Chapter 28

Special Relativity

28.1 Events and Inertial Reference Frames

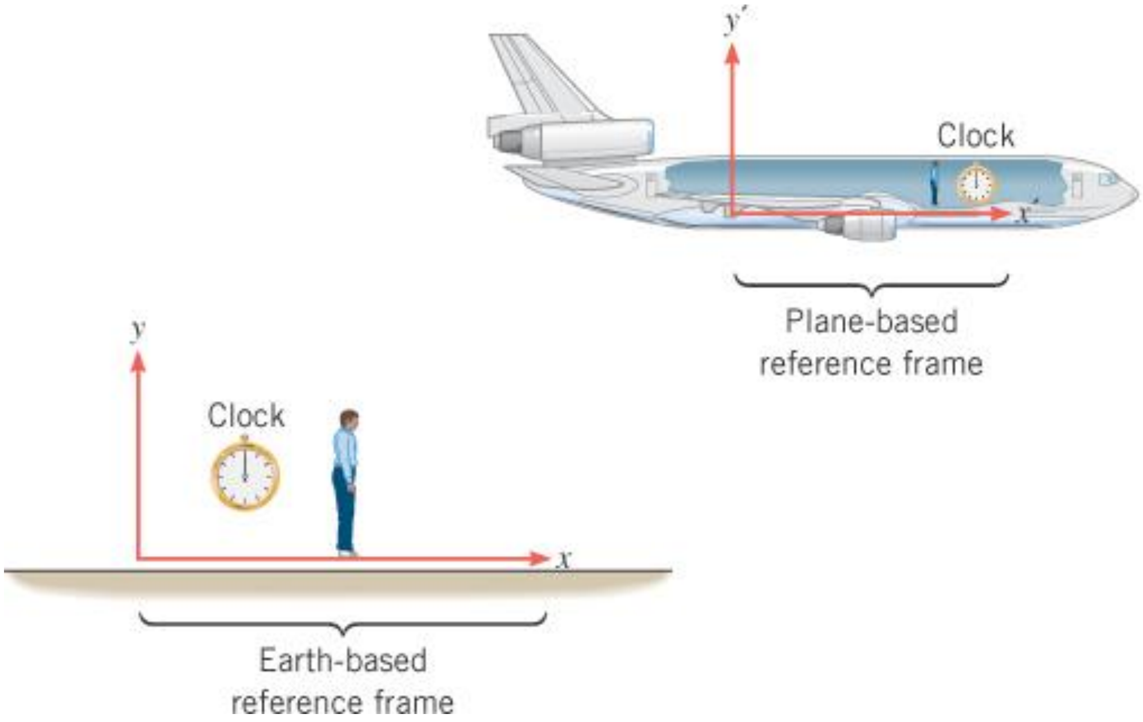
An ***event*** is a physical “happening” that occurs at a certain place and time.

To record the event, each observer uses a ***reference frame*** that consists of a coordinate system and a clock.

Each observer is at rest relative to her own reference frame.

An ***inertial reference frame*** is one in which Newton’s law of inertia is valid.

28.1 Events and Inertial Reference Frames



In this example, the event is the space shuttle lift off.

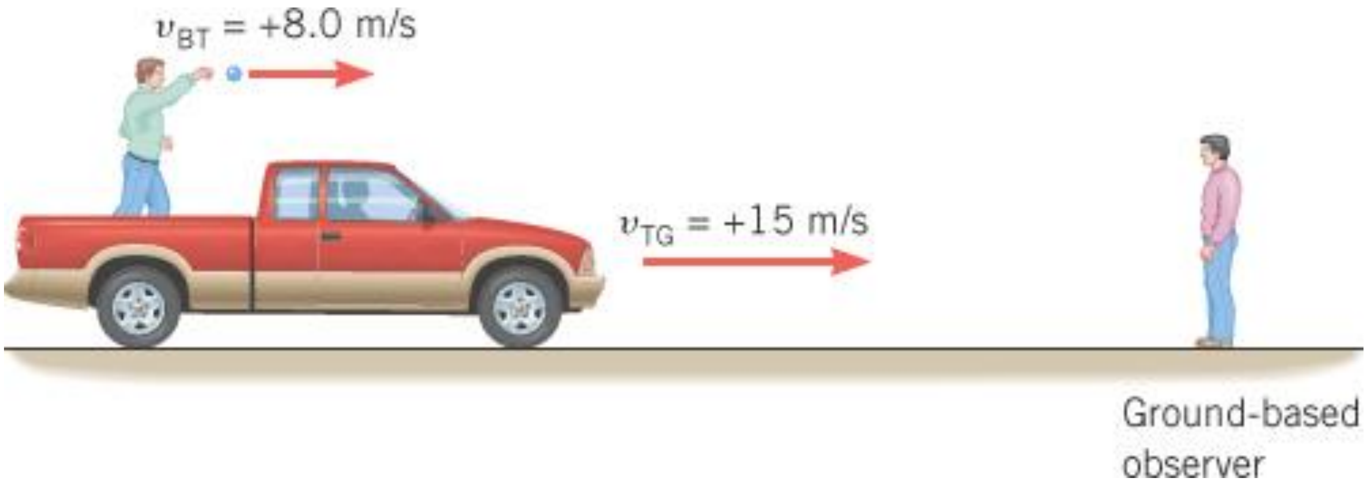
28.2 *The Postulates of Special Relativity*

