Chapter 37: Relativity

- Events and Inertial Reference Frames
- Principles of Einstein’s Special Relativity
- Relativity of Simultaneity, Time Intervals, Length
- Lorentz Transformation
- Relativistic Momentum & Energy
- General Relativity
Albert Einstein and the Special Theory of Relativity

The Special Theory of Relativity was published by Albert Einstein in 1905 when he was still working in a Swiss patent office.

It stands as one of the greatest intellectual achievement of the 20th century. (In the same year, two groundbreaking works on the theory of Brownian motion and the Photoelectric Effect were also published.)

Special Relativity led to a fundamental rethinking of the concepts of space and time:

- The measurement of a time interval
- The measurement of length
- The concept of simultaneity/Causality
Summary of Changes

Before Special Relativity: “space and time” are thought to be as “absolute” properties of the “background” or “stage” where objects act upon.

→ Different observers from different “inertial reference frames” will agree on all the measurements on the previous slide.

After Special Relativity: These “space and time” measurements are relative to the observer’s frame of reference. A stationary observer with respect to a moving observer will see:

- a moving clock runs slower
- a moving meter-stick gets shorter
- two events being simultaneous for one inertial observer will not necessarily be simultaneous for the other.
Reality Check

One should note that these relativistic effects are only dramatic for objects moving at large relative speeds near c!

For everyday objects moving with ordinary slower speeds, these effects are small.

In fact, one can show that Einstein’s theory reduces to Newtonian mechanics in the limit $u \ll c$!

There are numerous experiments as well as practical applications that have demonstrated Einstein’s predictions:

- Muon’s life time
- Atomic clocks on flight
- Trajectories of subatomic particles in accelerators
- Nuclear reactors
- Symmetry between magnetic & electric forces
- GPS system
- NAVSTAR
- ....
Events

Since relativity deals with the fundamental concepts of space and time, we need to have a concrete basis for our analysis of these quantities:

**Event**: An occurrence in the physical universe characterized by its position **and** time. We label each event by its space-time coordinates \((x,y,z,t)\)

Example: a car crash (the event) occurs at a particular location and time.

\[
\begin{array}{c}
\text{space-time} \\
(x,y,z)
\end{array}
\]

\[
\begin{array}{c}
t \\
\end{array}
\]

\[
\begin{array}{c}
an \text{ event} \end{array}
\]
Observers

We focus on the description of the physical world according to two different observers $S$ and $S'$

$S'$ is on a moving boxcar moving at constant velocity $u$ to the left

$S$ is stationary on the ground
Relative Motion

But, does it really make sense to be “stationary”? Nothing in the universe are absolutely at rest… All objects are in relative motion wrt to each other!
Relative Motion with Constant Velocity is Symmetric

$S$ and $S'$ in relative motion with constant velocity are equivalent!

$S$ would say that $S'$ moves to the right with respect to him/her at a constant speed $u$.

$S'$ would equivalently say that $S$ moves to the left with respect to him/her with the same constant speed $u$. 
Inertial Reference Frames

Inertial Reference Frames:

A coordinate system \((x,y,z,t)\) for labeling events attached to an observer who is not accelerating and there is no net force acting on it.

e.g., A space ship far away from any stars in deep space in relative motion with constant velocity wrt the universe.

“Effective” Inertial Reference Frames:

Both \(S\) and \(S'\) are not truly inertial ref. frames because gravity acts on them!

But since \(\vec{g}\) acts on them equally and is \(\perp\) to \(\vec{u}\) (their relative velocity), we can treat them as effective inert. ref. frames.