Lecture 19: Special Relativity
Readings: Section 24-1 and Box 24-1

Framework
Postulates
    Facts <u>assumed</u> to be true
    Example: the speed of light is the same for all observers
Consequences
    What happens when moving quickly or in strong gravitational fields
    Example: moving clocks run slow
Tests
    Observational proof
    Example: the bending of light by the Sun
Relevance
    When special or general relativistic equations <u>must</u> be used
    Example: Special Relativity – fast
    General Relativity – strong gravitational fields

Key Ideas for Special Relativity:

<u>Central Postulates:</u>
    The laws of physics are the <u>same</u> for all uniformly moving observers
    The speed of light is the <u>same</u> for all observers
<u>Consequences</u>
    Different observers measure <u>different</u> times, lengths, and masses
    Only <u>spacetime</u> is observer independent
<u>Tests</u>
    Michelson-Morley Experiment
    Muon decays
    $E=mc^2$
    Many, many particle accelerator experiments
<u>Relevance</u>
    When an object is moving close to the speed of light relative to you
    When very accurate results are required

Newton's Universe

In Newton's view:

The Universe keeps absolute time
Objects move through absolute space
Universe looks the same to all observers, regardless of how they move through it.

Result:
A set of laws formulated from the perspective of an absolute "God's Eye View" of the Universe.

Einstein's Challenge

1905: Einstein challenged Newton's view:

We cannot take a "God's eye-view" of the Universe
We can only compare our view with that of other observers
All information we have is carried by light
But, light moves at a finite speed.

Result

Introduces an irreducible relativity to our physical perspective of the world.

Seeing the World

All information about the Universe is carried by light.

Speed of Light: c=299,792.458 km/s
Compared to everyday scales

65 mph=0.028 km/s=9.3 x10^{-8} c
light travels across this room in ~30 nanoseconds
human reflexes: ~0.1 sec (10^8 nanoseconds)

Postulates

Definition of a postulate: An idea that is assumed to be true.
Not just observed to be true in experiments. A fundamental statement about the way the world has to be.

If a postulate is proven to be untrue, then large parts of theory can be put in doubt.
Many experimental tests of the postulates have been done.

1st Postulate of Relativity

The laws of physics are the <u>same</u> for all uniformly moving observers.

(“Uniformly” = “with a constant velocity”)

<u>Implications:</u>

No such things as “absolute rest”
Any uniformly moving observer can consider themselves to be “at rest”

Uniformly moving observers (examples)

Traveling on a moving sidewalk
In an airplane or car moving smoothly

Laws of Physics are the same

A game of pool played in your house, on the moving sidewalk, or in the place would be the same. The laws of physics (conservation of momentum, F=ma, etc) will work both places as will an observer watching the pool game go by on the moving sidewalk.

Counterexample: accelerating in a car or plane. Here the laws of physics, in particular Newton’s Law of Inertia, does not appear to hold. All the balls will appear, without an outside force, to rush to one end of the table.

Every observer would agree about the laws of physics in every frame.

No experiment you can perform can tell you whether you are in the stationary or the moving frame.

The Laws of Physics are Universal

One of the great advances of Galileo/Newton was to expand the reach of the laws of physics.

The power of physics comes from its universality. "Laws" that only work on the third Thursday of the month in MP 4025 are pretty useless.

2^{nd} Postulate of Relativity

The speed of light in a vacuum is the <u>same</u> for all observers, regardless of their motion.

<u>Implications:</u>

The speed of light is a <u>Universal Constant</u>
We cannot send or receive information faster than the speed of light
Cosmic speed light

Experimentally verified in all cases

Reminder: Light is an Electromagnetic Wave

Traveling Waves

Waves on Earth travel in a medium

Water waves: water
Sound waves: air
Earthquakes: earth

No medium, no wave
By moving through the medium yourself, you can experience a different speed for the wave. Example: running into or away from ocean waves.

But what is the medium that light travels in?

Thought to be the "ether", a medium that was at absolute rest

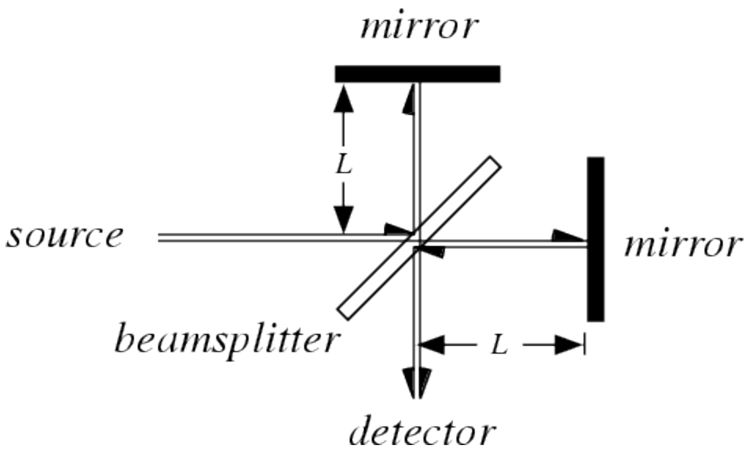
Motion through the ether would affect the speed of light.

Michelson-Morley Experiment

A really cool experiment to test whether the ether existed and whether it affected the speed of light.

It used the motion of the Earth through the ether to test its effect.

Analogy: swimming perpendicular or parallel to the ocean shore.



It found no difference in the speed of light going with the motion of the Earth through the ether vs. the speed of light going perpendicular to the ether. Ether does not exist! Light does not need a medium to travel in.

The Consequences of the Constancy of the Speed of Light

Unlike waves that travel in a medium, we cannot change the observed speed of light.
Therefore we can only change the *length* and *time* we observe
Leads to

- *Length contraction*
    - Moving objects are shorter
- *Time dilation*
    - Moving clocks run slow

Essential Relativity

Two observers moving relative to each other experience the world differently:

- Both measure the same speed of light

Both find the same physical laws relating distance, time, mass, etc.

But, both measure different distances, times, masses, etc. when applying those laws.

The key is the role of light.

How do you measure…..?

Time: it is not absolute. You need to define how you measure it precisely. The period of a pendulum? The return of a light beam?

Length: it is not absolute either. At rest, measuring length is easy: compare it with a yardstick, etc. How do you measure something moving? Example: time it takes to pass you x the speed it is traveling.

Implication: A Real Speed Limit

Imagine that you start running at the same time your friend turns on a flashlight. You are racing a beam of light. Can you win?

NO! You can view this as you are standing still and the whole world is running past you. And the speed of light you measure is always the same = faster than you standing still.