Albert Einstein

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On this website, you can learn more about Albert Einstein. If you want to learn more about his life, you can view a timeline. There is also information about his most famous theories, including the Theory of Relativity, Quantum Physics, and the Photo Effect.

Theory of Relativity

There are two papers by Albert Einstein about the theory of relativity. The first one is the special theory of relativity, published in 1905, which explains how speed affects mass, time, and space. The second one is the general theory of relativity, which got popularized in 1916; it is about gravity and the curvature of spacetime. His view understanding of the universe was and remains incredible. Thinking about some of the consequences of relativity can give you a headache.

As a consequence of its motion the clock goes more slowly than when at rest. (Albert Einstein, "On the Electrodynamics of Moving Bodies")

An essential concept for the theory of relativity is the inertial reference frame:

> It is a state or frame of reference where Newton's laws hold true because no external force is acting on the body. It is at rest or in uniform motion. There is no preferred frame and no absolute motion.

The special theory of relativity

In order to have a complete description of the motion, we must specify how the body alters its position with time; i.e. for every point on the trajectory it must be stated at what time the body is situated there. (Albert Einstein, "On the Electrodynamics of Moving Bodies")

The special theory of relativity is based on two postulates.

1. The principle of relativity
    a. The laws of physics are the same in any inertial frames of reference.
2. The speed of light is invariant.
    a. Light always has the same speed in empty space.

The principle of relativity

To visualize the concept of an inertial frame of reference, Einstein uses the thought experiment of sitting on a train. When sitting in a train in motion, everything inside will appear to a person inside as stationary, as the observer and the train are moving at the same speed. The outside world seems to be moving. What happens when you throw a ball straight into the air while being at a constant speed on that train? It will not behave any differently than standing still at the train station.

Invariance of the speed of light

Before Einstein, there was a hypothesis on how light moves through the air called the Ether Hypothesis. It was believed that light waves travel through a medium called ether, like water waves, and sound waves need a medium to get transmitted. This theory got disproved with the Michelson-Morley Interferometer. This interferometer compares the optical path length for light moving in perpendicular directions. If there were a medium for light, the length of these paths would be different, which would have resulted in a different interference pattern than observed. Therefore is, the speed of light constant, and there is no light ether.

https://upload.wikimedia.org/wikipedia/commons/b/bd/Michelson%C5%AFv_interferometr.gif

CONSEQUENCES:

The truth of both these postulates leads to some consequences:

Simultaneity

If two spatial separated events occur at the same time depends on the observer's frame of reference.

https://www.fourmilab.ch/documents/RelativityOfSimultaneity/figures/ros.gif

Time dilation

Time observed by a moving observer will be slower than by a stationary one.

This effect was also measured in an experiment. One atomic clock was stationary on earth; the other was flown at high speeds in a plane. The clock on the plane moved slower than the one on earth.

Learn more about the Twin paradox
https://www.youtube.com/watch?v=0iJZ_QGMLD0&feature=youtu.be

Length contraction

Similar to time dilation, an object in motion will appear shorted in the direction of movement. Both of these effects can be calculated with the Lorentz transformation. Where $\tilde{L}$ is the length of an object as a function with the velocity v. L_0 is the length of an object at rest, and c is the speed of light.

$$\tilde{L} = L_0 * \sqrt{1 - \frac{v^2}{c^2}}$$

This calculation only becomes only important when the velocity is high. For example, adding v1 = 0.5c and v2 = 0.8c (when they are parallel) is impossible because nothing can be faster than the speed of light.

$$0.5c + 0.8c = 1.3c > c$$

Calculating the total speed with a relativistic approach leads to a different result.

$$v_{sum} = \frac{v_1 + v_2}{1 + \frac{v_{1}v_{2}}{c^2}} = \frac{0.5c + \ 0.8c}{1 + \frac{0.5c * 0.8c}{c^2}} = \frac{1.3c}{1.4} \approx 0.93c$$

We can use a modified version of this formula to show why moving at the speed of light is impossible or at least very difficult.

With

$$E = \frac{m * c^2}{\sqrt{1 - \frac{v^2}{c^2}}}$$

we can calculate how much energy is needed to move at the speed of light. v -> c

$$E = \frac{m * c^2}{\sqrt{1 - \frac{c^2}{c^2}}} = \ E = \frac{m * c^2}{\sqrt{1 - 1}} = \ \infty$$

Infinite energy is needed to move at the speed of light.

https://www.youtube.com/watch?v=CYv5GsXEf1o&feature=youtu.be

General relativity

Instead of seeing gravity as an invisible force that attracts objects to one another, gravity is the curving of space. The more massive an object is, the more it warps space. But because space and time are connected, gravity can affect the passing of time. The general theory is built on "field equations," which describe the relationship between mass and the curvature of spacetime.

To get a better understanding of the curvature of space. We can think about two cities on earth with some distance between them; I will pick Los Angeles and Ulm (Einstein's birthplace). If we wanted to fly from one to the other, we would like the plane to take the shortest route. So that would be a straight line. Looking at a globe gives us a straight path. But when looking at a 2-dimensional flat map. It seems like the path is curved.

Earth-globe.png

earth-map.png

These curved lines are called geodesics. They are straight paths on a curved surface.

