Inertial Reference Frame

We must define a reference frame in which to measure motion.

If a frame of reference is not accelerating we say it is an inertial frame of reference.

Frames of reference

P1: Is it an inertial frame of reference? i.e., is it “gentle enough” for our purposes

- A car driving straight down a freeway at constant speed
- An airplane at constant velocity
- A car going around a curve at constant speed
- A space ship which has zero net force on it
- The Eyring science center

Symmetry

A symmetrical object is one which can be viewed from different points of view and still appear the same.

Does a cube have symmetry? change your location?
Does a sphere have symmetry?
Do you have symmetry? Demo: cube, sphere, crystal, mirror

Symmetry of Nature

Nature is said to be symmetric under a transformation (i.e. a change of perspective) if no experiment you could perform would allow you to detect whether the change in perspective has taken place, i.e., no change in the laws of nature.

As we learn about the ways nature is symmetric, we are better able to predict what will happen. Symmetry limits the number of distinct possibilities and makes life easier.

Time and Position symmetry

Some things change with time but, the laws of nature are symmetric under changes in time.
Consequence:
The laws of nature are the same as they were in the remote past and will be the same in the future.

Natural laws are symmetric under changes in position.
Consequence:
The laws of nature are the same everywhere in the universe.
Which description is valid?

All of them are okay. They differ by the frame of reference or the perspective.

Motion symmetry or Special Principle of Relativity:
The positions and velocities measurements are different but the laws of nature are the same for all observers who are in inertial reference frames.

Compare:

1. sitting on runway
   a. throw a ball up - Newton’s Laws
   b. play with cat fur - electromagnetic force
   c. eat soup - Newton’s Laws

2. at 30,000 ft going 600 mph straight line (no turns or bumps)
   a. throw a ball up - Newton’s Laws
   b. play with cat fur - electromagnetic force
   c. lunch soup - Newton’s Laws

Example

P2: A pigeon is flying horizontally and drops a small package. The pigeon continues to fly straight ahead with the same speed and also watches the package drop. What does the pigeon see? (Neglect air friction.)

The person receiving the package on the ground watches the package released by the pigeon. What does he see?

Imagine 2 spaceships

P3: Imagine 2 spaceships, A and B. There is nothing in the cosmos except these two ships. They move toward each other at uniform velocity. By using the laws of nature is there any way astronauts on either ship can really decide which of the following is “true” or “absolute”?

1. Spaceship A is at rest, B is moving.
2. Spaceship B is at rest, A is moving.
3. Both ships are moving.
Study Question

P4: 2 cars drag. One starts coasting. The other continues to accelerate. But each sees the other to be accelerating in opposite directions. Is there an experiment that would tell which is accelerating?

Frames of reference

If a frame of reference is accelerating we say it is a non-inertial frame of reference
- Laws of motion do not hold
- We feel unbalanced forces which are not real pushes or pulls
Example: As a car speeds up we “feel” we are being pushed back in our seats

Results of the Michelson/Morley experiment (1887)

Albert Michelson

Conclusion: While different speeds can be assigned to the lady’s motion earlier, only one value is found for the speed of light. Light does not obey Galilean Relativity!

Special Relativity Postulates

The laws of nature are the same for all observers who are in uniform motion.
- The speed of light in empty space is the same for all observers regardless of their motion or the motion of the source of light.

“Everything should be made as simple as possible, but not simpler.” ~Albert Einstein

time marches on: twentieth century

- Newtonian view?
  - added to; adjusted – still useful for things that are large (compared to atoms), and slow-moving (compared to speed of light)
- relativistic model – explains the experiments that proved the Newtonian view to be inadequate

How fast is “high speed”

- 50 mph
- 225 mph
- 550 mph
- 670,000,000 mph
- 39,000 mph
New horizons mission

Fastest man made object ever at 45,000 mph (after it gets a little slingshot from Jupiter's gravity)
Will cover the 3 billion miles to Pluto in just 10 years.
Still only 1/20,000 of the speed of light

Motion Example: measure a pen

Pen is at rest
Pen is moving
Make marks on a ruler at the same time as the pen flies by.
Careful: if the mark at the front is made before the mark at the back, the pen is measured to be short.

