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| Teaching Standard Model at high school  Timeline |

This is the story of the ideas that led to the Standard Model. The most important points are highlighted. The new terms are linked to the Glossary.

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| **What Happened (Timeline)** | **Concept, Philosophy, Importance** | **Suggestion for Interaction (questions, discussions)** |
| 624-212 B.C.: Thales of Miletus: everything is made of water and forces. Empedocles: four elements: earth, air, fire, and water. Democritus: the universe consists of atoms. | The Greeks gave much to the world of physics by developing the basis of fundamental modern principles as the conservation of matter, atomic theory. Aristotle formalized the gathering of scientific knowledge. | The term 'atom' is a misnomer. Why? Answer: The Greek root for the word atom, 'atomon', means 'that which cannot be divided'. But the entities we call atoms are made from more fundamental particles! |
| 1214-1294 AD: Roger Bacon taught that in order to learn the secrets of nature we must first observe. | Great thinkers began to reject the Greek ideas in favor of new ideas based on empirical methods. |  |
| 1564-1630: Galileo Galilei, Tycho Brahe, Johannes Kepler. Replace old assumptions in favor of new scientifically deduced theories and develop theory of elliptical planetary motion. | It was apparent that scientific theories could not be accepted without rigorous testing. | Are Kepler's laws independent? Answer: No, Newton’s laws explain object motion in a mathematical fashion more generally. |
| 1773-1829: Thomas Young develops the wave theory of light and describes light [interference](http://teachers.web.cern.ch/teachers/archiv/HST2003/publish/standard%20model/History/layer2.htm#interference). |  |  |
| 1808: John Dalton's atomic theory (all material is made of a few elements). |  |  |
| 1871: Mendeleyev invents the Periodic Table of elements. | People soon realized that they could categorize atoms into groups that shared similar chemical properties. | What is the connection between the Periodic Table of the Elements and number of the electrons? |
| 1873: James Clerk Maxwell performs important research in three areas: color vision, molecular theory, and electromagnetic theory. | The ideas underlying Maxwell's theories of electromagnetism describe the propagation of light waves in a vacuum. |  |
| 1874: George Stoney develops a theory of the electron and estimates its mass. |  | Finds mass and charge of the electron on the WWW! |
| 1895: Wilhem Röntgen discovers the X-rays. |  |  |
| 1898: Marie and Pierre Curie separate radioactive elements. |  |  |
| 1898: Joseph Thompson measures the electron, and puts forth his 'plum-pudding' model of the atom (the atom is a positive sphere with small negative electrons inside) | It was the first time 'rays' were deflected with an electric field, something that had been done previously with a magnetic field. Thomson and his student Ernest Rutherford were the first to demonstrate the ionization of air by X rays. | There are two Thompsons. Can you say something about the other one? |
| 1900: Max Planck suggests that radiation is quantized (it comes in discrete amounts.) | And after that the quantum theory began. Because of  the contribution, he got the Nobel Prize in 1918. | Can you list other physicists who play an important role on quantum physics? |
| 1905: Albert Einstein, one of the few scientists to take Planck's ideas seriously, proposes a quantum of light (the photon) in his explanation of the photoelectric effect. | There are other two important works Einstein did in 1905, which are special relativity and theoretical calculations for Brownian Motion. Einstein received the Nobel Prize in 1921 but not for relativity, rather for his work on the photoelectric effect. | What is the difference between Special and General relativity? |
| 1911: Ernest Rutherford proved the existence of the nucleus as the result of the alpha-scattering experiment performed by Hans Geiger and Ernest Marsden. | The discovery of nucleus in the middle of atom proved that the 'plum-pudding' model of J. J. Thompson was not correct. |  |