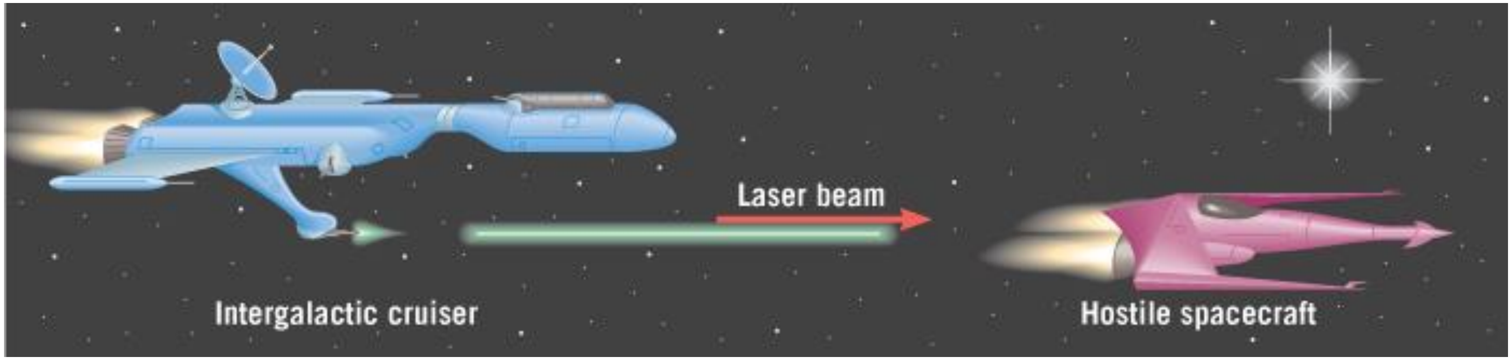
THE POSTULATES OF SPECIAL RELATIVITY

1. The Relativity Postulate. The laws of physics are the same in every inertial reference frame.

2. The Speed of Light Postulate. The speed of light in a vacuum, measured in any inertial reference frame, always has the same value of *c*, no matter how fast the source of light and the observer are moving relative to one another.

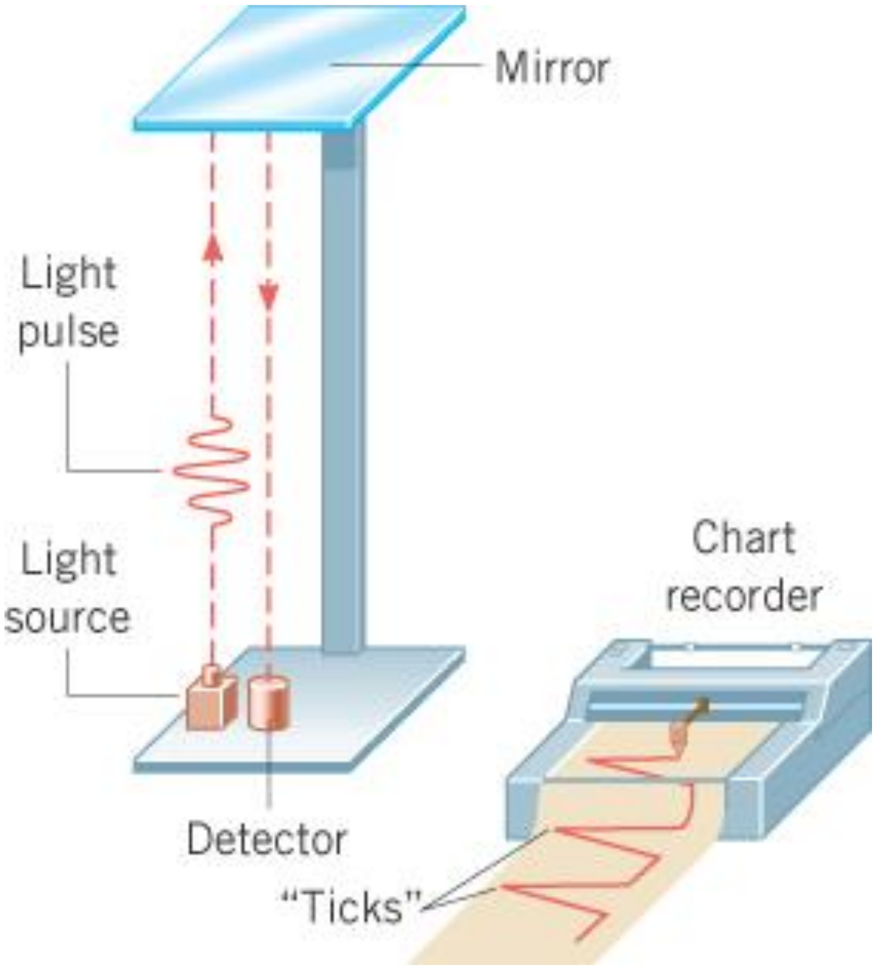
28.2 The Postulates of Special Relativity



