Brief History

- modern physics ⇒ started around the beginning of the 20th century
- quantum mechanics ⇒ physics of the very, very small (protons, electrons, …)
- relativity ⇒ physics of the very, very fast (speeds approaching c)

⇒ modern physics showed that Newton’s laws were incomplete

⇒ Newton’s laws only apply to objects of macroscopic size (bigger than protons and electrons) and relatively small speeds (much less than the speed of light)

⇒ the theory of special relativity was published by Albert Einstein in 1905
In 1905, Albert Einstein (age 26) published three papers of extraordinary importance:

- an analysis of Brownian motion
- photoelectric effect (Nobel Prize)
- special theory of relativity

The special theory of relativity has made wide-ranging changes in our understanding of nature.

**Warning**

- The Special Theory of Relativity defies common sense!
- However, the results of the Special Theory of Relativity have been extensively tested numerous times and are in fact true!

**Special Theory of Relativity**

**Preview** ⇒ with speeds approaching the speed of light, clocks run slow (time dilation), metersticks become shorter (length contraction), and objects become more massive as their speed increases.

**Simultaneity**

⇒ One consequence of Einstein's second postulate is a modification of the concept of simultaneity.

⇒ Two events that occur at exactly the same time are said to be simultaneous.

⇒ However, two events that are simultaneous in one frame of reference will not be simultaneous in another frame of reference moving with respect to the first frame.
Simultaneity

⇒ As an example, consider a light source in the exact middle of a moving rocket.

⇒ An observer in the rocket will see the light hit the front and back ends of the ship at the same time (simultaneously).

⇒ An observer on the ground, however, will see the rocket move forward so the back of the rocket moves towards the beam while the front of the rocket moves away from the beam.

⇒ An observer on the ground will therefore see light hitting the back of the rocket before hitting the front of the rocket.

⇒ The observer on the ground therefore does not see the two events as occurring simultaneously.

Time Dilation

⇒ If there is relative motion between two observers (if they are moving at different velocities), they will not agree in their measurements of space and time.

⇒ However, the two observers will agree on their measurement of the speed of light.
Since speed equals distance divided by time, both observers will measure the same ratio of space (distance) and time for light.

\[
\frac{\text{SPACE}}{\text{TIME}} = \frac{\text{SPACE}}{\text{TIME}} = c
\]

⇒ The observer and the clock are in the same frame of reference.

An observer in the rocket moving with the clock sees the light traveling straight up and down.

An observer on the ground (who is not in the same reference frame as the clock) sees the light traveling in a diagonal path.

In the frame of reference of the observer on Earth, the light travels a longer distance.

Since the speed of light is the same in all reference frames, the light must travel for a longer time in the Earth based reference frame than in the reference frame of the rocket.

The stretching out of time is called time dilation.
**Time Dilation**

⇒ Moving clocks run slow!

⇒ Time dilation has nothing to do with the mechanics of clocks but with the nature of time itself.

⇒ Time passes more slowly in a reference frame that is moving then in a reference frame that is at rest.

**Length Contraction**

⇒ For a moving object, space as well as time undergoes changes in measurement.

⇒ The lengths of objects appear to be contracted (shortened) when they move by us at relativistic speeds.

⇒ This length contraction is really a contraction of space.

⇒ As the speed increases, length in the direction of motion decreases. Lengths in the perpendicular direction do not change.
Length Contraction

Solutions to HW Exercises

1) The effects of relativity become pronounced only at speeds near the speed of light or when energies change by amounts comparable to $mc^2$. In our "non-relativistic" world, we don't directly perceive such things, whereas we do perceive events governed by classical mechanics. So the mechanics of Newton is consistent with our common sense, based on everyday experience, but the relativity of Einstein is not consistent with common sense. Its effects are outside our everyday experience.

3) (a) The ball is moving faster relative to the ground when the train is moving (forward). (b) The ball moves at the same speed relative to the freight car whether the train is moving or not.

4) In the case of a light beam shining from atop a moving freight car, the light beam has the same speed relative to the ground as it has relative to the train. The speed of light is the same in all reference frames.

15) It's all a matter of relative velocity. If two frames of reference are in relative motion, events can occur in the order AB in one frame and in the order BA in the other frame. (See the next exercise.) Answer to exercise 16: Yes. If the distance the rocket ship moves forward in the time it takes the light to reach the rear is greater than the distance by which the light bulb was shifted, the outside observer will still see the light getting to the rear first. You can see this, too, by considering such a tiny displacement of the light bulb that it makes hardly any difference to the outside observer, who still sees the light reaching the rear first. But to the inside observer, the light will reach the front first no matter how tiny the displacement.

22) Yes, as strange as it sounds, it is possible for a son or daughter to be biologically older than his or her parents. Suppose, for example, that a woman gives birth to a baby and then departs in a high-speed rocket ship. She could theoretically return from a relativistic trip just a few years older than when she left to find her “baby” 80 or so years old.

19) If a person travels at relativistic speeds - that is, very close to the speed of light - distances as far as those that light takes thousands of years to travel (in our frame of reference) could be traversed well within an average lifetime. This is because distance depends on the frame of reference in which it is measured. Distances that are quite long in one frame of reference may be quite short in another.
30) Elongated like an ellipse, longer in the direction of motion than perpendicular to that direction. The Lorentz contraction shortens the long axis of the elliptical shape to make it no longer than the short axis. If it appeared circular to the observer on the ground, it would have to be longer in the direction of motion for the person moving with it.

44) E= mc^2 means that energy and mass are two sides of the same coin, mass-energy. The c^2 is the proportionality constant that links the units of energy and mass. In a practical sense, energy and mass are one and the same. When something gains energy, it gains mass. When something loses energy, it loses mass. Mass is simply congealed energy.

47) Just as time is required for knowledge of distant events to reach our eyes, a lesser yet finite time is required for information on nearby things to reach our eyes. So the answer is yes, there is always a finite interval between an event and our perception of that event. If the back of your hand is 30 cm from your eyes, you are seeing it as it was one-billionth of a second ago.