| 1913: Niels Bohr succeeds in constructing a theory of atomic structure based on quantum ideas. | Bohr proposed a positively charged central nucleus with electrons moving about it in circular orbits. The important feature in Bohr's theory was that electron orbits could occur only in specific, predetermined paths. If an electron absorbs energy, it is moved to an orbit further from the nucleus. Conversely, when it drops to an orbit nearer the nucleus, it gives off energy in the form of light. Different colors of light are produced depending on which orbit the electron starts from and to which orbit it drops. | Can you list some debate between Einstein and Bohr? |
| 1924: Louis de Broglie proposes that matter has wave properties. | This is an idea that was to revolutionize our understanding of the physical world at the most fundamental level. Because of his contribution he got the Nobel Prize in 1929. | "The smaller of the particle is the shorter wavelength it is." Is it right? |
| 1925: Wolfgang Pauli formulates the [exclusion principle](http://teachers.web.cern.ch/teachers/archiv/HST2003/publish/standard%20model/History/layer2.htm#exclusion) for electrons in an atom. | This principle helps to explain the regularities of the Periodic Table. | Who is the teacher of Pauli and who are the students of Pauli? |
| 1926: Erwin Schrödinger develops wave mechanics, which describes the behavior of quantum systems for [bosons](http://teachers.web.cern.ch/teachers/archiv/HST2003/publish/standard%20model/History/layer2.htm#boson). Max Born gives a probability interpretation of quantum mechanics. G. N. Lewis proposes the name 'photon' for a light quantum. | It came as a result of his dissatisfaction with the quantum condition in Bohr's orbit theory and his belief that atomic spectra should really be determined by some kind of eigenvalue problem. For this work he shared the Nobel Prize with Dirac on 1933. |  |
| 1927: Werner Heisenberg formulates the [uncertainty principle](http://teachers.web.cern.ch/teachers/archiv/HST2003/publish/standard%20model/History/layer2.htm#uncertain). | It proved that Bohr's model of the atom is incorrect. | Try to write down the different types of uncertainty principle. |
| 1928: Paul Dirac combines quantum mechanics and special relativity to describe the electron. | The importance of Dirac's work lies essentially in his famous wave equation, which introduced special relativity into Schrödinger's equation. The remarkable notion of an [antiparticle](http://teachers.web.cern.ch/teachers/archiv/HST2003/publish/standard%20model/History/layer2.htm#antimatter) to each particle stems from his equation. For this work he shared the Nobel Prize for 1933 with Erwin Schrödinger. | Which professor did Dirac have? Do you know other physicists who got the same position in Cambridge University? |
| 1930: Wolfgang Pauli suggests the neutrino to explain the continuous electron spectrum for beta decay. | Since not participating in strong and electromagnetic interactions, neutrinos are difficult to observe. They were put into theory before observation. | List the Nobel Prizes in physics related to the neutrino! |
| 1931: James Chadwick discovers the neutron. The mechanisms of nuclear binding and decay become primary problems. | For this, he received the Nobel Prize in physics in 1935. |  |
| 1933: Carl. D. Anderson discovers the positron (the [antiparticle](http://teachers.web.cern.ch/teachers/archiv/HST2003/publish/standard%20model/History/layer2.htm#antimatter) of electron) in [cosmic rays](http://teachers.web.cern.ch/teachers/archiv/HST2003/publish/standard%20model/History/layer2.htm#cosmic). | Nobel Prize in 1936. The positron appeared first in Dirac's theory. |  |
| 1934: Hideki Yukawa combines relativity and quantum theory to describe nuclear [interactions](http://teachers.web.cern.ch/teachers/archiv/HST2003/publish/standard%20model/History/layer2.htm#interaction) by the exchange of certain particles ([mesons](http://teachers.web.cern.ch/teachers/archiv/HST2003/publish/standard%20model/History/layer2.htm#meson) called '[pions](http://teachers.web.cern.ch/teachers/archiv/HST2003/publish/standard%20model/History/layer2.htm" \l "pion)') between protons and neutrons. | From the size of the nucleus, Yukawa concludes that the mass of the conjectured particles (mesons) is about 200 electron masses. This is the beginning of the meson theory of nuclear forces. |  |