Simultaneous events

Two events are said to be simultaneous if light from the events reaches an observer located half way between the events at the same time.

Simultaneity thought experiment

Time and distance affected by motion

Dick's View  Jane's View

Hendrik Lorentz and Albert Einstein, the stars of relativity

Length Contraction

Length measurements of moving objects require simultaneous measurement of positions
An observer moving with respect to the thing being measured will always measure the front first.
(According to the observer who is moving with the ruler)
Moving objects are measured to be shorter than when they are at rest ("length contraction")
**Light Clock**

Each tick marks a unit of time

\[
\text{time} = \frac{\text{distance}}{\text{speed of light}} = \frac{d}{c}
\]

A moving clock runs slow.

Traveling a longer distance at the same speed takes more time.

**Special theory of relativity**

• Implications are that space and time are not absolute quantities

How does time appear to be passing in objects moving fast relative to us?

Surprise # 1

Clocks tick at different rates when they move relative to one another. The moving clocks run slower.

**Surprises #2-5**

2. Simultaneity is relative!
3. Moving meter sticks contract!
4. Moving mass increases!
5. Mass and energy are equivalent!

\[ E = mc^2 \]

**Present Model for Earth/Moon Motion**

- Earth is "spherical"
- Rotates daily around a north-pole south-pole axis
- Revolves annually around the sun
- Moon revolves around earth in 29 ½ days

**Planar view of earth’s motion**

Axis of earth’s rotation is tipped 23.5° wrt sun/earth plane (ecliptic). Rotates counter-cw when looking from northstar direction toward ecliptic.

**Model easily explains many things:**

- Daily motion of sun, moon, and stars
- Why the moon has phases
- Why it is hotter in summer
- Why the full moon rises about the time the sun sets
- Why we need time zones
- Why the sun sets further north in summer
- Why days are longer in summer
- Etc., etc.,
**Latitude Locations on Earth**

Locations on earth are given in terms of latitude and longitude. (Altitude of Polaris above the horizon is also equal to latitude.)

- Provo is about 40° north latitude.

North pole

Equator

Latitude, 0

North pole is 90° north latitude

**Longitude Locations on Earth**

Longitude is measured around the equator.

- Looking from north to south pole

Greenwich

England is 0° longitude

Date Line is 180° longitude

Provo is 112° west longitude

**Are we in Uniform Motion?**

The earth rotates around its axis

The earth revolves around the sun

**How can we tell earth’s rotation?**

- Pendulum at north pole;
  - Viewed from outside the earth it swings in space, and earth rotates under it.
  - Viewed on earth at north pole the pendulum rotates around once each day.

- Foucault pendulum (demo) See foyer in ESC.

**What about the Earth’s motion around the sun?**

- Stellar parallax
  - Demo: left and right eye

Stars change relative positions during the year

**Time Zones**

- Earth rotates 15° per hour.
- Time zones are thus 15° apart. Same time everywhere in a single zone.
- Mountain time zone is centered on 105° longitude. We are on the western edge of MT zone (112°).
- **P5:** We see the sun at its highest overhead (a) before, (b) after or, (c) just as our MT clocks read 12:00 noon?
**Summer heat**

Why is it hotter in summer? Earth moves in the ecliptic plane but the axis is tilted 23.5°.

[NCP (north celestial pole)]

[Six months later]

Winter Solstice

Summer Solstice

Demo: cardboard and flashlight

**Solstice and equinox**

June 21, Dec. 22 summer and winter solstices (sun or ecliptic plane is at extreme high and low, respectively; tilt toward or away from the sun).

March 21, Sept. 22 vernal and autumnal equinoxes (ecliptic plane is on the celestial equator; tilt is not toward or away).

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**The Phases of the Moon**

[Waxing Crescent, Waning Gibbous, First Quarter, Waxing Gibbous, Last Quarter]

http://stardate.org/nightsky/moon/

http://home.hiwaay.net/~krcool/Astro/moon/moonphase

Demo: moon phases

**Retrograde planetary motion**

Planets usually move during the year from west to east among the stars (move eastward).

Occasionally they appear to us to stop and move westward for a short time among the stars.

This is “retrograde” motion

Smaller orbit means faster speed.

Looking down on ecliptic from the North star.