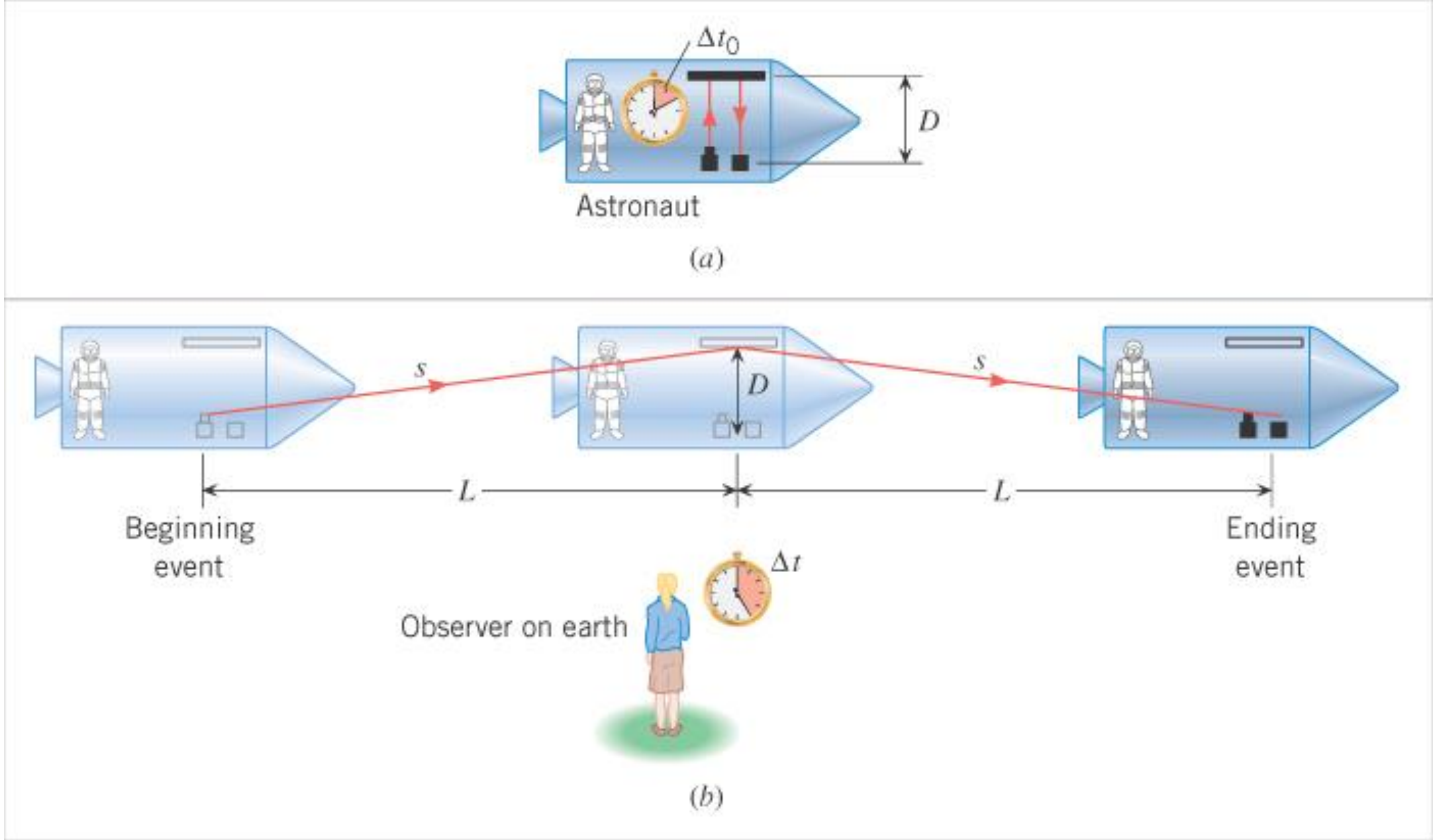


TIME DILATION

A light clock

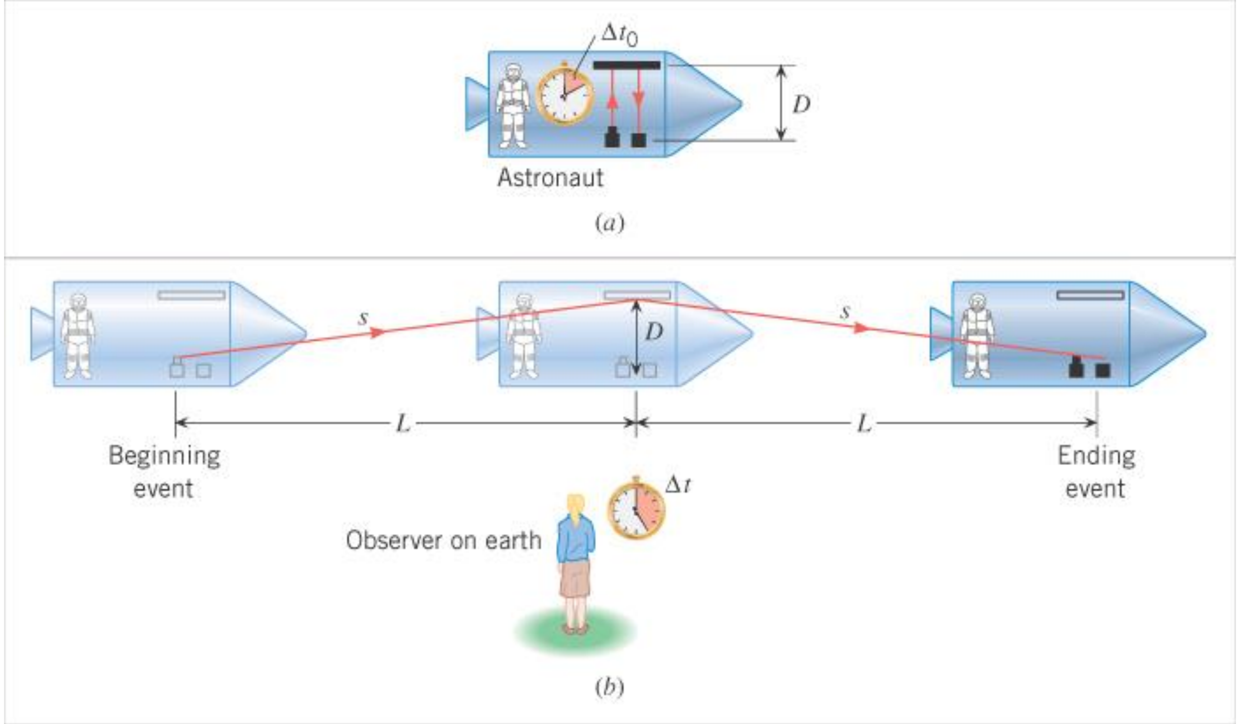


28.3 *The Relativity of Time: Time Dilation*



An observer on the earth sees the light pulse travel a greater distance between ticks.