| 1937: the muon (a particle with 200 times heavier than the electron) is discovered in [cosmic rays](http://teachers.web.cern.ch/teachers/archiv/HST2003/publish/standard%20model/History/layer2.htm#cosmic). (J. C. Street, E. C. Stevenson, using a [cloud chamber](http://teachers.web.cern.ch/teachers/archiv/HST2003/publish/standard%20model/History/layer2.htm#cloud).) | It was thought first, that it can't be anything else than the [pion](http://teachers.web.cern.ch/teachers/archiv/HST2003/publish/standard%20model/History/layer2.htm#pion) proposed by Yukawa earlier. By 1946 it was obvious it can't be: it didn't interact with the nucleus. In fact, the muon was the first observed 'second generation'-particle. I. I. Rabi commented: "who ordered that?" |  |
| 1947: A meson that does interact strongly discovered in [cosmic rays](http://teachers.web.cern.ch/teachers/archiv/HST2003/publish/standard%20model/History/layer2.htm#cosmic). Determined to be Yukawa’s [pion](http://teachers.web.cern.ch/teachers/archiv/HST2003/publish/standard%20model/History/layer2.htm#pion). |  |  |
| 1947: Introduction of [Feynman diagrams](http://teachers.web.cern.ch/teachers/archiv/HST2003/publish/standard%20model/History/layer2.htm#feynman) |  |  |
| 1948: Berkley builds first high-energy [cyclotron](http://teachers.web.cern.ch/teachers/archiv/HST2003/publish/standard%20model/History/layer2.htm#cyclotron)  (only 184 inches). Production of the first artificial [pions](http://teachers.web.cern.ch/teachers/archiv/HST2003/publish/standard%20model/History/layer2.htm" \l "pion). | A technological innovation that allows experimentalists to have more control in what they are looking for in the search for higher energy particles. Scientists are no longer dependants on the unpredictability of [cosmic rays](http://teachers.web.cern.ch/teachers/archiv/HST2003/publish/standard%20model/History/layer2.htm#cosmic). |  |
| 1952: Development of [bubble chamber](http://teachers.web.cern.ch/teachers/archiv/HST2003/publish/standard%20model/History/layer2.htm#bubble) at Brookhaven Cosmotron 1.3 GeV [accelerator](http://teachers.web.cern.ch/teachers/archiv/HST2003/publish/standard%20model/History/layer2.htm#accelerator). | Bubble chamber provided a greater tool to observe higher energy collisions. This allows for the discovery of many new particles. |  |
| 1953: Found through the scattering of electrons off of nuclei that protons and neutrons have a charge density. Particles still considered fundamental. | Even though a neutral particle contains a charge distribution, scientists still hold onto the concept of the neutron being fundamental. | When we say an atom is neutral, does that mean it has no charges at all? |
| 1957: Schwinger, Bludman, Glashow separately suggest [weak force](http://teachers.web.cern.ch/teachers/archiv/HST2003/publish/standard%20model/History/layer2.htm#weak) is mediated by a heavy [boson](http://teachers.web.cern.ch/teachers/archiv/HST2003/publish/standard%20model/History/layer2.htm#boson) W+ and W-. | A more fundamental version of the weak interaction is presented. |  |
| Number of particles being discovered increasing. | Physics is becoming too complicated. The theory of protons and neutrons being the fundamental building blocks does not explain many of the new particles. New conservation laws are invented (baryon number, strangeness), some of which are not universal (eg. only hold for strong interactions). A theory is needed to explain the number of particles. |  |
