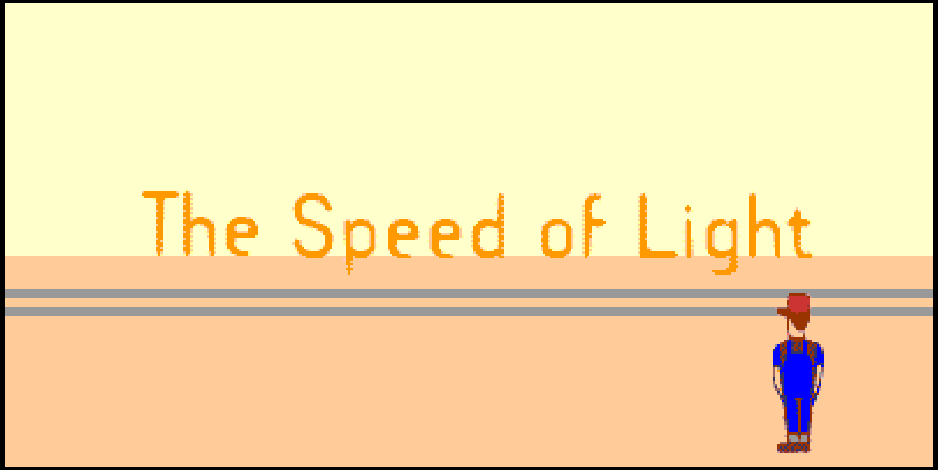
To ld



$v = v_a$

S.3 The Speed of Light

However if the same experiment is repeated using light instead of a moving object



Both observers see

the speed $v = c$ t

as

Not as $v = c + v_T$

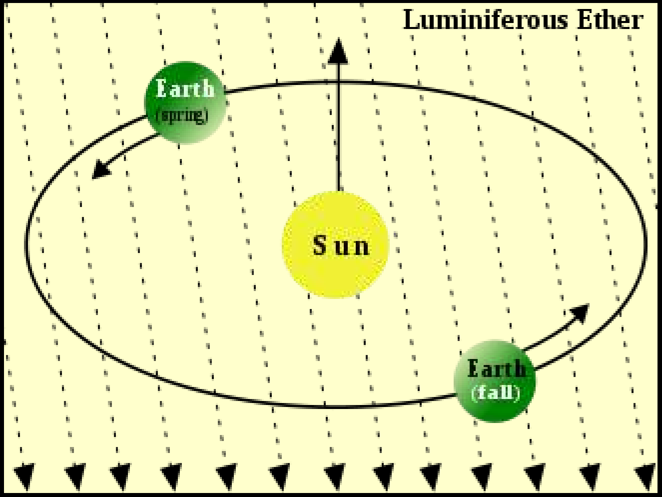
We must conclude, either

1. The addition laws for velocity are incorrect
2. The laws of electricity and magnetism

S.3 The Speed of Light

It was purposed that a medium for EMR existed called luminiferous either

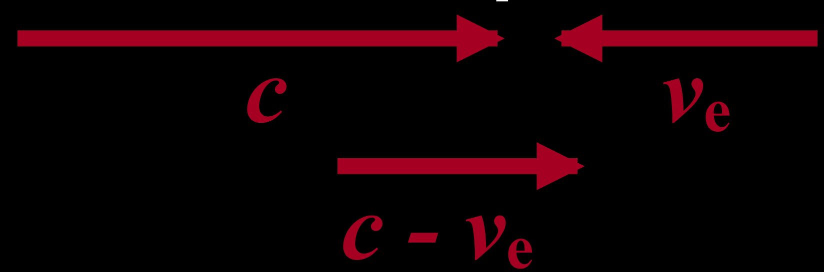
The laws of electricity and magnetism would be constant in the absolute frame – at rest with respect to the either



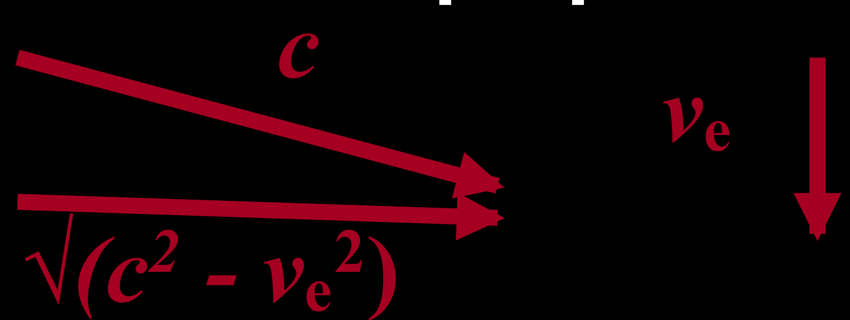
Experiments should be able to prove the direction of the ether wind

If an observer were downwind

If an observer were upwind



If the observer was perpendicular to the wind



S.3 The Speed of Light

Nobody could ever prove a change in the observed speed of light

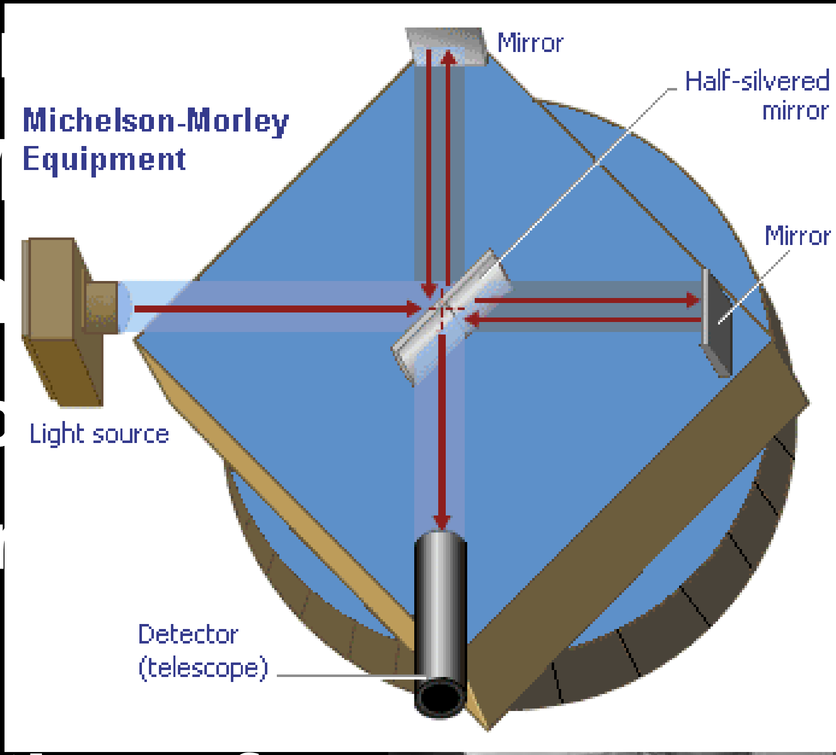
So it was concluded that the laws of electricity and magnetism are the same in all intertial frames of reference

Relativity

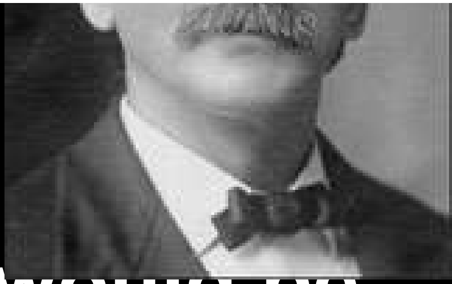
S.4 The Michelson-Morley Experiment

S.4 The Michelson-Morley Experiment

1881 Albert Michelson, a
Michelson and Edward M
Experiments to detect ch
the speed of light – veloc
earth relative to the ethe



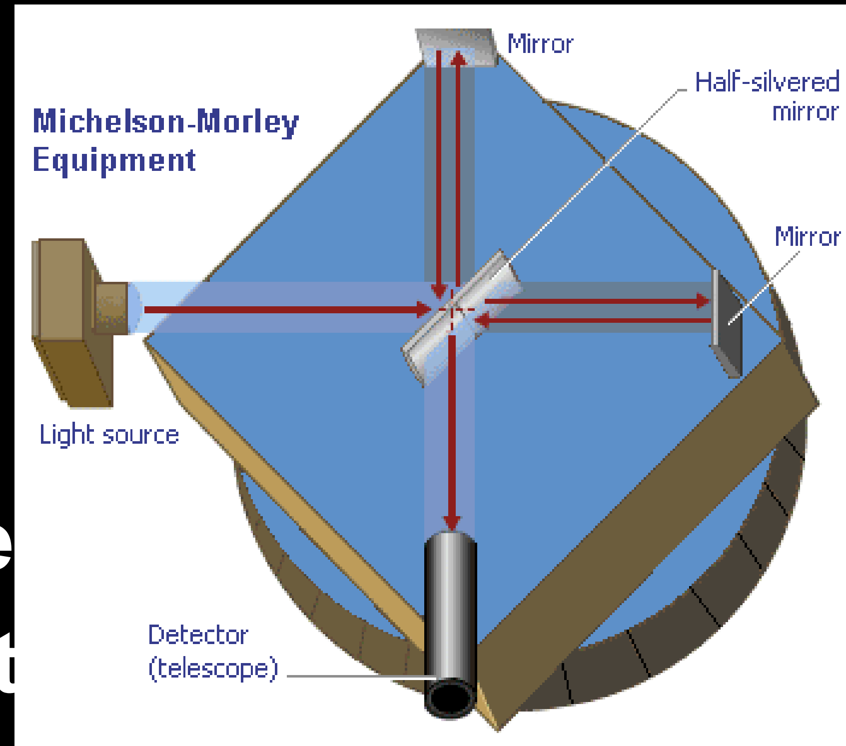
The light and 1 mirror were aligned in the direction of Earth's motion



