Understanding Einstein: The Special Theory of Relativity

A Stanford Online Course

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Physics and Einstein *circa* 1900:
Selected Events and Trends of Significance in Physics, 1800-1900

(The scientific and technological world into which Albert Einstein was born)

Note: Date ranges are often approximate.

***ca.* 1800 (narrowing of scope):** "Physics," in the sense of the science of the properties of matter and energy is from about 1715, though it often included both organic and inorganic phenomena. "Physicist" is coined by the English polymath Rev. William Whewell in 1840 to denote a cultivator of physics (he also coins "scientist" at the same time). Around 1800 "physics" is narrowing to inorganic phenomena that could be investigated with instruments such as air pumps (for vacuums), electrical machines, thermometers, balances, etc. Key areas of inquiry are mechanics, optics, electricity, magnetism, heat, and pneumatics.

***ca.* 1800 (imponderable fluids and quantification):** In the late eighteenth and early nineteenth centuries Pierre-Simon Laplace of France and others establish the first "standard model" of physics, basing it on several imponderable (weightless) fluids (e.g., one for heat, one for positive electricity, one for negative electricity, one for magnetism, etc.). The behavior of each fluid is modeled and quantified via short-range, central forces between elements of the fluid (and perhaps regular matter) following the supreme example of Newton's seventeenth-century theory of gravity.

1800-1830s (physics in universities): During the first decades of the nineteenth century, physics has a place with the other sciences in the curriculum of universities in the Western world, though it has second-class status when compared to the emphasis on medicine, law, and the classics (Greek and Latin literature). Yale University in 1828 is being progressive when it "emphasized that one requirement of a liberal education was to encourage in students a 'proper balance of character,' a balance that could be achieved only by exposing them to the different branches of science as well as literature." (Daniel J. Kevles, *The Physicists: The History of a Scientific Community in Modern America*, p. 5).

1800 (the battery): Invention of the battery by Alessandro Volta of Italy; electricity is generated by contact of different metals. (A result of investigations into animal electricity by Luigi Galvani, Volta, and others.) A key consequence is the possibility of sustained electric currents.

1800-1807 (wave theory of light): Research by Thomas Young of England on interference and other effects in light that leads him to develop a wave theory of light, attributed to the vibrations of an ether.

1810s-1820s (chemical atomic theory): Early development of the chemical atomic theory by Amedeo Avogadro, André-Marie Ampère, William Prout and Jöns Jacob Berzelius, using earlier work by Antoine-Laurent Lavoisier, John Dalton, and Joseph Louis Gay-Lussac.

1820 (electromagnetism): Hans Christian Oersted of Denmark notices that a current-carrying wire deflects a compass needle and, partly inspired by the "all forces are one" emphasis of *Naturphilosophie*, proposes a connection between electricity and magnetism. His work is almost immediately extended and mathematized by André-Marie Ampère of France (e.g., that two current-carrying wires attract or repel each other).

1820s-1830s (the railroad): Development of first steam-power-based railways in Britain, Europe, and the United States.

1827 (Brownian motion): The English botanist Robert Brown demonstrates that small particles (both organic and inorganic) in a liquid suspension move in random paths.

1831 (electromagnetic induction): Michael Faraday of England shows that a moving magnet may generate an electric current (e.g., a bar magnet that moves through a closed coil of wire).

1830s (the telegraph): Development of working electric telegraphs by several, including Carl Friedrich Gauss and Wilhelm Weber at the University of Göttingen (1833), William Fothergill Cooke and Charles Wheatstone in Britain (1837), and Samuel Morse and Alfred Vail in the United States (1837).

1840s (conservation of energy): In 1842 Julius Robert Mayer, a German physician, proposes the concept of the conservation and equivalence of all forms of energy. Independently, experiments by James Joule and analysis by William Thomson (later Lord Kelvin) in England and work by Hermann von Helmholtz in Germany in the 1840s lead to similar ideas.

1845 (the field concept): Michael Faraday introduces the concept of a "field" as a way to explain electric and magnetic phenomena.

1850s-1870s (thermodynamics): Development of the kinetic theory of gases, the laws of thermodynamics, and statistical physics by Rudolf Clausius, William Thomson, James Clerk Maxwell, Ludwig Boltzmann, and others.

1851 (world expositions): The Great Exhibition of the Works of Industry of All Nations in London at the Crystal Palace opens in 1851. It starts a trend of popular World Expositions, held every few years throughout Europe and the United States during the nineteenth century and into the twentieth. These fairs and exhibitions, though permeated with nationalism, are often the occasion for international conferences on scientific, technological, and other topics.