This theory was proven during a solar eclipse in 1919 when the light from stars behind the sun was deflected because the mass of the sun curved spacetime. Another more recent proof was made during the discovery of gravitational waves in 2016. (https://www.ligo.caltech.edu/page/what-are-gw)

An actual application for this theory in the real world is that GPS satellite networks consider gravity's effects to achieve accurate location.

Quantum Physics

Our view of atoms has changed because of Quantum Physics. In the past, an atom was portrayed as a nucleus orbited by electrons. Modern quantum physics describes the probability of the location of an electron in a time frame. Electrons can jump from one orbital to another depending wether they gain or lose energy, but they cannot be inbetween orbitals.

Wave-Particle Duality

This principle is the result of experiments showing that light can have the property of particles or waves depending on how it was measured. Today we know that these forms of energy are neither particles nor waves but instead distinct quantum objects.

Superposition

The Term "Superposition" describes when an object has multiple states simultaneously. An object in superposition can have more than one solution to an equation.

Uncertainty Principle

With a quantum object, we can not know the precise position and velocity simultaneously. If we know the exact position of an electron, we do not know its actual speed.

Entanglement

Entanglement occurs when two or more objects are connected to each other so that they can be thought of as existing in a single system, even though their position might be far apart. These objects can only be fully described by knowing the other object. But this also means that learning information about one object automatically tells you information about the other object.

The Double Slit Experiment

One of the most famous experiments in quantum physics is the double-slit experiment. Originally used to prove that light behaves like a wave in 1801, it has evolved and demonstrated superposition, entanglement, and the observer effect principles.

Photoelectric Effect

The photoelectric effect solved the question of whether light is made up of particles or waves. It is an interaction of electromagnetic radiation with matter. Electrons are released from the surface if you shine a light with the right wavelength onto a negatively charged metal surface.

What are the consequences this effect has?

- Light is neither made of particles nor waves but in small energy portions called Photons.
- The intensity of light is determined by the frequency and not amplitude.
- Brighter light has more Photons, not Photons with higher energy.

This effect is only possible below a specific wavelength (or above a specific frequency).

> *According to the assumption considered here, when a light ray starting from a point is propagated, the energy is not continuously distributed over an ever increasing volume, but it consists of a finite number of energy quanta, localized in space, which move without being divided and which can be absorbed or emitted only as a whole. (Albert Einstein, "On a Heuristic Viewpoint Concerning the Production and Transformation of Light")*

Albert Einstein's Life

- March 14, 1879
  - Born in Ulm, Kingdom of Württemberg, German Empire
    Father: Hermann Einstein, Mother: Pauline Koch
- 1880
  - He moves with his family to Munich
- 1885-88
  - Attends a Catholic Elementary school
- 1889-94
  - Student at the Luitpold Gymnasium (now called Albert Einstein Gymnasium)
- 1894
  - His family moved first due to money issues, but he followed because he resented the school's regimen and teaching methods
- 1895-96
  - Attends the cantonal school of Aarau, Switzerland
- 1896
  - He renounces his citizenship in the German Kingdom of Württemberg to avoid military service
- 1901
  - He was admitted to the Polytechnic School in Zurich after he failed the entrance exam in the general part but was exceptional in Physics and Math
- 1901
  - Obtains Swiss nationality

- 1902
  - Works at a Swiss patent office in Berne
- 1903
  - Marries Mileva Maric
- 1904
  - His son Hans Albert is born
- 1905
  - The University of Zurich awards him a Ph.D
- 1909
  - Leaves his job at the patent office and becomes an associate lecturer at the University of Zurich
- 1910
  - His son Eduard is born
- 19011-12
  - Lectures at the University of Prague
- 1912-14
  - Lectures at the Federal Technological Institute of Zurich
- 1914
  - Lectures at the University of Berlin while Mileva and his children stay in Zurich
- 1917
  - Become the director of the Kaiser Wilhelm Institute of Physics in Berlin
- 1917-19
  - Einstein's health deteriorates. His cousin, Elsa Löwenthal, looks after him
- 1919
  - Divorces Mileva and marries Elsa. Solar eclipse confirms Einstein's predictions on the deflection of light rays. Remarkable jump to world fame
- 1922
  - Nobel prize for Physics & publishes his first work on the unified field theory & becomes a member of the League of Nations Committee on Intellectual Co-operation.
- 1933
  - Einstein flees to Princeton, USA, with his family after Anti-Semitism intensifies
- 1936
  - His wife Elsa dies
- 1939
  - Einstein sends a letter to President Roosevelt with a warning that Germany is manufacturing an atomic bomb. (Outbreak of World War II)
- 1940
  - He takes American citizenship

- 1944
  - His rewritten manuscript on the special theory of relativity is auctioned off to aid the allied forces for six million dollars
- 1946
  - Takes the chair for the Emergency Committee of Atomic Scientists
- 1952
  - Declines the presidency for the state of Israel
- 1955
  - He drafts a manifesto against the nuclear threat with Bertrand Russell
- April 18, 1955
  - Einstein dies from an aortic aneurysm in the abdominal aorta at Princeton hospital. He was cremated and scattered into the Delaware River.