The light reflecting off that mirror would be expected to change velocity

S.4 The Michelson-Morley Experiment

The mirror in the middle was half silvered, allowing some light to pass and some to reflect



Light would be unaffecte

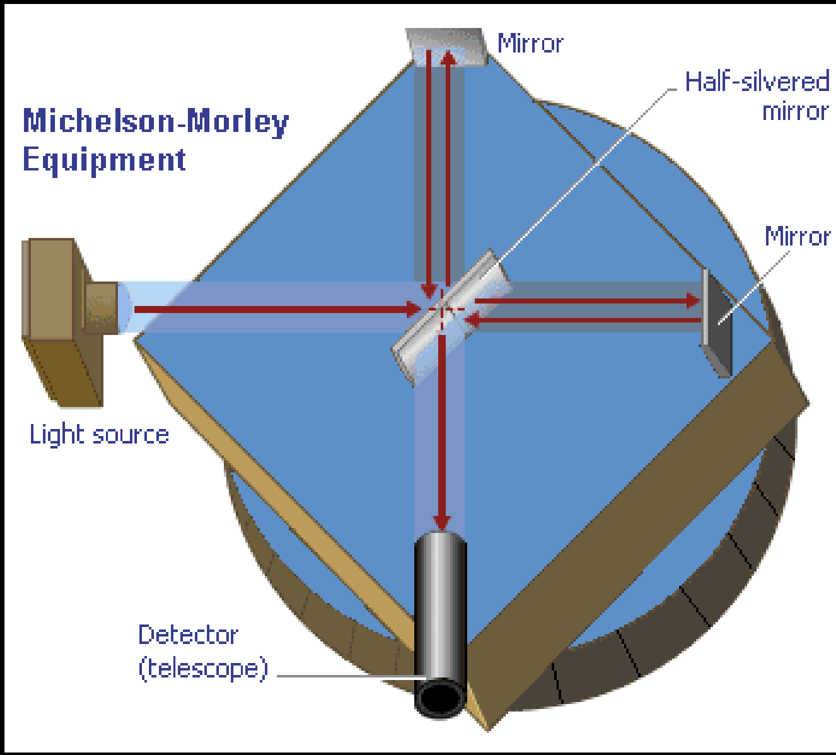
when it reflected off the t
speed would stay the same)

If there was a change in speed, we would expect and interference pattern to be observed

S.4 The Michelson-Morley Experiment

The experiment was performed at different times of year and no interference pattern was every observed

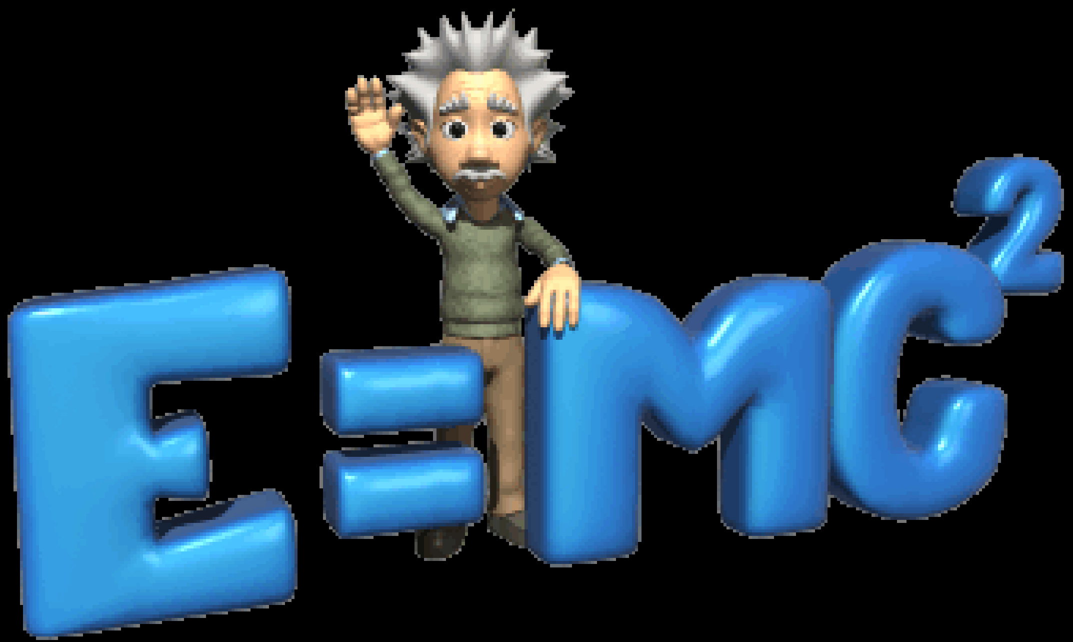
Michelson-Morley Video



S-169

Countdown G minus 11 and counting

Relativity



S.5 Einstein's Theory of Relativity

S.5 Einstein's Theory of Relativity

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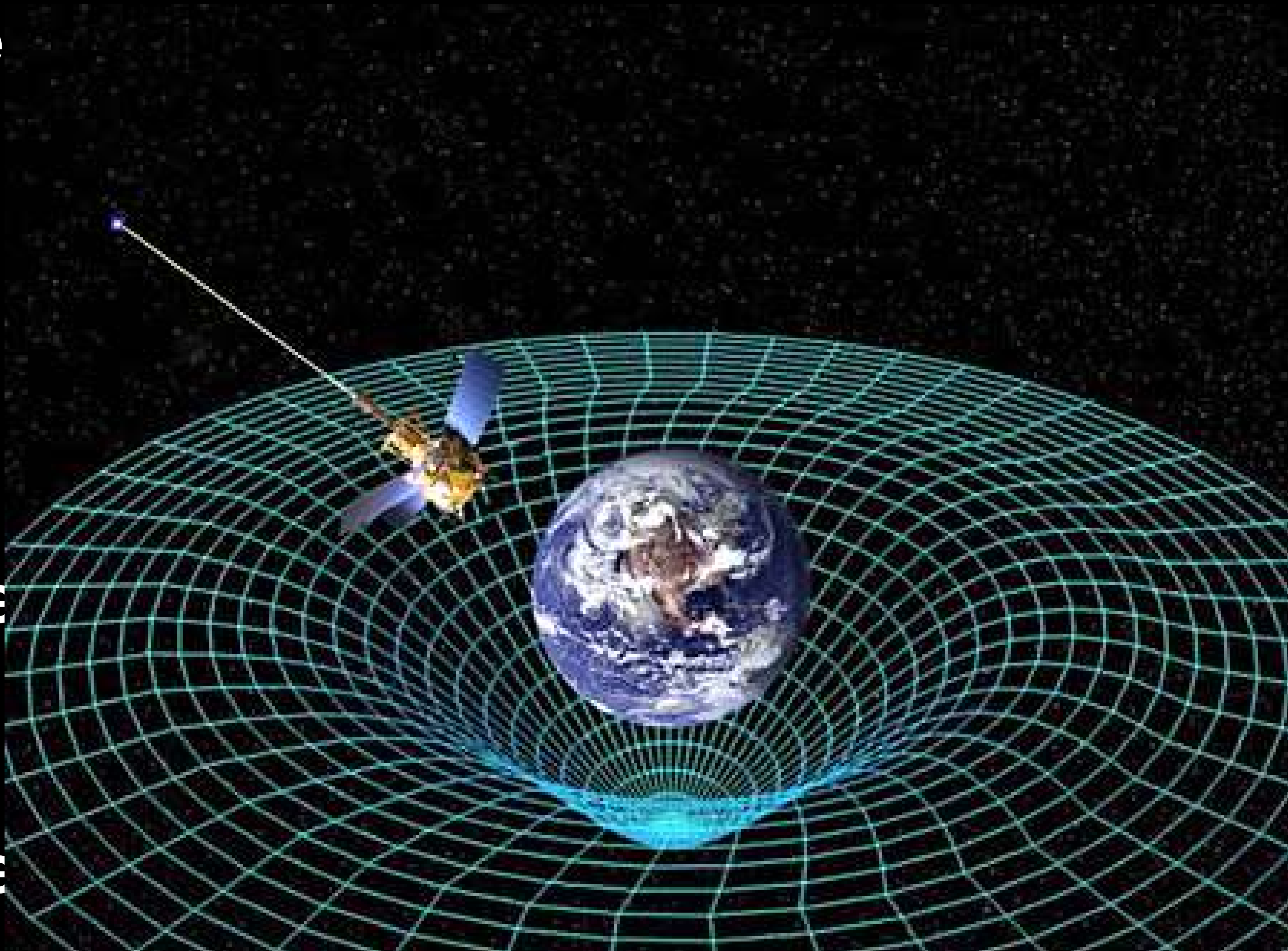
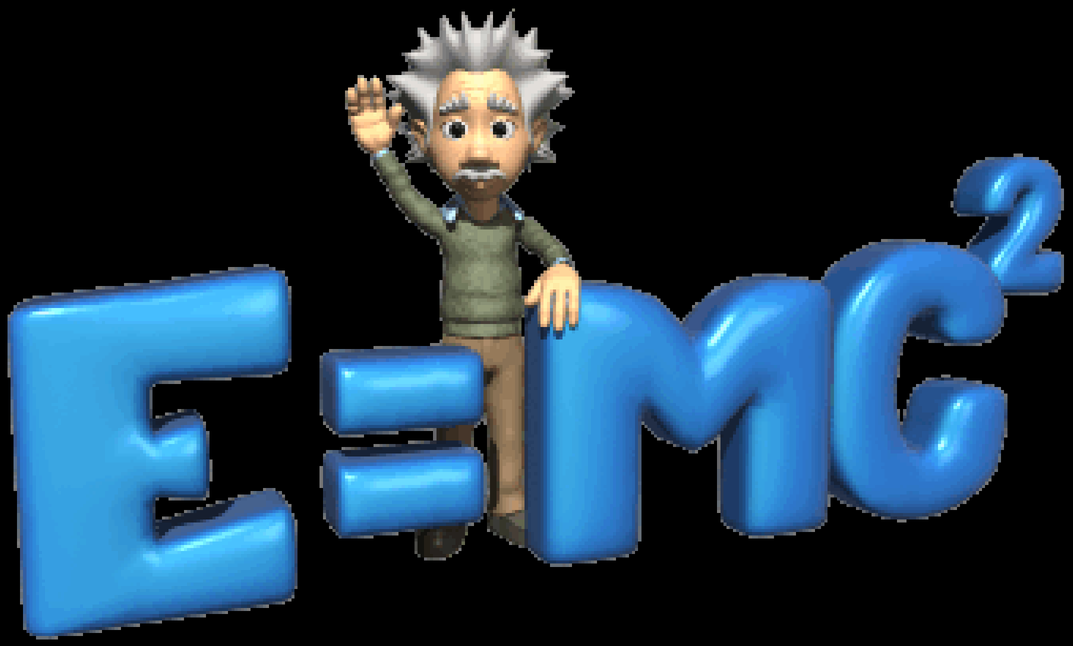
of space and time