28.3 The Relativity of Time: Time Dilation

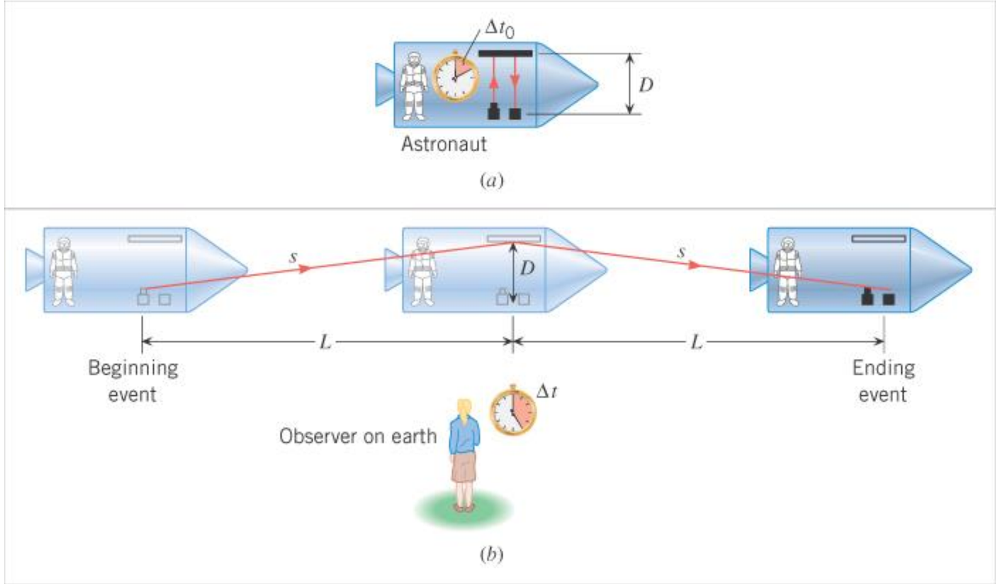


Time dilation

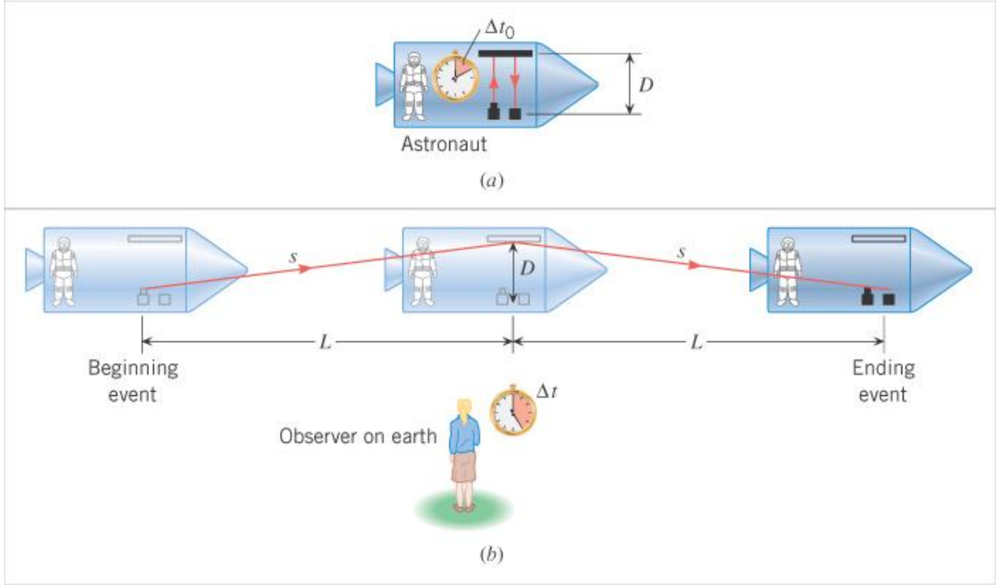
$$\Delta t = \frac{\Delta t_o}{\sqrt{1 - v^2/c^2}}$$

Example 1 Time Dilation

The spacecraft is moving past the earth at a constant speed of 0.92 times the speed of light. The astronaut measures the time interval between ticks of the spacecraft clock to be 1.0 s. What is the time interval that an earth observer measures?



28.3 The Relativity of Time: Time Dilation



$$\Delta t = \frac{\Delta t_o}{\sqrt{1 - v^2/c^2}} = \frac{1.0\,\text{s}}{\sqrt{1 - (0.92c/c)^2}} = 2.6\,\text{s}$$

PROPER TIME INTERVAL

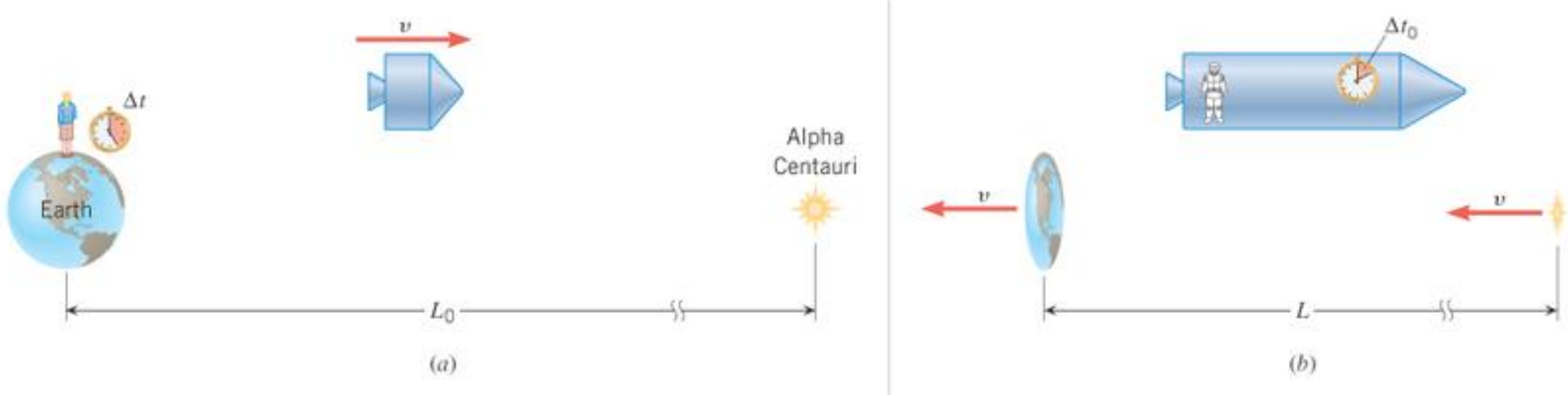
The time interval measured at rest with respect to the clock is called the ***proper time interval***.

In general, the proper time interval between events is the time interval measured by an observer who is at rest relative to the events.

Proper time interval Δt_o

28.4 The Relativity of Length: Length Contraction

The shortening of the distance between two points is one example of a phenomenon known as ***length contraction***.



