Basic Theoretical Ideas

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Particle and Universe

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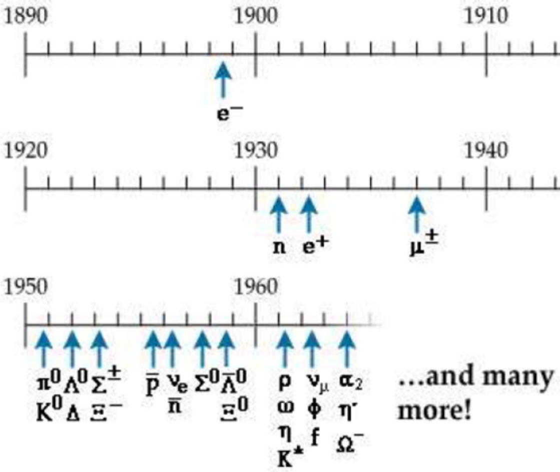


I. 1900-1928 II. 1930-1956

III. 1956 - 1975 IV. 1977 -

I. Quantum Mechanics and Special Relativity 1900-1928 Maxwell equations 1864

- Blackbody's radiation - energy quantum Planck 1900
- Quantum (particle) of light - Einstein 1905
- Wave property of matter - de Broigle 1924
- Bohr's atom 1913 (stationary orbits, quantum numbers)
- Pauli exclusion 1925, a new two-valued quantum number
- Spin- Goudsmit,Uhlenbeck '25

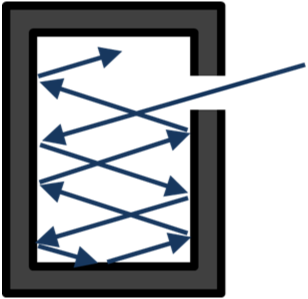
- Special relativity - Einstein 1905 (velocity of light c, space-time, time dilatation, Lorentz contraction, $E = mc^2$)
- General relativity - Einstein 1915

QM - Heisenberg (matrix 1925, uncertainty principle'27), Schrodinger (wave 1925-6); Dirac 1928 - first description of photon-electron int. based on QM and relativity: antiparticles,creation/annihilation particles

Blackbody radiation

Radiation is a process in which energy is transfered by electromagn. waves (no matter needed). Absorption and emission (by and from an object) - surface of the object is important. Vibration of molecules (studied 1860-90)

- black object - absorption of visible light. Perfect blackbody absorb all e-m waves (cavity).
- Energy of radiation depends on time, area, wave length λ (frequency f $\sim 1/\lambda$), temperature T^4 (Stefan law)
- Blackbody radiation intensity Rayleigh-Jeans -wrong at short waves. Wien displacement (maxium) law (wrong at long waves). Planck - correct.



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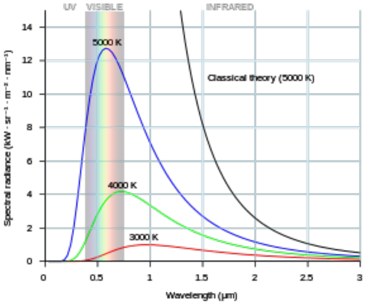

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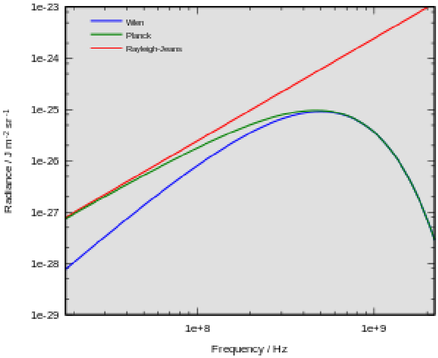


After many attempts he found in 1900 that only by assuming radiation by walls of cavity in discrete bundles (quanta) can get a proper description of the whole spectrum of radiation.

- Portion of energy (quantum of energy) proportional to its frequency $E = h\nu, \nu$ - frequency $[c/\lambda]$; Planck constant $h = 6,63x10^-34J \cdot s$
- First presentation Oct 19, 1900,– Berlin Phys. Soc.; next day - new measurement by Rubens, in agreement with Planck prediction. Quantum - presented on 14 Dec. 1900 at Prussian Phys. Soc.
- However Planck did not accept himself this finding. He described it as ”an act of despair “. But he knew - “Today I have made a discovery - as important as that of Newton”.

Quantum = “How much?”

Einstein made the next step in 1905 -
he assumed that these quanta of energy occur not only in the emission or absorption - but they travel as a whole.

- “Indeed, it seems to me that the observations of black-body radiation, photoluminescence, production of cathode rays by ultraviolet light, and other related phenomena associated with the emission or transformation of light appear more readily understood if one assumes that the energy of light is discontinuously distributed in space. “
- The only physicist who supported Einstein was Johannes Stark. In 1909 he wrote the momentum of a light quantum explicitly $p = E/c$.