Relativity



S.6 Consequences of Special Relativity

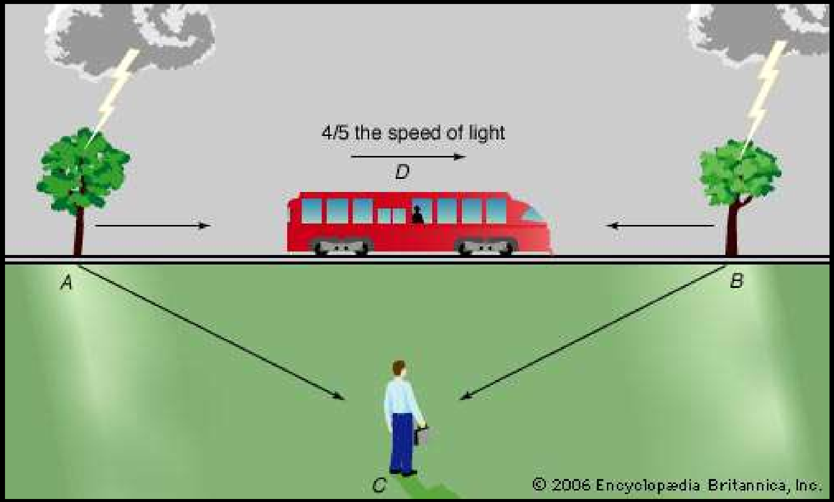
S.6 Consequences of Special Relativity

In relativity

1. There is no such thing as absolute time or absolute length
2. Events that are simultaneous in one frame of reference are not in another frame moving uniformly past the first

Simultaneity

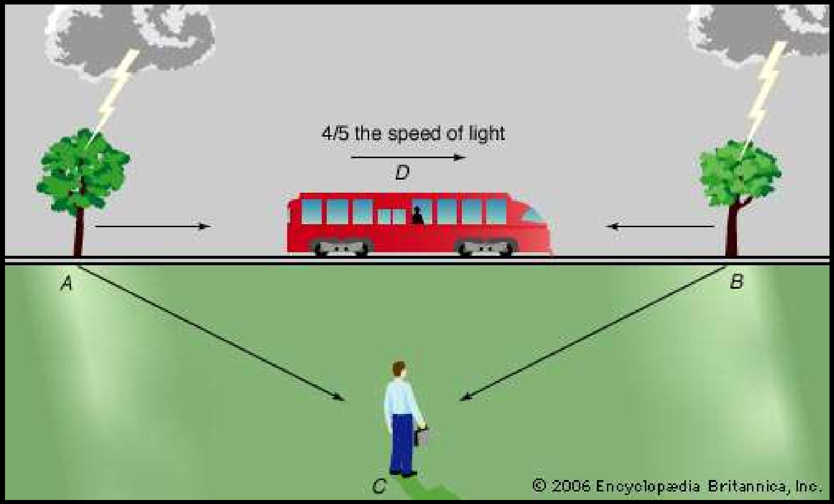
S.6 Consequences of Special Relativity



Einstein's Thought Experiment

1. Lighting Strikes two trees that are equal distances from observer C.
2. C corretly determines that the events were simultaneous because the light traveled over the same distance at the same speed
3. Observers on the train D, are traveling at 0.20c

S.6 Consequences of Special Relativity



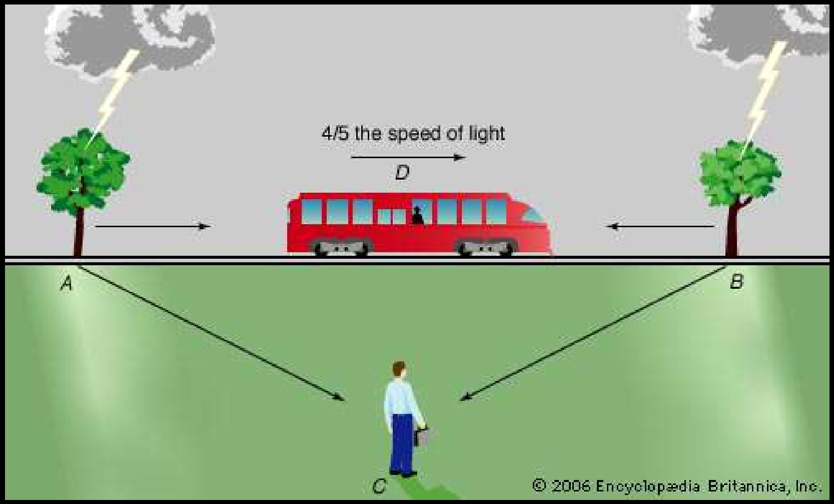
Einstein's Thought Experiment

4. By the time the light has reached C, the train has moved
5. The flash from tree B has already gone past the train, and the flash from A has yet to reach the train

S.6 Consequences of Special Relativity

Einstein's Thought Experiment

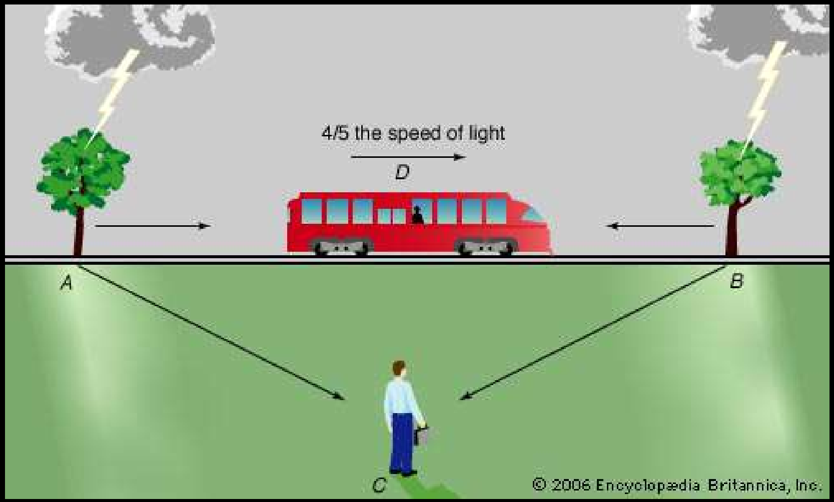
6. Knowing that the speed of light is a constant – the train observes that the lightning struck tree B before it struck tree C.