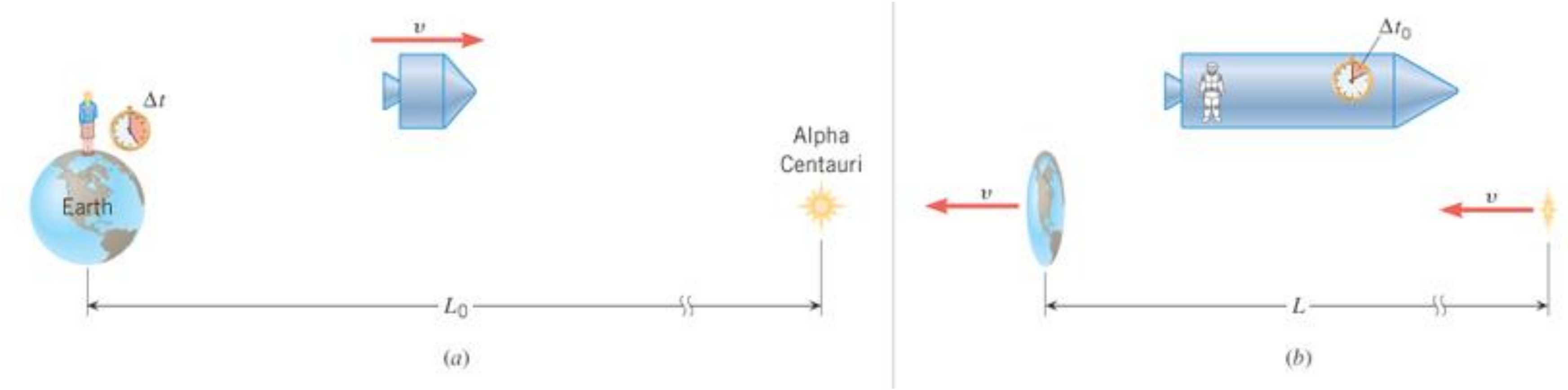
Length contraction

$$L = L_o \sqrt{1 - \frac{v^2}{c^2}}$$

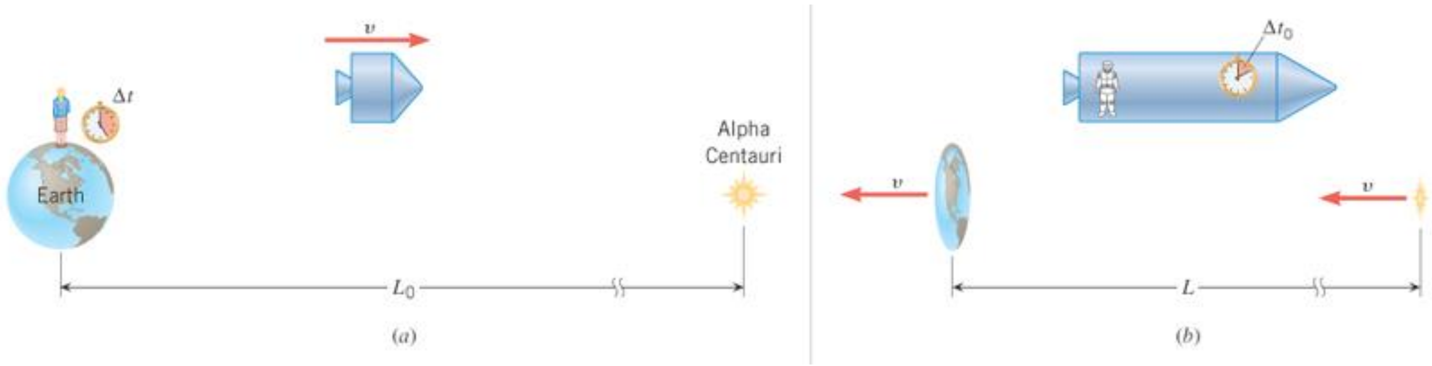
28.4 *The Relativity of Length: Length Contraction*

Example 4 The Contraction of a Spacecraft

An astronaut, using a meter stick that is at rest relative to a cylindrical spacecraft, measures the length and diameter to be 82 m and 21 m respectively. The spacecraft moves with a constant speed of 0.95*c* relative to the earth. What are the dimensions of the spacecraft, as measured by an observer on earth.



28.4 The Relativity of Length: Length Contraction



(a)

(b)