| 1964: Murray Gell-Mann and George Zweig propose the theory that[mesons](http://teachers.web.cern.ch/teachers/archiv/HST2003/publish/standard%20model/History/layer2.htm#meson) and [baryons](http://teachers.web.cern.ch/teachers/archiv/HST2003/publish/standard%20model/History/layer2.htm#baryon) are composed of smaller particles called '[quarks](http://teachers.web.cern.ch/teachers/archiv/HST2003/publish/standard%20model/History/layer2.htm#quark)' which have a fraction of a charge. The prediction is for three [quarks](http://teachers.web.cern.ch/teachers/archiv/HST2003/publish/standard%20model/History/layer2.htm#quark)(and antiquarks) called up, down, and strange. | The introduction of quarks is a bold conjecture that is not easily accepted. The theory was incomplete and highly mathematical. |  |
| 1967: The unification of electromagnetic and the weak [interaction](http://teachers.web.cern.ch/teachers/archiv/HST2003/publish/standard%20model/History/layer2.htm#interaction) to be called the Electroweak interaction by Steven Weinberg and Abdus Salam. | This theory included a new weakly interacting boson, called the Z0 as well as the Higgs Boson. | If a theory predicts the existence of a particle does that mean it is discovered? |
| 1968: Stanford linear particle [accelerator](http://teachers.web.cern.ch/teachers/archiv/HST2003/publish/standard%20model/History/layer2.htm#accelerator) provides first experimental evidence for the existence of [quarks](http://teachers.web.cern.ch/teachers/archiv/HST2003/publish/standard%20model/History/layer2.htm#quark). | The researchers did not initially refer to the constituents as quarks. |  |
| 1970: It is suggested by Glashow, Iliopoulos, and Maiani that a fourth[quark](http://teachers.web.cern.ch/teachers/archiv/HST2003/publish/standard%20model/History/layer2.htm#quark) (called charm) is needed to allow for the neutral [weak interaction](http://teachers.web.cern.ch/teachers/archiv/HST2003/publish/standard%20model/History/layer2.htm#weak)of Z0. |  |  |
| 1973**:**Harald Fritzsch and Murray Gell-Mann develop the theory of[strong interaction](http://teachers.web.cern.ch/teachers/archiv/HST2003/publish/standard%20model/History/layer2.htm#strong) between [quarks](http://teachers.web.cern.ch/teachers/archiv/HST2003/publish/standard%20model/History/layer2.htm#interaction).  The quark is considered a real particle (rather than mathematics) containing a new type of charge known as 'color'.  The [boson](http://teachers.web.cern.ch/teachers/archiv/HST2003/publish/standard%20model/History/layer2.htm#boson) responsible for the [strong interaction](http://teachers.web.cern.ch/teachers/archiv/HST2003/publish/standard%20model/History/layer2.htm#strong)between quarks is termed the gluon.  [Quarks](http://teachers.web.cern.ch/teachers/archiv/HST2003/publish/standard%20model/History/layer2.htm#quark) are now considered real particles that combine to form heavier particles. |  |  |
| 1974: Iliopoulos presents a summary of known particle physics called the [Standard Model](http://teachers.web.cern.ch/teachers/archiv/HST2003/publish/standard%20model/History/layer2.htm#standard). | Particle physics now has a theory that explains how quarks, leptons, and bosons combine to create all known particles. |  |
| 1977: The 'bottom' [quark](http://teachers.web.cern.ch/teachers/archiv/HST2003/publish/standard%20model/History/layer2.htm#quark) is discovered at Fermi Lab.  Leon Lederman predicts the existence of a sixth [quark](http://teachers.web.cern.ch/teachers/archiv/HST2003/publish/standard%20model/History/layer2.htm#quark), known as 'top'. |  | Why should the discovery of a fifth quark suggest a sixth? |
| 1983: The W+, W-, and Z0 are detected at CERN by use of a proton-antiproton collision. | A new technology is developed which allows higher energy collisions. |  |
| 1995: The top [quark](http://teachers.web.cern.ch/teachers/archiv/HST2003/publish/standard%20model/History/layer2.htm#quark) is discovered at Fermi Lab with an unusually, surprising mass of 175 GeV. |  | Why is the mass so much larger any of the other quarks? |
| To present: experimental confirmation of the [Standard Model](http://teachers.web.cern.ch/teachers/archiv/HST2003/publish/standard%20model/History/layer2.htm#standard). |  |  |
| Future: refining the [Standard Model](http://teachers.web.cern.ch/teachers/archiv/HST2003/publish/standard%20model/History/layer2.htm#standard). | Why is the top quark so much heavier than all of the other quarks? Are quarks really fundamental? Discovery of the Higgs Boson? (LHC) |  |