Two events that are simultaneous in one reference frame are in general not simultaneous in a second frame moving relative to the first

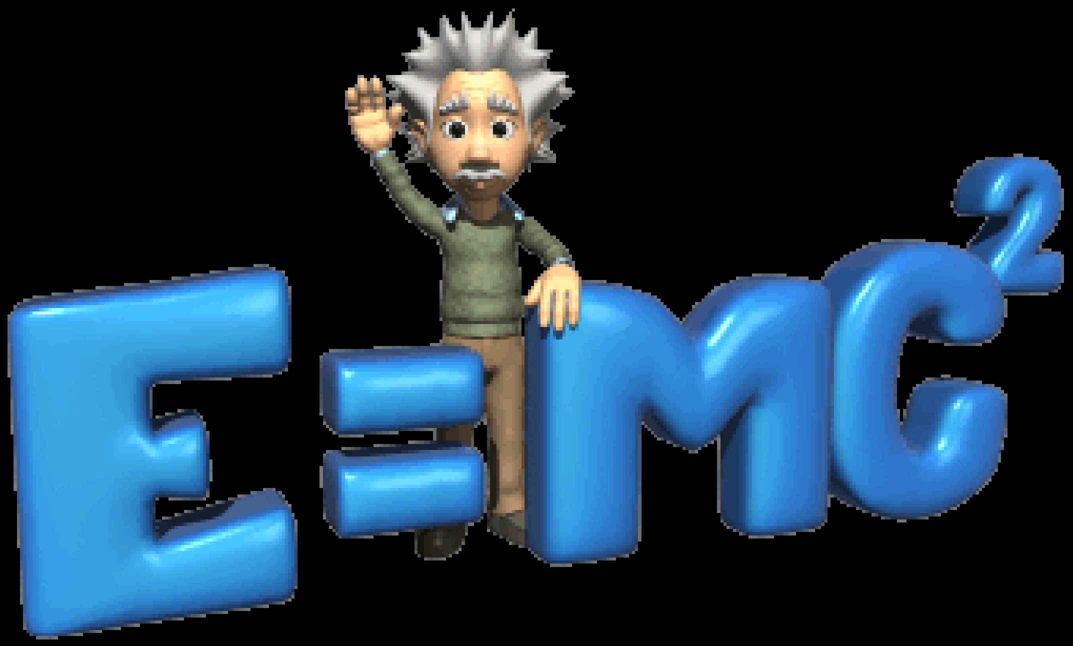
S.6 Consequences of Special Relativity

Both observers are correct – there is no preferred inertial frame of reference



Countdown G minus 5 and counting

Relativity

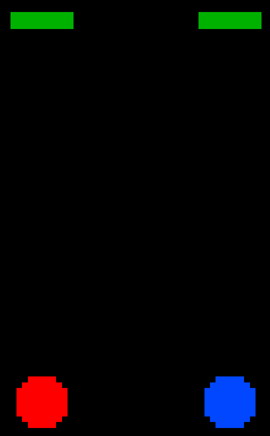


S.7 Time Dilation

S.7 Time Dilation

If two observes, stationary relative to each other shoot light at a mirror

They observe that the events occur at the same time



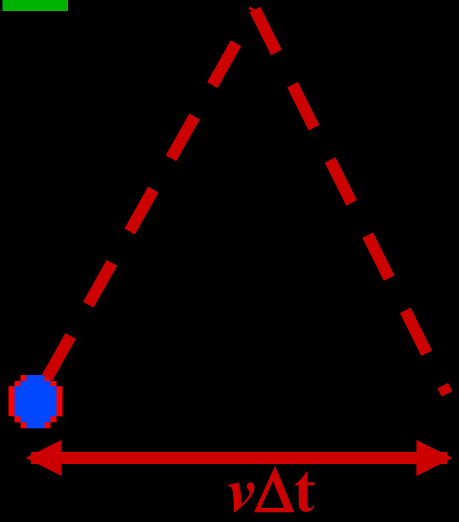
$$\Delta t_p = \frac{2d}{c}$$

Δt_p = the time interval between two events as measured by an observer who sees two events occur at the same position

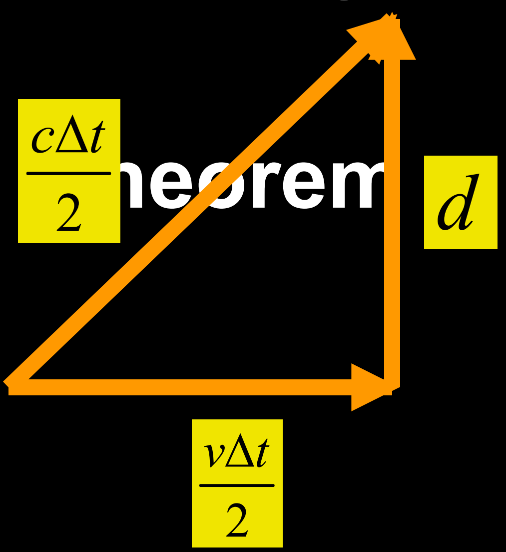
S.7 Time Dilation

Now if the observer shooting the light, moves relative to the other

Knowing that light travels a constant velocity we can set up a displacement vector diagram



Using Pythagorean theorem



$$\left(\frac{c\Delta t}{2}\right)^2 = \left(\frac{v\Delta t}{2}\right)^2 + d^2$$

S.7 Time Dilation

$$\left(\frac{c\Delta t}{2}\right)^2 = \left(\frac{v\Delta t}{2}\right)^2 + d^2$$

Solving for Δt gives

$$\Delta t = \frac{2d}{c\sqrt{1 - {v^2}/{c^2}}}$$

Because

$$\Delta t_p = \frac{2d}{c}$$

$$\Delta t = \frac{\Delta t_p}{\sqrt{1 - {v^2}/{c^2}}}$$

Or

$$\Delta t = \gamma \Delta t_p$$

Where

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

S.7 Time Dilation

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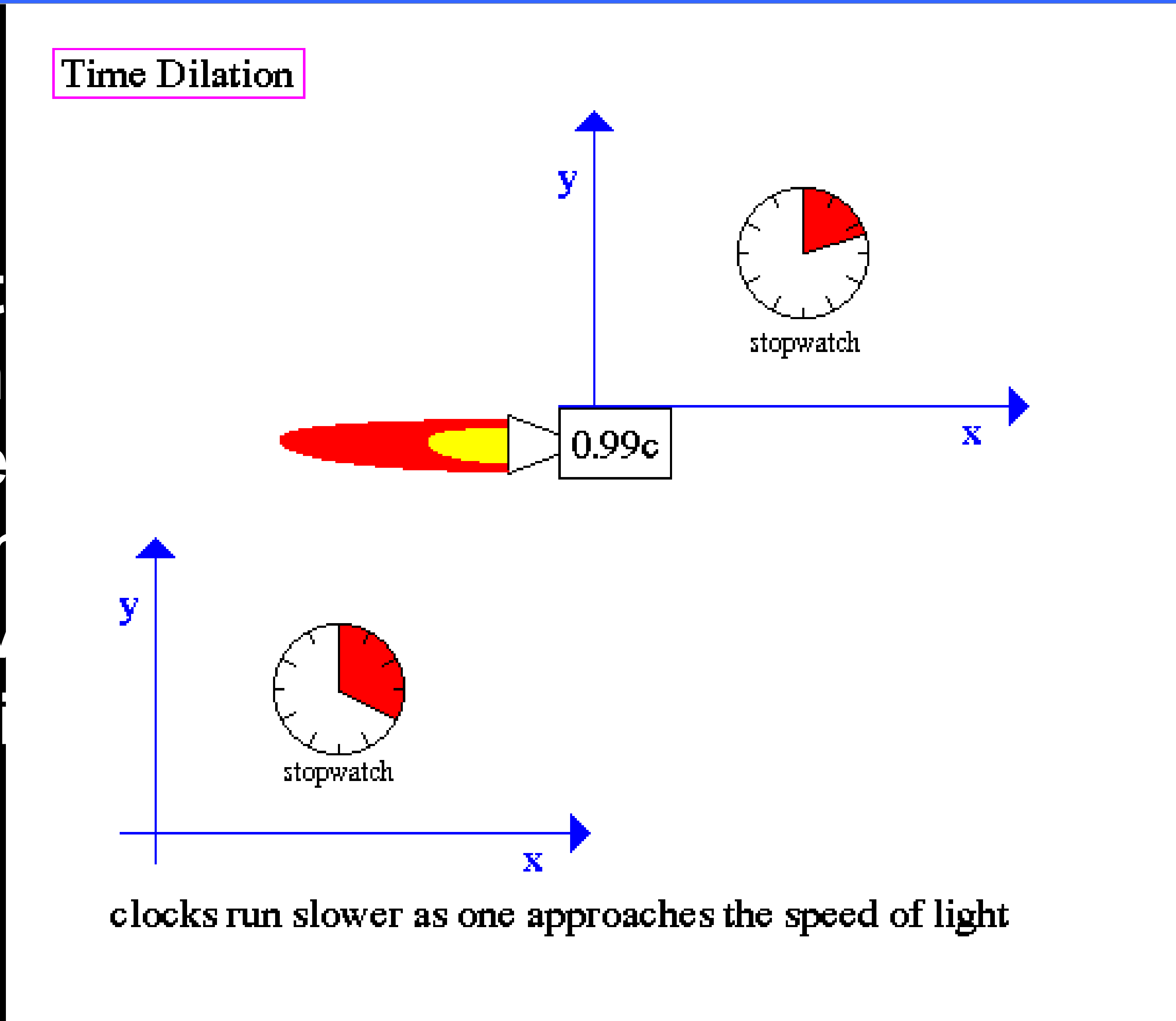
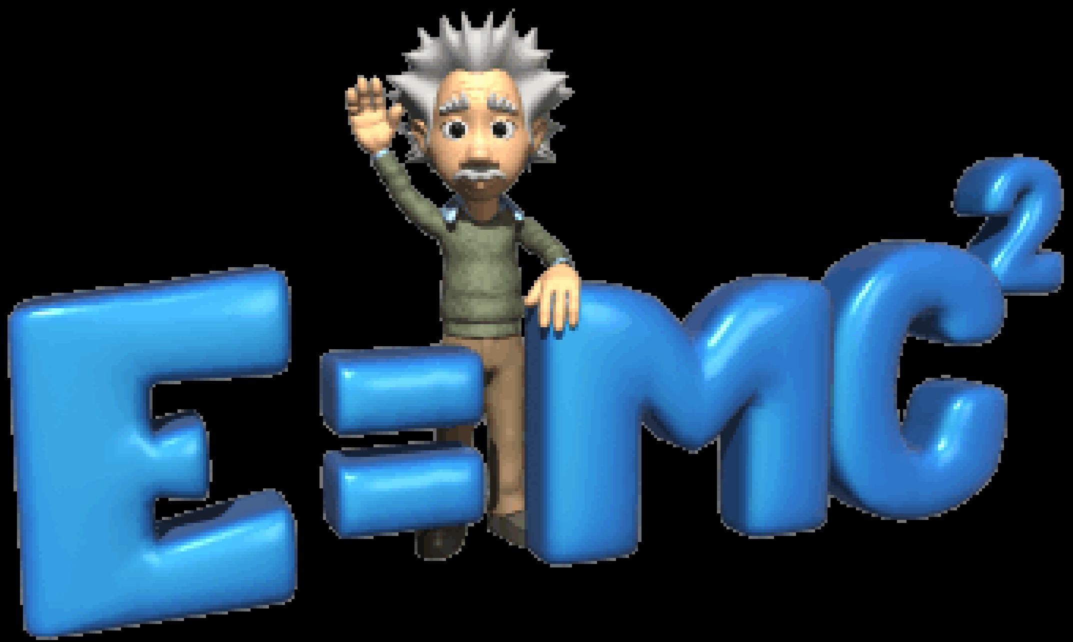


