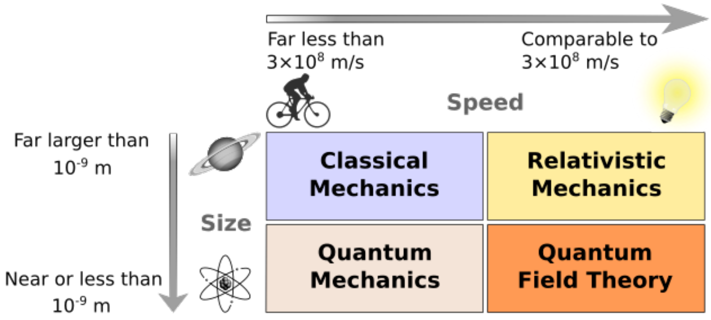
Physics



Classical Mechanics

Newton's Laws of Motion

Published in his 1687 paper Principia, these laws describe the motion of objects and continue to serve as the foundations of classical mechanics in the modern day.

1. An object remains at rest or in motion at a constant speed unless acted on by an external force. (aka the principle of inertia)
2. The resultant force acting on a body is the rate of change of the momentum of the object:

$$F = \frac{d\boldsymbol{P}}{dt} = m\boldsymbol{a}$$

3. Every action results in an equal and opposite reaction. This can also be used to show the conservation of linear momentum.

Frame of Reference

A coordinate system whose origin and basis are specified in space.

A frame of reference itself can be in motion, for example when considering an object on the Earth's surface as "stationary" the frame of reference in which we are thinking is moving with the same velocity as that object when compared to any other object in space. It would be considered as moving at the same velocity as the Earth's surface in a different frame of reference with the sun as the origin.

Inertial Reference Frame - A reference frame in which objects obey the principle of inertia; ie. the frame itself is moving at a constant velocity in relation to any other intertial reference frame. The Earth's surface is a good approximation of an inertial reference frame which we are accustomed to thinking in terms of.

Non-Inertial Reference Frame - It is accelerating in some way; objects defined as stationary / moving at a constant velocity with respect to the frame are therefore also accelerating in relation to any other inertial reference frame without the need of any external force and thus violate the principle of inertia.

TODO: Rotating frame of reference

Galilean Transformation

The coordinates of two inertial frames of reference can be transformed between one another using the following equations:

$$x' = x - vt$$
$$y' = y$$
$$z' = z$$
$$t' = t$$

This approximation is accurate when considering systems with velocities significantly slower than the speed of light (non-relativistic).

Transformations between reference frames can also be represented as a matrix allowing easier vector calculations.

Special Relativity

Spacetime - A 4-dimensional representation of the universe as 3D space + time. Classical mechanics treats time as a uniform quantity throughout the universe with a constant rate of passage. However relativistic effects mean that time passes at different rates in different frames of reference, hence a 4th dimension is introduced.

TODO: Minkowski space

TODO: Michelson-Morsley experiment, Lorentzian electrodynamics and the aether

After the failed Michelson-Morsley experiment, a new theory was needed to explain the speed of light. Special relativity is a theory published in 1905 (On the Electrodynamics of Moving Bodies) by Albert Einstein, accurately modelling motion through spacetime when gravitational and quantum effects are negligible.

In special relativity, time and distances become relative to the velocity of particles.

Postulate - Something assumed as true in a theory.

It is based on 2 postulates:
1. The laws of physics are invariant in all inertial frames of reference. This is known as the principle of relativity.
2. The speed of light is the same for all observers, regardless of all motion.

Lorentz Transformation

Two inertial spacetimes can be transformed between one another with the following relationships:[1]

$$t' = \gamma\left(t - \frac{vx}{c^2}\right)$$
$$x' = \gamma(x - vt)$$
$$y' = y$$
$$z' = z$$

Where γ represents the Lorentz factor, which appears in many equations from Classical mechanics adjusted for relativistic effects:

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

[1] The derivation is mathematically very simple and a great exercise in thought. Consider a pulse of light being emitted from a torch in a frame of reference moving at velocity v, the distance travelled by the light and the time taken with respect to each frame of reference can be expressed using the Pythagorean theorem. Due to the 2nd postulate, time and distance are different in both frames so that the speed of light remains constant.

Implications

The second postulate leads to many extremely important implications in spacetime:

- Time dilation - Time passes at a different rate in different frames of reference; slower the closer to the speed of light an inertial frame is translating with respect to another. The intuition for this is that time must be slower to accountfor the added velocity of an inertial frame itself to the speed of light (which much remain constant across all frames).
- Length contraction - Lengths in a relativistic frame of reference are shorter with comparison to another frame at rest.

Conservation of momentum and energy also lead to the following implication:

- Relativistic mass - Observed mass increases when an object's speed approaches the speed of light: $m = \gamma m_0$ where m_0 is the object's rest mass.
- The same can be applied to kinetic energy and momentum.

TODO:

- Field & thermionic emission / photoelectric effect
- Feynman or University Physics
- Lagrangian & Hamiltonian mechanics