Relativity

Frame of Reference:
a coordinate system in which measurements of time and distance can be made (x,y,z, axes and a clock)

Galilean Transformations and Relative Velocities

Galilean Transformation – transformation of measurements made in one frame of reference to another frame of reference without taking into account the theory of relativity

Stationary frame: ground based observer

Moving frame: truck

x' = position of an object as measured in moving frame

x = position of an object as measured in stationary frame

u_x' = velocity of object in x-direction as measured in moving frame

u_x = velocity of object in x-direction as measured in stationary frame

v = velocity of frame 2 in x-direction as measured in stationary frame

Galilean transformation of positions and velocities

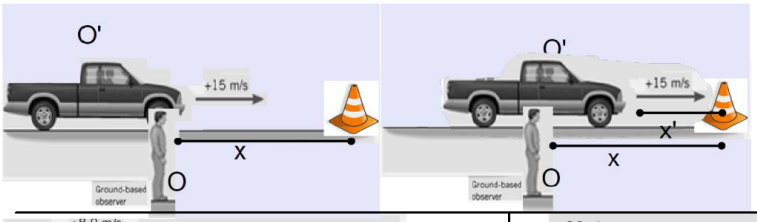
$u'_x = u_x - v$

$u = u' + v$

$t' = t$

$x' = x - vt$

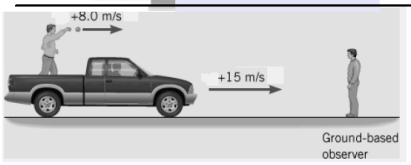
1) A truck passes a person on the ground at t = 0, and they are a distance 'X=60. m' from a road cone.
Some time '*t=2s*' later, where is the cone, as measured by the truck?



$X' = X - vt$

$60m - 15m/s \cdot 2s$

$= 30m$



1. What is the velocity of the ball:

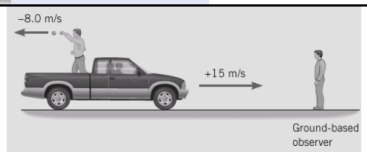
a) as measured by the person in the truck?

8 m/s

b) as measured by the ground-based observer?

$v' = v - v$ $\quad u = u' + v$

$8m/s + 15m/s = 23m/s$



2. What is the velocity of the ball:

a) as measured by the person in the truck?

$-8 m/s$

b) as measured by the ground-based observer?

7 m/s

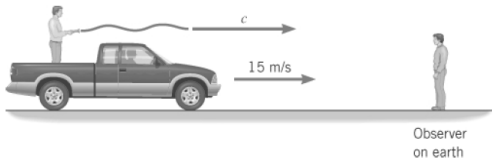
Galilean principle of relativity:

1. laws of mechanics are the same in all inertial reference frames
2. there is no preferred frame of reference (absolute frame) for describing the laws of mechanics

$$c = \frac{1}{\sqrt{\varepsilon_0 \mu_0}}$$

What is the problem with the Galilean principle of relativity?

- different observers will measure different values for the speed of light
- but according to the laws of electromagnetism (Maxwell's equations), the speed of light in a vacuum is a fixed value



How can this contradiction be resolved? Is the speed of light variable or is it fixed? Two possibilities exist:

1. The Galilean transformation laws are incomplete or incorrect. This means that the formulas for adding and subtracting relative velocities will need to be revised so that the speed of light is the same for all observers.
2. The laws of electromagnetism are not the same in all inertial reference frames. This means that there must exist a preferred reference frame in which the speed of light is a constant value but in other reference frames the speed of light can vary according to the Galilean transformations.

Possible solution: Find an absolute frame of reference in which light travels at its predicted constant speed and then all other reference frames can be compared to this absolute frame using the Galilean transformations.

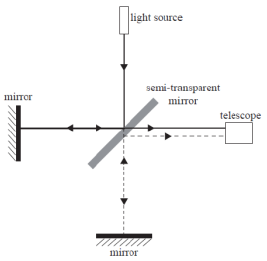
Luminiferous ether: a massless fluid that fills all space that is the medium through which light travels

Absolute Frame: a frame of reference at rest with respect to the ether

Michelson-Morley experiment – (1887) by Albert Michelson and Edward Morley at what is now Case Western Reserve University in Cleveland, Ohio.

Purpose:

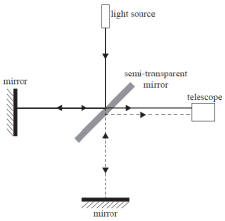
- To measure the speed of the Earth in its orbit relative to the ether
- To detect the ether
- To find an absolute frame of reference



Essential features of the Michelson-Morley apparatus

Experiment:

A beam of light is split by a half-silvered (semi-transparent) mirror into two beams which then reflect off mirrors and recombine at the detector (telescope) where an observer looks at the interference pattern these two beams make. The interference pattern should be caused by the path difference between the two beams due to the difference in speed of light relative to the supposed ether. If the ether existed, then when the apparatus is turned 90^{o} the interference pattern would change or shift because the rotation would exchange the beam directions relative to the Earth's motion through the ether. The amount of the shift would allow the speed of the Earth relative to the ether to be determined.



Essential features of the Michelson-Morley apparatus

The Michelson-Morley experiment is perhaps the most famous "null-result" experiment in all of physics. More recent experiments have confirmed the absence of the ether to sensitivities of 10^{-17}.

Results:

No shift was detected so there was no change in the optical path lengths of two beams (no change in path difference). Therefore time taken by the light to travel these distances is independent of the path taken.

Implications:

1) The speed of light in a vacuum (in free space) is **invariant** (independent of path – same in all frames of reference)
2) The ether does not exist.
3) There is no absolute frame of reference
4) The Galilean transformation laws must be revised

Special Relativity

Special Theory of Relativity (1905): Einstein's attempt to resolve the paradox about the speed of light and the laws of electromagnetism

Two Postulates of Special Relativity:

I. The laws of physics are the same in all inertial reference frames

Consequence: There is no preferred frame of reference

II. The speed of light in a vacuum is the same for all observers

Consequence: The speed of light is independent of the speed of its source or the speed of any observer

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Inertial Frame of Reference:

- a frame of reference in which Newton's law of inertia is valid (an object with no unbalanced forces will remain at rest or move at a constant velocity)
- frame of reference that is at rest or moving with a constant velocity (not accelerating