S.7 Time Dilation

The observation that the stationary object has a slower clock is also valid, as observed from the moving object.

Time dilation has been verified by experiments

Relativity



S.8 The Twin Paradox

S.8 The Twin Paradox

Two twins are 20 years old

Twin A sets out on a trip to a planet 20 lightyears from earth

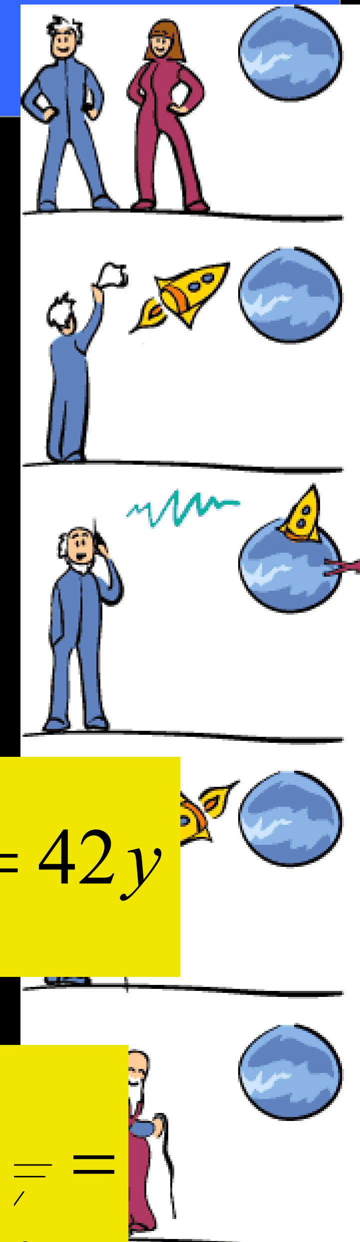
His ship travels at a constant 0.95c.

As soon as he arrives, he turns around and comes back to earth.

Twin Paradox Song

What is the difference in age? And who is younger?

S.8 The Twin Paradox



Are both twins in inertial frames of reference?

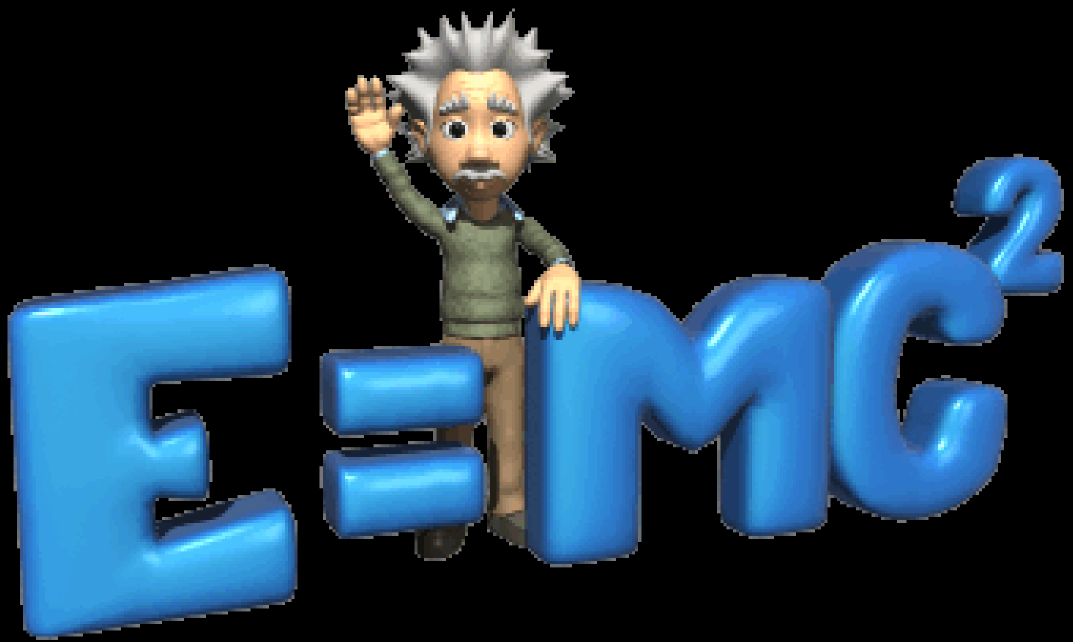
The twin in the rocket experiences acceleration, this is a non-inertial frame of reference

So to the twin on earth

$$\Delta t_p = \frac{2(20y)}{0.95y/y} = 42y$$

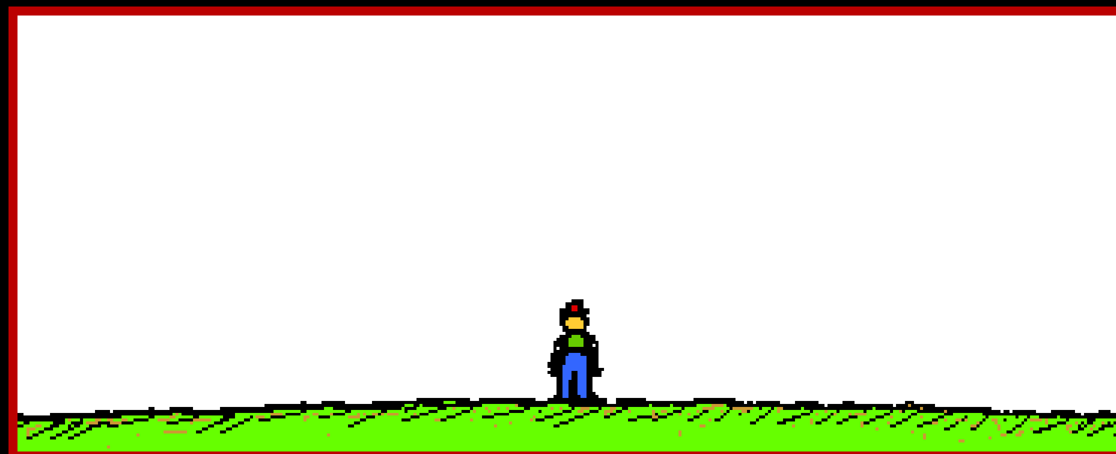
For the twin in the rocket

$$42y \; \Delta t_p = 13.1y = \frac{\Delta t}{\sqrt{1 - \;/c^2}}$$



14.9 Length Contraction

The measured distance between two points also depends on the frame of reference of the observer