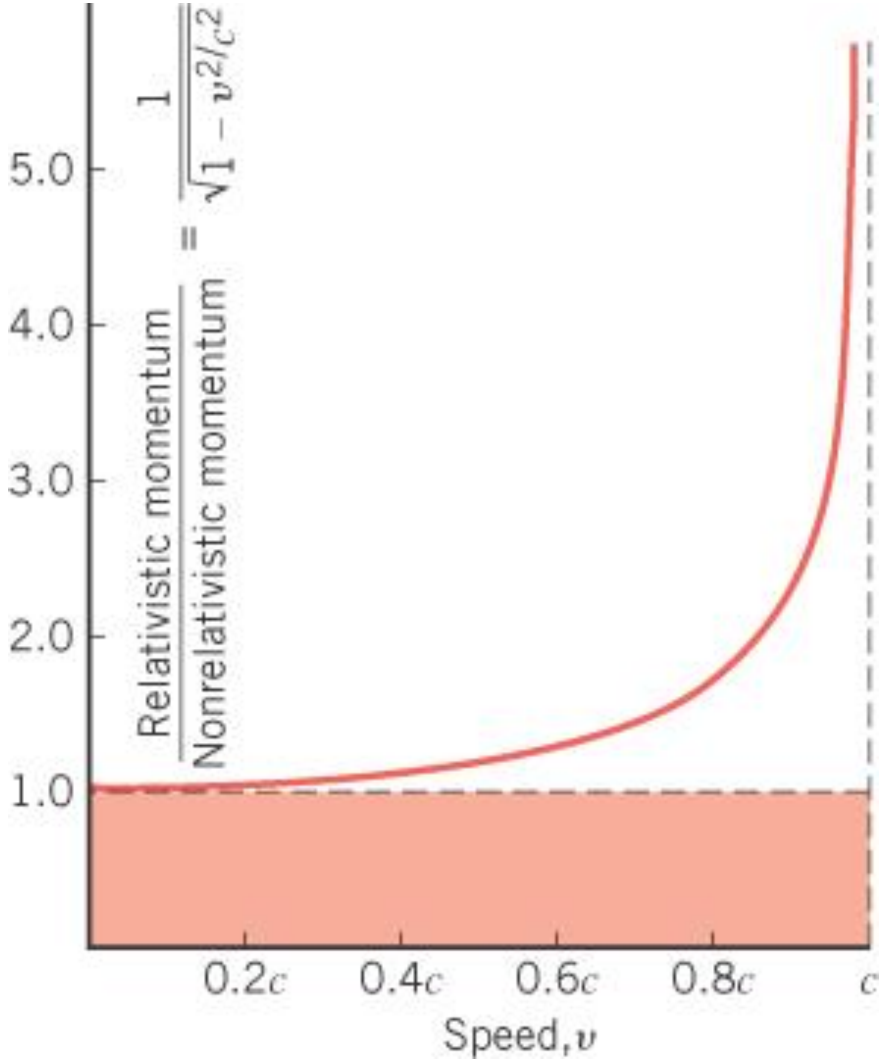
$$L = L_o\sqrt{1-\frac{v^2}{c^2}} = (82\text{ m})\sqrt{1-(0.95c/c)^2} = 26\text{ m}$$

Diameter stays the same.

28.5 Relativistic Momentum

Relativistic momentum

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



THE TOTAL ENERGY OF AN OBJECT

Total energy of an object

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

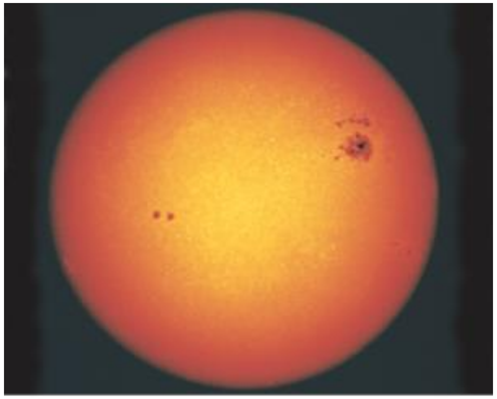
Rest energy of an object

$$E_o = mc^2$$

$$\mathrm{KE} = E - E_o$$

Example 8 The Sun is Losing Mass

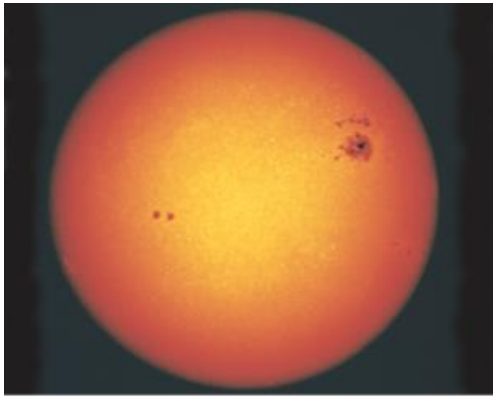
The sun radiates electromagnetic energy at a rate of 3.92x10^{26}W. What is the change in the sun's mass during each second that it is radiating energy? What fraction of the sun's mass is lost during a human lifetime of 75 years.