1860s (periodic table): Building on increasing agreement about relative atomic weights and on various proposals for partial periodicity of the elements, Dmitrii Mendeleev constructs the first comprehensive periodic table, leaving vacant places for undiscovered elements.

1860s-1870s (Maxwell's equations and EM nature of light): William Thomson and James Clerk Maxwell mathematize and extend Faraday's notion of an electromagnetic field, resulting in Maxwell's laws of electromagnetism and the theoretical realization that light was an electromagnetic phenomenon (a wave).

1860s-1870s (internal combustion engine): Development of first commercially viable internal combustion engines by Nikolaus Otto, Gottlieb Daimler, Wilhelm Mayback, Dugald Clerk, Karl Benz, and others.

1866 (telegraph cables): First successful transatlantic telegraph cable (earlier attempts in 1857, 1858, and 1865 failed). William Thomson is a key participant.

1869 (expansion of railways): Completion of the transcontinental railway in the United States (symbolic of the great expansion of railways world-wide between 1850 and 1900, which also spurs efforts to establish uniform time zones).

1870s-1900s (mechanical reduction): Following Maxwell's successes, British physicists seek to describe the electromagnetic field and related phenomena via elaborate mechanical models of the ether. This program eventually develops into a uniquely British style of doing physics; the French, who prize clarity of thought, compare the British approach to an ugly factory, though they too practice methods of reducing all phenomena to mechanical phenomena and/or equations, just in what they consider more elegant ways.

1870s-1890s (precision measurement and metrology): Precision measurement as the *sine qua non* of physics. One significant example is the development of a system of electrical and magnetic standards (ohm, volt, ampere, etc.), in which prominent physicists such as William Thomson, Maxwell, and Helmholtz are involved. Albert Michelson expresses a common attitude: "The future truths of Physical Science are to be looked for in the sixth place of decimals" (1894).

1870s-1890s (division of labor): A division of labor into "experimental physicists" and "theoretical or mathematical physicists" begins to occur in the second half of 19th century, though the latter usually have second-class status.

1878-1882 (electric lighting): Development by Thomas Edison of the first commercially viable incandescent light and a system for distributing electric power.

1879 (Einstein born): Albert Einstein born to Hermann and Pauline Einstein on March 14, 1879 in Ulm, Germany. He was their first child. After moving to Munich in 1880, a daughter, Maria (or Maja), is born in 1881.

1885-1889 (discovery of EM waves and the photoelectric effect): Heinrich Hertz of Germany experimentally demonstrates existence of electromagnetic waves. In 1887 he also discovers the photoelectric effect. In later years (before his untimely death in 1894 at the age of 36), he clarifies Maxwell's theories and works to develop an ether-based physics.

1887 (Michelson-Morley null result): Using a setup that took advantage of the interference effects of two light beams (an interferometer), Albert Michelson and Edward Morley of the United States announce that they found no evidence for the effect of an ether wind on the velocity of light.

1889 (FitzGerald contraction): Based on Maxwellian theory, the work of Oliver Heaviside on the electric field of a high-velocity moving charge, and the idea that intermolecular forces are electromagnetic in nature, George Francis FitzGerald proposes the movement of all bodies through the ether causes them to contract along the line of motion, thus explaining the null result of Michelson and Morley.

1890s (electric traction): Rapid development and deployment of electric tramways for urban commuting (previously horse-drawn).

1890s (physics construction boom): Beginnings of building boom in bigger and better-equipped physics laboratories and institutes at universities in Europe, Great Britain, and the United States, primarily due to increased numbers of students pursuing technical studies. Metrological needs of governments also spur the building of national bureaus of standards in Germany (1887), the United States (1901), and Britain (1905). An international bureau is established in France (1895).

1890s (electromagnetic worldview): Some physicists, most notably Hendrik Antoon Lorentz, Henri Poincaré, Joseph Larmor, and Walter Kaufmann, work on constructing an electromagnetic theory of matter that would explain mechanical as well as electromagnetic phenomena, based on an electromagnetic ether and electrons (whether as fundamental units or particles). Lorentz's version includes the concept that the dimensions of an electron (a charged sphere) would be contracted along the line of its motion at high speeds (thus explaining the Michelson-Morley null result).

1895 (X rays): Experimenting with cathode rays (originally discovered 1858), Wilhelm Conrad Röntgen discovers a penetrating radiation that he calls X rays. Publication of X-ray photographs causes a sensation. (Their identity as electromagnetic radiation as opposed to particles will not be settled until 1912, when it is shown that they can be diffracted using a crystal lattice.)