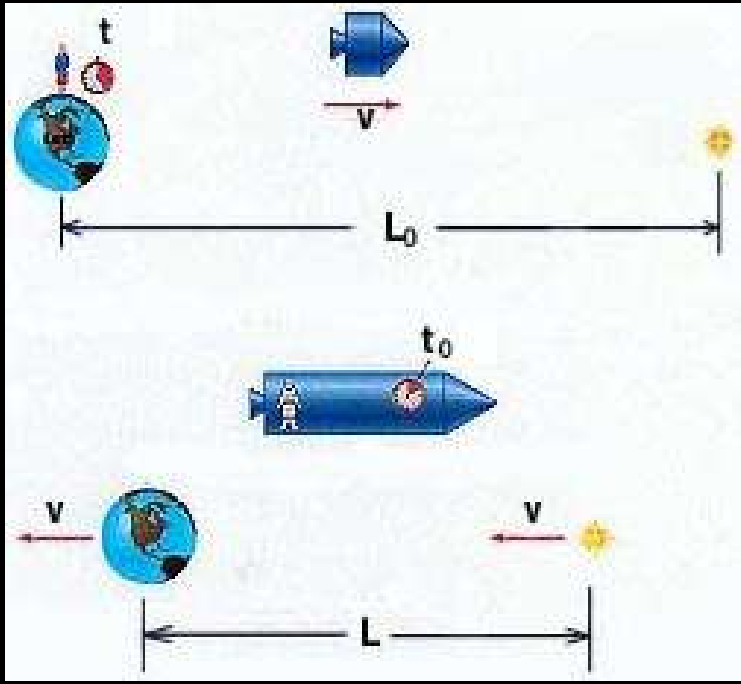


This length is always less than the proper length

14.9 Length Contraction

Quantitatively then

1. Two observers, one on Earth (and at rest relative to the star), and the other in a spaceship



2. The observer on Earth measurses the distance to the stars as being L_p

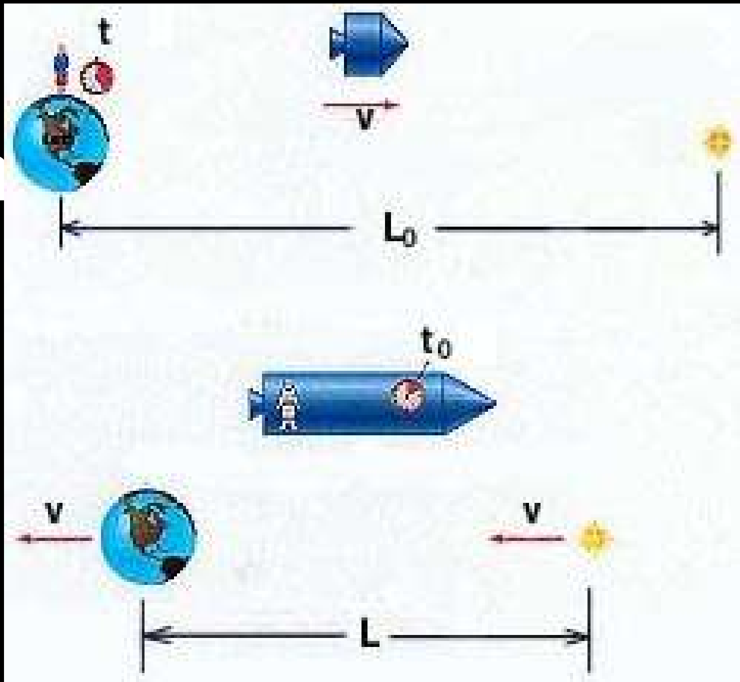
3. According tot his observer the tin for the trip is

$$\Delta t = \frac{L_p}{v}$$

Quantitatively then

4. Because of time dilation the space traveler measures a smaller period of time

$$\Delta t_p = \frac{\Delta t}{\gamma}$$

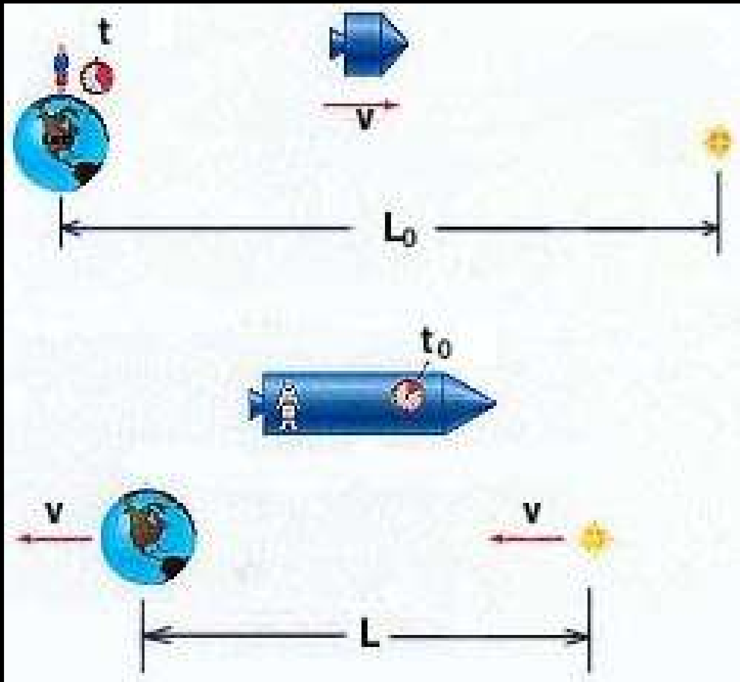


5. The space traveler claims to be at rest and sees the destination start moving with a speed v

14.9 Length Contraction

Quantitatively then

6. Because the spaceship reaches the star in the time Δt_p, the traveler concludes that the distance between starts is shorter than L_p



7. The distance measured by the space traveler is

$$L = v\Delta t_p = v\frac{\Delta t}{\gamma}$$

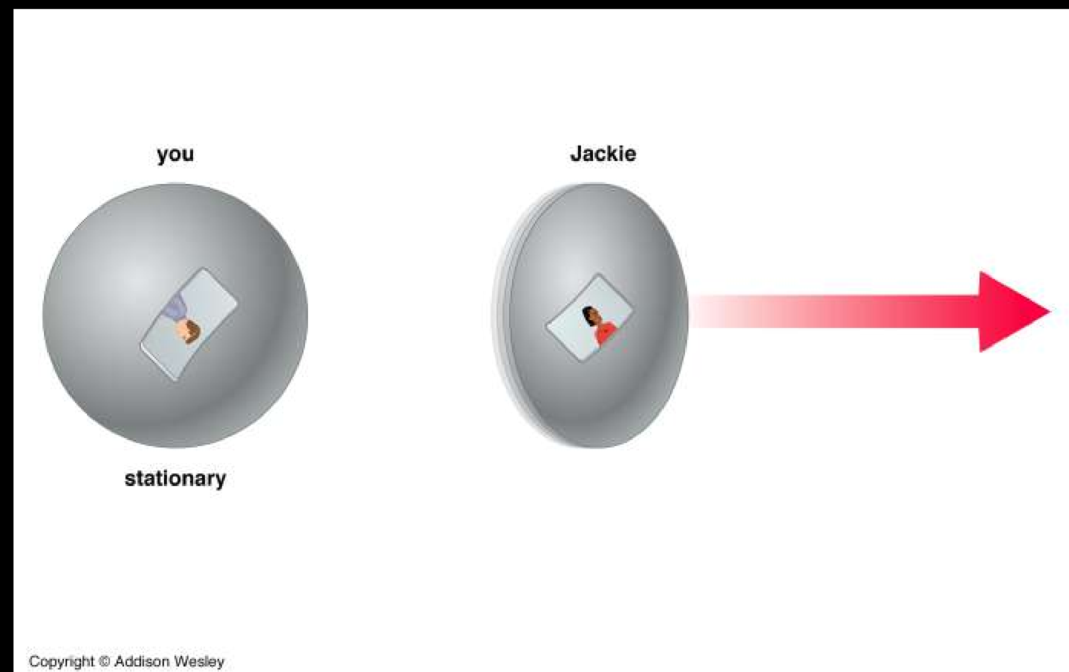
14.9 Length Contraction

$$L = v\Delta t_p = v\frac{\Delta t}{\gamma}$$

Because

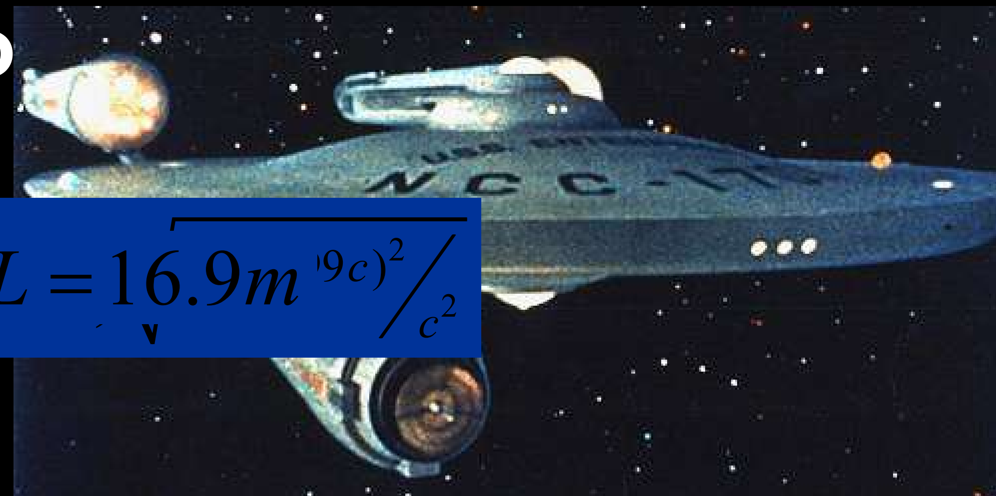
$$L = L_p\sqrt{1 - v^2/c^2}$$

Length contraction takes place only along the direction of motion.



