## Lesson 22

Tuesday, June 01, 2010
1:47 PM

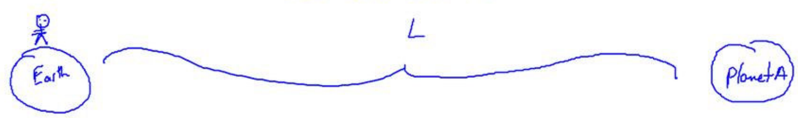
Lesson 2
Saturday, February 20, 2010
7:19 PM

# Length Contraction

if the velocity of light is absolute, $\therefore$ distance and time is not

2 cases to consider

We want to send a space vehicle the distance from earth to another distant planet w.r.t to an observer on Earth.




$V = \frac{d}{t}$

$\boxed{V_E = \frac{L_0}{t_E}}$

$V_E$ - The speed the ship travels wrt to $O_E$

$t_E$ " time " " " " " $O_E$

$L_0$ = " proper length " " "


$\boxed{V_{vehicle} = \frac{L}{t_{vehicle}}}$

$= \frac{L}{t_0}$

$V_{vehicle}$ - speed of spaceship

$t_{vehicle}$ - time it takes to reach the other planet

$L$ - distance as measured from the vehicle

We use $t_0$ notation based on last class

$V_E = \boxed{\frac{L_0}{t_E} = \frac{L}{t_0}} = V_V$ $\boxed{\frac{L}{t_0} = \frac{L_0}{t_E}}$ but $\boxed{t_E} = \frac{t_0}{\sqrt{1-\frac{v^2}{c^2}}}$

Time dilation

$$\Rightarrow \frac{L}{t_0} = \frac{L_0}{\frac{t_0}{\sqrt{1-\frac{v^2}{c^2}}}}$$

$$\Rightarrow \frac{L}{t_0} = \frac{L_0}{1} \cdot \frac{\sqrt{1-\frac{v^2}{c^2}}}{t_0}$$

$$\cancel{t_0}\,\frac{L}{\cancel{t_0}} = \left[\frac{L_0\sqrt{1-\frac{v^2}{c^2}}}{\cancel{t_0}}\right]\cancel{t_0}$$

$$L = L_0\sqrt{1-\frac{v^2}{c^2}}$$

$L$ = length experienced by object traveling very fast

$L_0$ = proper length
length experienced by observer on earth

$L \leq L_0$ always

length contraction is only in the direction of motion

ex) a space vehicle that is 50.0m long is travelling @ a constant speed of .75c past an observer standing on earth. How long does it appear to an observer on Earth?

$$L = L_0\sqrt{1-\frac{v^2}{c^2}}$$

$$= 50.0\sqrt{1-\frac{(.75c)^2}{c^2}}$$

$= 33\ m$

ex) a space vehicle flies parallel to a horizontal meter stick. The meter stick appears to be only 0.50m long. How fast was the ship travelling?

$$L = L_0 \sqrt{1-\frac{v^2}{c^2}}$$

$$\left(\frac{L}{L_0}\right)^2 1-\frac{v^2}{c^2} \Rightarrow c^2 \boxed{1-\left(\frac{L}{L_0}\right)^2 = \frac{v^2}{\cancel{c^2}}} \cdot c^2$$

$$c^2\left[1-\left(\frac{.5}{1}\right)^2\right] = \frac{v^2}{\cancel{c^2}} \cdot c^2$$

$$\sqrt{c^2 \cdot \left(1-\left(\frac{L}{L_0}\right)^2\right)} = v$$

$$v = \underline{2.6\times10^8 m/s}$$

$$\sqrt{c^2(1-.25)}$$

$$\sqrt{.75c^2} = v$$

$$\sqrt{.75}\sqrt{c^2} = v$$

$$.87c = v$$

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Mass Increase

The same way time and distance depends on the frame of reference, mass also depends on the frame of reference. The mass of an object increases with speed according to the following relativity equation

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

$m$ = relativistic mass
$m_0$ = mass @ rest
$v$ = speed of the object
$c$ = speed of light.