1896-1900 (Einstein in college): In 1896 Einstein enrolls in the Swiss Federal Polytechnic in Zurich, choosing a course of study in physics that would qualify him for high school science teaching. He graduates in July 1900 with good, though not exceptional, marks.

1896 (radioactivity): Inspired by a seeming connection between fluorescence, phosphorescence, and x-rays, Henri Becquerel discovers a substance that spontaneously emits radiations. By 1902 Marie and Pierre Curie identify the origin of the radiations as a new element, radium. All three receive the second Nobel Prize in Physics in 1903. (Marie Curie also receives the Nobel Prize in Chemistry in 1911.)

1897 (the electron): The idea of an electron had been around in various forms for many years, as a fundamental unit of charge (not necessarily a particle) that might explain various chemical and electrical phenomena (such as the laws of electrolysis, spectral lines, and the Zeeman effect—the magnetic splitting of spectral lines, discovered 1896). Interest in the nature of cathode rays revives after the discovery of x-rays, and the work of four men—Philipp Lenard, Emil Wiechert, Walter Kaufmann, and Joseph John Thomson—eventually shows that cathode rays are streams of negatively charged particles, about 2,000 times lighter than atoms. Thomson proposes that all atoms are built up from these "corpuscles," which eventually took the name "electrons" (first proposed in 1891 by George Johnstone Stoney).

1900 (clouds on the horizon): In his Baltimore Lectures of 1900, William Thomson (Lord Kelvin) notes that despite great progress in the recent decades there are two clouds on the horizon: the interaction of ether with matter (e.g., the Michelson-Morley null result) and problems with the concept of the equipartition of energy, especially modeling the distribution of energy in the light radiated by a glowing solid ("blackbody radiation").

1900 (descriptionism): Physicists around the turn of the century hesitate to assert that physics has much of anything to do with ultimate truth, especially in public forums. In part this is due to the anti-science tenor of the times, which is related to feelings that technology is outstripping human capacities and that civilization is in a state of senescence and decline, marked by spiritual and physical degeneracy.

1900 (introduction of the quantum): Max Planck constructs a correct empirical law for blackbody radiation and subsequently is able to derive it using a statistical model of the solid as a population of electric oscillators, plus the assumption that energy is exchanged between the oscillators and the radiation in integral multiples of hf (a "quantum" of energy, where f is the frequency of vibration of the oscillator and h is a constant).

1900 (demographics): By 1900 there are approximately 500-1000 academic physicists worldwide (the higher number if assistants and research affiliates are counted; otherwise, 500-600). Of the 500-600, the United Kingdom, for example, has 76, spread among 30 or so universities and colleges; France has 53 among 21 universities/colleges; Germany has 77 in 21 universities and 26 others in Technische Hochschulen; and the United States has 99 among 21 universities and colleges with significant programs. (But note that these numbers leave out others doing primarily physics in other academic positions, such as mathematics, mechanics, electrotechnology, and physical chemistry.) In terms of the general population of these countries, there are roughly 3 physicists per million inhabitants. (Today in the U.S., there are approx. 9,000 full-time physics faculty/lecturers in degree-granting departments, plus probably a roughly similar number of post-docs, plus many more in two-year colleges. So roughly in the range of 100 per million of population.)

1900-1902 (Einstein's life and job difficulties): After graduating from the Swiss Polytechnic, Einstein's efforts to find a physics assistantship at a university, a permanent teaching position in a high school, or a job in the insurance industry are unsuccessful. One bright spot is the publication of his first physics paper, on the theory of capillarity. But tensions with his family increase, especially over his relationship with his fellow student Mileva Marić, a Serb. In 1901, after Albert and Mileva spend a romantic weekend in Italy, Mileva discovers she is pregnant. The child, "Lieserl," is born in early 1902. Her fate is unknown, though some evidence exists that she died at a young age from scarlet fever.

1902-1904 (Einstein at the Patent Office): Through the connections of a friend's father, in 1902 Einstein secures a position as a patent clerk in the Swiss Patent Office in Bern. Working on the side, from 1902 to 1904 he is able to publish several papers on the theory of heat. In 1903 he and Mileva are married, and a son, Hans Albert, is born in 1904.

1905 (The miracle year): Still at the Patent Office, Einstein publishes five papers. One paper provides a long-sought convincing argument for the existence of atoms, one would become one of the most cited papers of its time, one shakes physicist's understanding of the foundations of physical reality, one remakes the notions of space and time, and the final one introduces the most recognized equation in history. It would be another four years, however, before Einstein is able to attain a university position in physics and leave the Patent Office.