14.9 Length Contraction

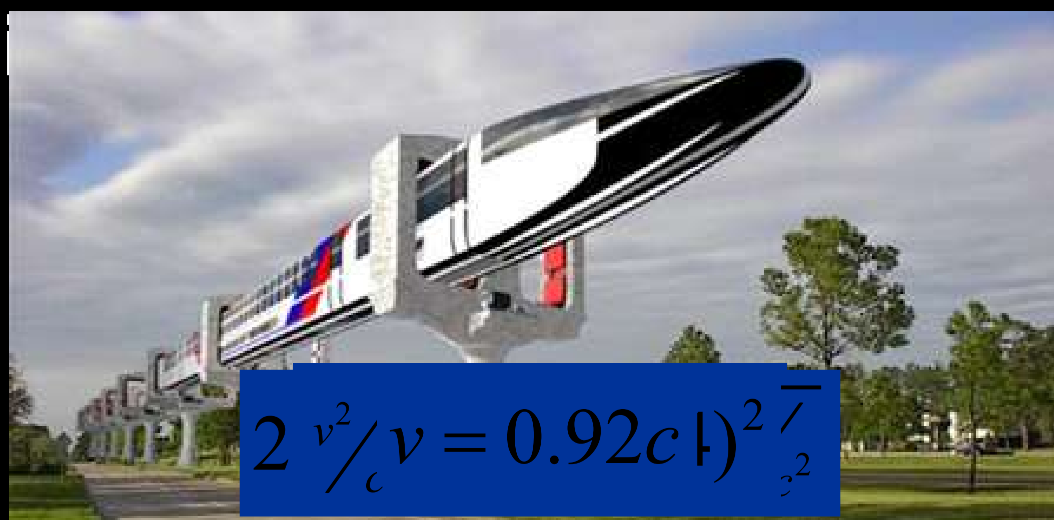
Example 1: A spaceship is measured to be 120 m long while it is at rest with respect to an o



$$L = (L = 16.9m\ {}^{\prime}9c)^2 / c^2$$

If this spaceship now flies past the observer with a speed of 0.99c, what length will the observer measure for the spaceship?

Example 1: A very fast train with a proper length of 500m is passing through a 200m long tunnel. The train's speed is so great that the train fits completely within the tunnel as seen by an observer at rest to the Earth. What is the trai



$v = 0.92c$

14.9 Length Contraction

14.10 Relativistic Momentum and Mass

An

So

Otl

$$p = \frac{m_0 v}{\sqrt{1 - v^2/c^2}}$$

$$m_{rel} = \gamma\, m_0$$

Example: What is the momentum of an electron when it has a speed of $4x10^7$m/s in the CRT of a television set?

$$p = 3.68x10^{-23}\ kgm/s$$

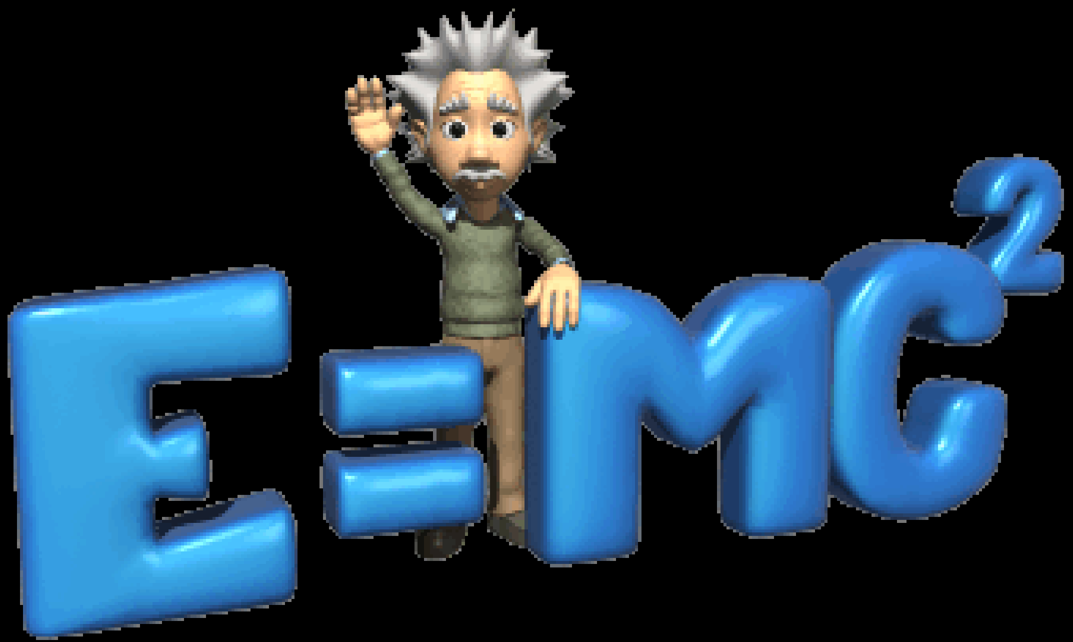
14.10 Relativistic Momentum and Mass

Example: What is the momentum of an electron when it has a speed of 0.98c?

$$p = \frac{(9.11x10^{-31})(0.98)(3x10^{8})}{\sqrt{1 - \quad /c^2}}$$

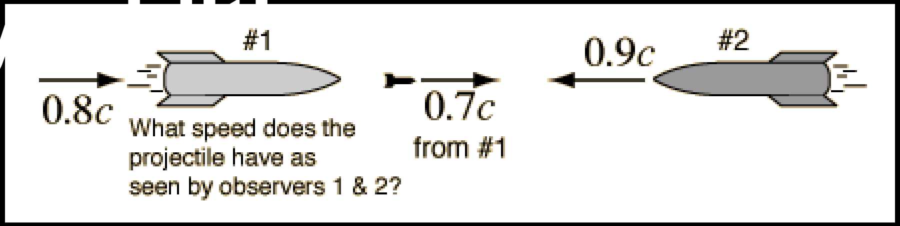
$$p = 1.82x10^{-22}\, kgm/s$$

14.10 Relativistic Momentum and Mass



14.11 Relativistic Addition of Velocities

If two objects moving at relativistic velocities, we can not use standard velocity



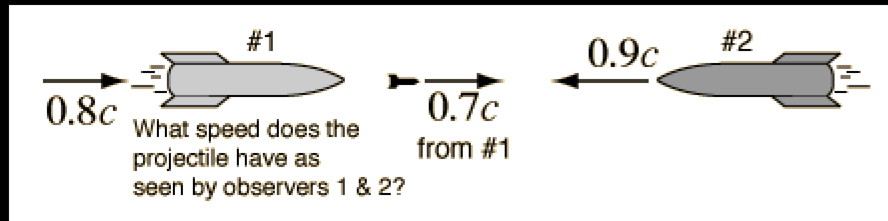
$$v_{ab} = \frac{v_{ad} + v_{db}}{1 + \frac{v_{ad} v_{db}}{c^2}}$$

v_{ad} – speed with respect to moving frame d

v_{db} – the speed of moving frame d with respect to frame b

14.11 Relativistic Addition of Velocities

So if we want to know the speed of the small rocket fired by the rocket on the left



relative to the person measuring the velocity of the rocket

$$v_{ab} = \frac{v_{ad} + v_{db}}{1 + \frac{v_{ad} v_{db}}{c^2}}$$

v_{ad} – 0.70c

v_{db} – 0.80c

$$v_{ab} = 0.96c$$

14.11 Relativistic Addition of Velocities

Example – A man on a motorcycle moving at 0.80c relative to the earth, throws a ball forward. If the ball is measured as traveling at 0.96c relative to the earth, what is the velocity of the ball in the eyes of the motorcycle driver?