Visible light image

X-ray image

28.6 The Equivalence of Mass and Energy



Visible light image

X-ray image

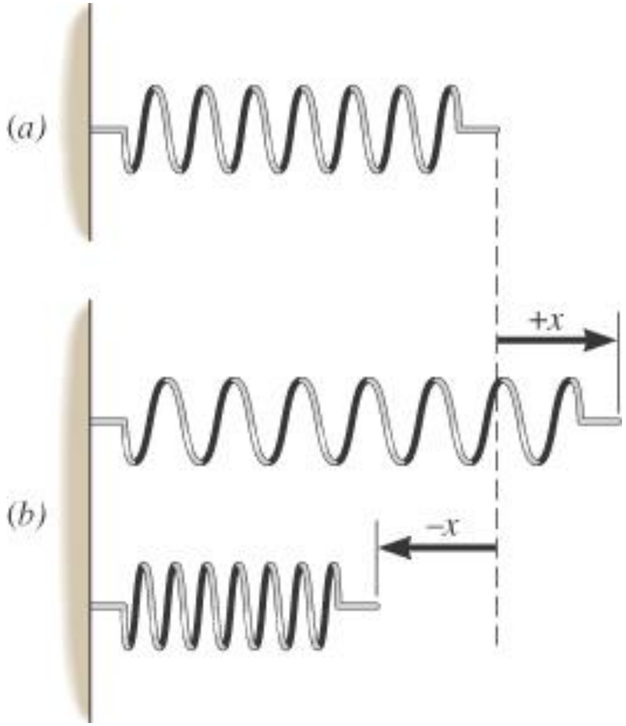
$$\Delta m = \frac{\Delta E_o}{c^2} = \frac{\left(3.92\times10^{26}\ \mathrm{J/s}\right)\left(1.0\ \mathrm{s}\right)}{\left(3.00\times10^{8}\ \mathrm{m/s}\right)^2} = 4.36\times10^{9}\,\mathrm{kg}$$

$$\frac{\Delta m}{m_{\mathrm{sun}}} = \frac{\left(4.36\times10^{9}\ \mathrm{kg/s}\right)\left(3.16\times10^{7}\ \mathrm{s/yr}\right)\left(75\ \mathrm{yr}\right)}{1.99\times10^{30}\,\mathrm{kg}}$$

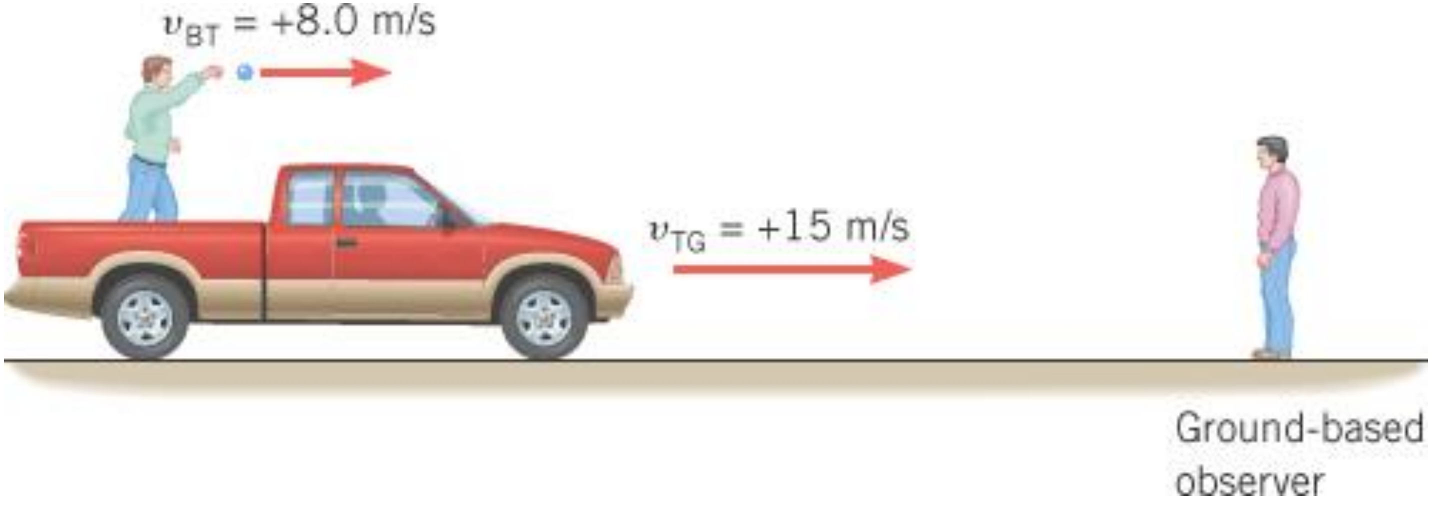
$$= 5.19\times10^{-12}$$

Conceptual Example 9 When is a Massless Spring Not Massless?

The spring is initially unstrained and assumed to be massless. Suppose that the spring is either stretched or compressed. Is the mass of the spring still zero, or has it changed? If the mass has changed, is the mass change greater for stretching or compressing?



28.7 The Relativistic Addition of Velocities



$$v_{BG} = \frac{v_{BT} + v_{TG}}{1 + \dfrac{v_{BT} v_{TG}}{c^2}}$$

Conceptual Example 11 The Speed of a Laser Beam

The cruiser is approaching a hostile spacecraft. The velocity of the cruiser relative to the spacecraft is +0.7*c*. Both vehicles are moving at constant velocity. The cruiser fires a beam of laser light at the enemy. The velocity of the laser beam relative to the cruiser is +*c*. (a) What is the velocity of the laser beam relative to the renegades aboard the spacecraft? (b) At what velocity do the renegades aboard the spacecraft see the laser beam move away from the cruiser?