$m > m_0$

Relativistic mass is always greater than rest mass

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Another consequence of Einstein's special theory of relativity is a relationship between

$E = mc^2$     $E$ = energy<br>$m$ = mass of object.<br>$c$ = speed of light.

This says that mass can be transformed into energy in fact, that mass and energy are the equivalent

ex) Calculate the relativistic mass of an electron that is travelling $2.0 \times 10^8$ m/s.

we know that the relativistic mass is always greater than mass @ rest.

Mass of electron = $9.11 \times 10^{-31}$ kg<br>$v = 2.0 \times 10^8$ m/s

$$\Rightarrow \quad m = \frac{m_0}{\sqrt{1 - \frac{v^2}{c^2}}}$$

$$\Rightarrow \quad m = \frac{9.11 \times 10^{-31}\text{ kg}}{\sqrt{1 - \left(\frac{2.0 \times 10^8 \text{ m/s}}{3.00 \times 10^8 \text{ m/s}}\right)^2}} = 1.2 \times 10^{-30}\text{ kg}$$

ex2) what mass would be required to produce $2.0 \times 10^{15}$ J of heat if the mass was converted to heat.

$E = 2.0 \times 10^{15}$ J<br>$c = 3.00 \times 10^8$ m/s

$$E = mc^2$$

$$m = \frac{E}{c^2} = \frac{2.0\times10^{15}\,J}{(3.00\times10^8\,m/s)^2}$$

$$= .022\,kg$$

Recall efficiency $= \dfrac{\text{Work out}}{\text{work in}} \times 100\%$

ex 3 let's assume we have a machine that is 90% efficient in converting matter into energy. How much matter would we need to convert into $\boxed{7.0\times10^7\,J}$

$$90\% = \frac{\text{Work out}}{\text{work in}} \Rightarrow \text{Work in} = \frac{\text{Work out}}{90\%}$$

$$\Rightarrow \frac{7.0\times10^7\,J}{.9} = \boxed{77777777.78\,J}$$

$$7.7\times10^7\,J = mc^2$$

$$m = \frac{7.7\times10^7}{c^2} = 8.6\times10^{-10}\,kg$$

ex 4) A .046 kg golf ball is lying on the green. If it was converted 100% into energy and this energy was used to run a 75 W bulb how long (yrs) would the light bulb be on?

$$E = mc^2$$

$= (0.046 \text{ kg})(3.00 \times 10^8 \text{ m/s})^2$

$= 4.1 \times 10^{15} \text{ J}$

$P = \frac{W}{t} = \frac{E}{t} \Rightarrow t = \frac{E}{P} = \frac{4.1 \times 10^{15} \text{ J}}{75 \text{ W}}$

$= 5.5 \times 10^{13} \text{ s}$

$5.5 \times 10^{13} \times \frac{1 \text{ min}}{60 \text{ s}} \times \frac{1 \text{ hr}}{60 \text{ min}} \times \frac{1 \text{ day}}{24 \text{ hrs}} \times \frac{1 \text{ yr}}{365 \text{ days}}$

$t = 1.7 \times 10^6 \text{ yr}$ or 1.7 million years

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$m = \frac{m_0}{\quad}$

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

$$3m_o = \frac{m_o}{\sqrt{1-\frac{v^2}{c^2}}}$$

$$\left(\sqrt{1-\frac{v^2}{c^2}}\right)^2 = \frac{\cancel{m_o}}{3\cancel{m_o}} = \left(\frac{1}{3}\right)^2$$

$$1-\frac{v^2}{c^2} = \frac{1}{9}$$

$$1-\frac{1}{9} = \frac{v^2}{c^2}$$

$$\frac{8}{9}c^2 = v^2$$

$$v = \frac{2\sqrt{2}}{3}c$$

$$= .94c$$