$$v + 0.80c$$

$$(0.96c\ 0.\ v = 0.69c\ 2v\ 0.80c$$

$$1 + (0.8v)$$

14.11 Relativistic Addition of Velocities

14.12 The Equivalence of Mass and Energy

Kinetic Energy also had to be modified to take into account relativity

$$K = \gamma mc^2 - mc^2$$

The constant mc^2 is called the rest energy

The term γmc^2 is the total energy

$$E = \gamma mc^2 = K + mc^2$$

Shows that a particle has energy by virtue of its mass alone

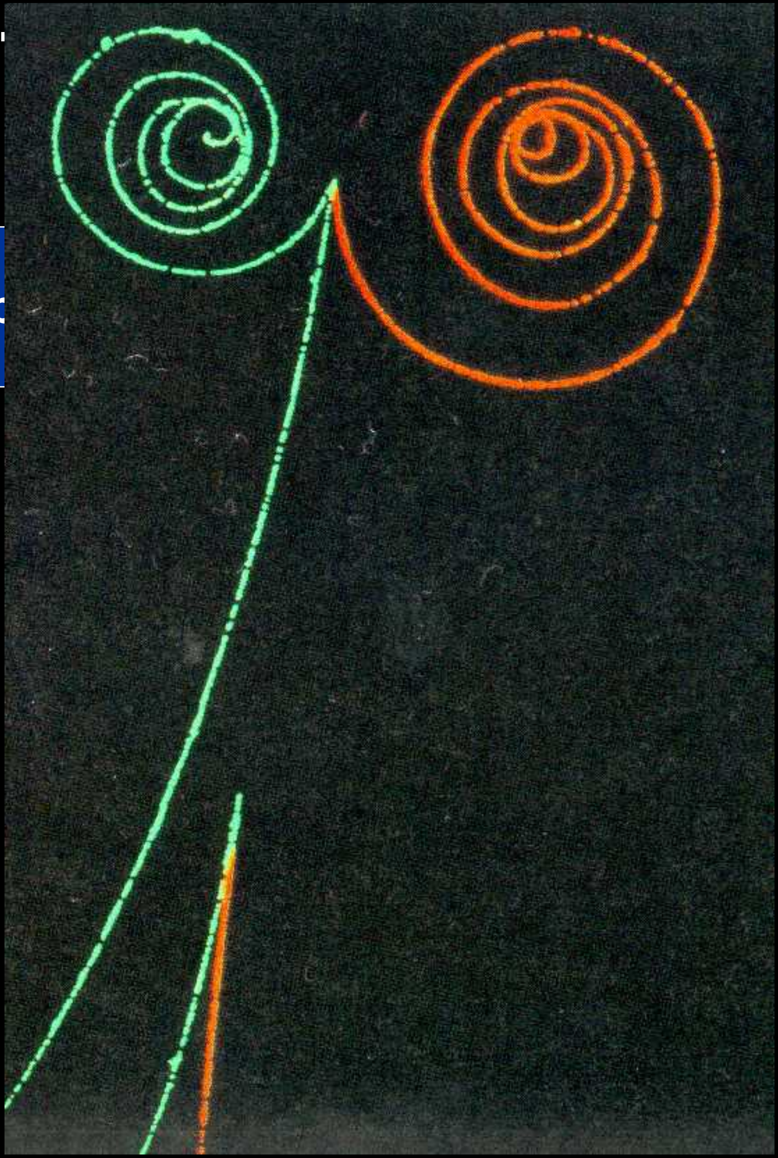
14.12 The Equivalence of Mass and Energy

Experiments have shown t
converted to energy

Atomic Bomb

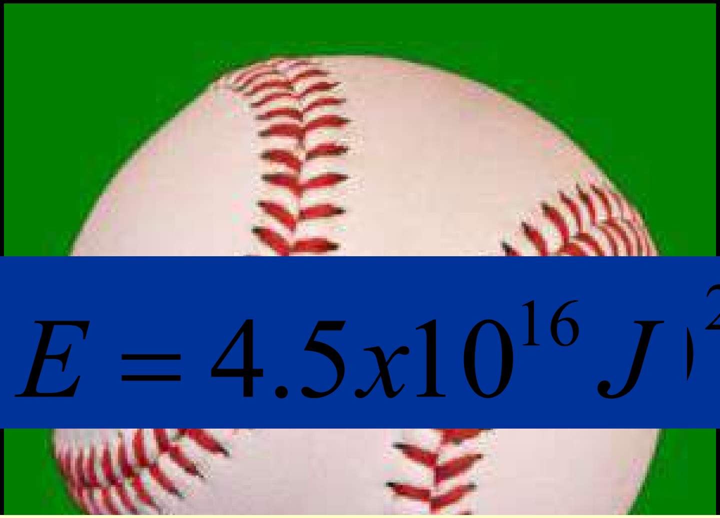
Energy can also be conve

A high energy gamma ray
an atom and produces
positron pair



14.12 The Equivalence of Mass and Energy

Example: If a 0.50kg baseball could be converted completely to energy of forms other than mass, how much energy of other forms would be released?



$$E = 4.5x10^{16} J$$

This is the energy needed to keep a 100W light bulb burning for 10 million years

14.12 The Equivalence of Mass and Energy

Example: An electron moves with a speed of 0.85c. Find its total energy and kinetic energy.

$$E = \frac{(9.11x10^{-31})(3x10^{8})^{2}}{\sqrt{1 - (.85c)^{2}/c^{2}}}$$

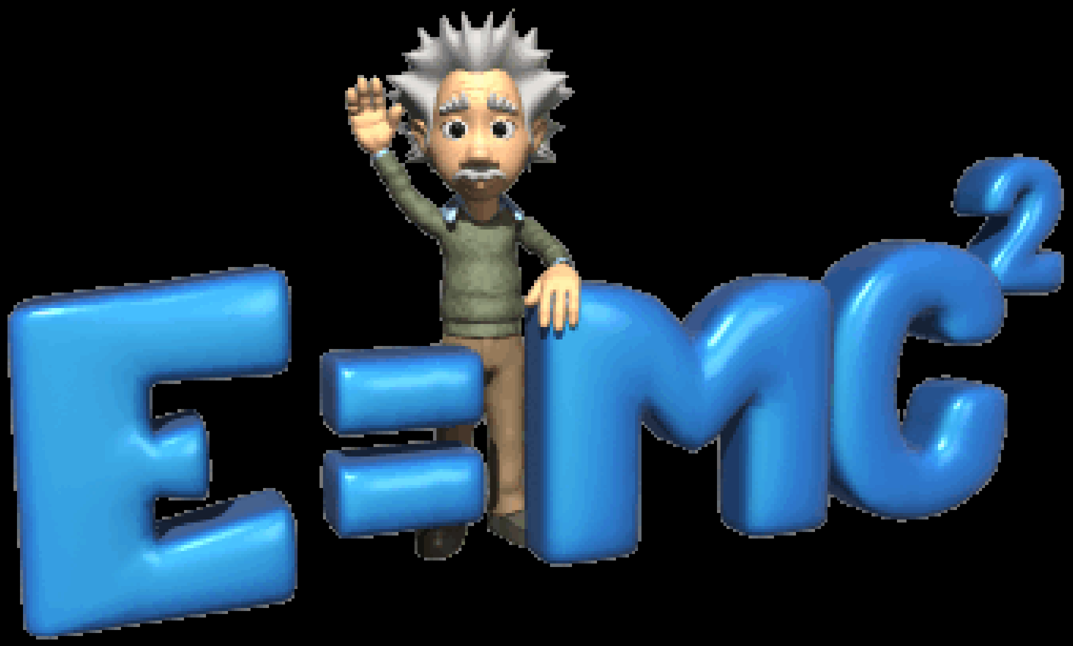
$$E = 1.56x10^{-13}\,J$$

$$E = \gamma mc^{2} = K + mc^{2}$$

$$K = 7.40x10^{-14}\,J$$

$$E - mc^{2} = K$$

14.12 The Equivalence of Mass and Energy



14.13 General Relativity

Puzzle

Mass appears to have two different properties

1. Gravitational Attraction

$$F_g = G\frac{m_g m_g^{'}}{r^2}$$

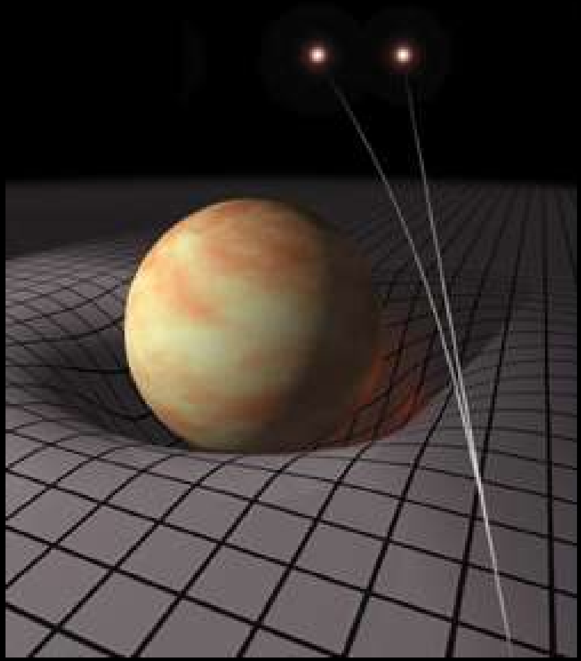
2. Inertia (resistance to acceleratio

$$F_i = m_i a$$

The gravitational mass is proportional to the inertial mass

Einstein's theory of gravitation – general relativity

Two Postulate

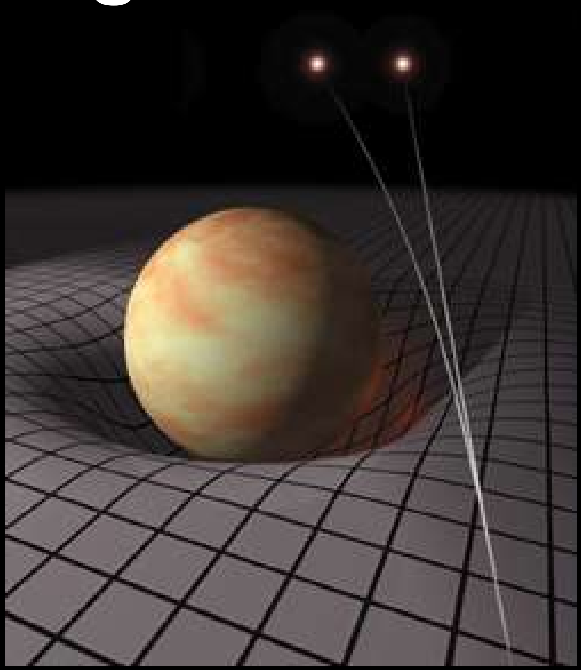


1. All the laws of nature have same form for observers in any frame of reference, whether accelerated or not

Einstein's theory of gravitation – general relativity

Two Postulate

2. In the vicinity of any given point, a gravitational field is equivalent to an accelerated frame of reference without a gravitational field



S-168

Countdown G minus 9 and counting

S-171

Countdown G minus 8 and counting

S-174

Countdown G minus 7 and counting

S-174

Countdown G minus 6 and counting