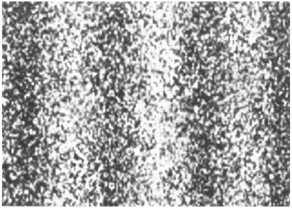
“The bold, not to say, the reckless, hypothesis”

- In 1913 Einstein - membership in the Prussian Academy of Sciences, Planck and others wrote: “That he sometimes has missed the target in his speculations, as for example, in his hypothesis of light quanta, cannot really be held too much against him, for it is not possible to introduce really new ideas, even in the most exact sciences, without sometimes taking a risk”.
- Millikan’s words from 1916 (on his own results on photoelectric effect) ‘We are confronted, however, by the astonishing situation that these facts were correctly and exactly predicted 9 years ago by a form of quantum theory which has now generally been abandoned.’
- Compton (photon-electron scattering) 1922/3 supports light quanta
- Still in 1925 James Jeans wrote that “The general opinion of physicists seems to be that the theory cannot be regarded as an expression of physical reality”.
- The name “photon” - Lewis 1926

Wave property of matter

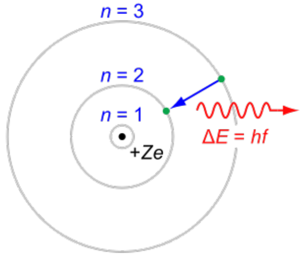
De Broigle 1924 postulated that electron (and all matters i.e. other particles) have wave properties.
This was his doctorate - Einstein supported this idea, supervisor was not sure...

Below - 70000 electrons passing the two-slit scheme



Bohr - hydrogen atom 1913

Two postulates:
Orbital angular momentum of electron L is equal to $n\hbar$ $(h/2\pi)$. Only on the orbital with such angular momentum electron does not radiate.
Difference of energies of electron at two orbitals is equal to a product of h and frequency $\rightarrow$ the atomic spectrum



- Stationary orbits? But how? de Broglie idea helps (standing waves...)
- Quantum numbers - states of the atom is described by the energy n , orbital momentum l , magnetic quantum number m_l

Pauli exclusion and spin

- Pauli (born 1900) postulated exclusion principle in 1925. The complicated system of electrons in closed shells can be reduced to the simple rule of one electron per state, if the electron states are defined using four quantum numbers (n, l, m_l and x). For this purpose he introduced a new two-valued quantum number (x).
- Samuel Goudsmit and George Uhlenbeck (students!) introduced electron spin in 1925.
- Pauli was against... after one year he accepted this idea.
- Today - we divide all particles to such as electron (one per state) - fermions, and such as the photon (many in a state) - bosons.

Einstein used only two postulates:

1. The velocity of light in empty space c is the same in all inertial frames independently of the relative motion of an observer and a source.
2. The principle of relativity, that the laws of physics are identical in all inertial frames.

Results:

- space-time (4-vectors),
- time dilatation, Lorentz contraction
- $E = mc^2$...

Lifetime of a particle depends on frame- but the fact that it is stable or not is frame-independent.

Relativistic effects important if velocity v is close to c.

Quantum Mechanics and quantum electrodynamics 1925-8

- Spring 1925 Heisenberg - first form of QM (matrix)
- Fall 1925 Schrodinger - alternative form (wave), in 1926 - two forms equivalent.
- 1927 - Uncertainty principle by Heisenberg $\Delta x \cdot \Delta p \geq \hbar/2$
- 1928 Dirac relativistic wave equation (for electron) - the first theory to account fully for special relativity in the context of quantum mechanics.
  Existence of an antimatter (the same mass and lifetime, opposite charge) (symmetry under transformation of charge C called also matter-antimatter transf.) - where is antielectron?
- Quantum Electrodynamics...(almost)

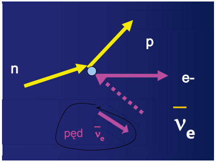
Possible to perform any computation for any physical process involving photons and charged particles !?

II. New era 1930 -1955

- 1930 neutrino - Pauli hypothesis(to save energy-momentum conservation in the beta decay); no mass, no el. charge - not seen directly. (Discovery in 1956.)
- 1932 neutron was discovered and

  A) 1932 Heisenberg postulated a description of nuclear (strong) interaction in terms of dublet of proton and neutron (common name - a nucleon). The isospin SU(2) symmetry was assumed (observed independence of nuclear force $pp \equiv nn \approx pn$)

  B) 1933 Fermi postulated description of process: neutron $\rightarrow$ proton + electron + neutrino (current-current interaction in analogy of QED with electric currents) - theory of weak interaction



Point-like interaction, Fermi constant $G_F = 1.1 \cdot 10^{-5} GeV^{-2}$, CC charged current interaction, weaker than el-mag. interaction

II. New era 1930 -1956 cont.

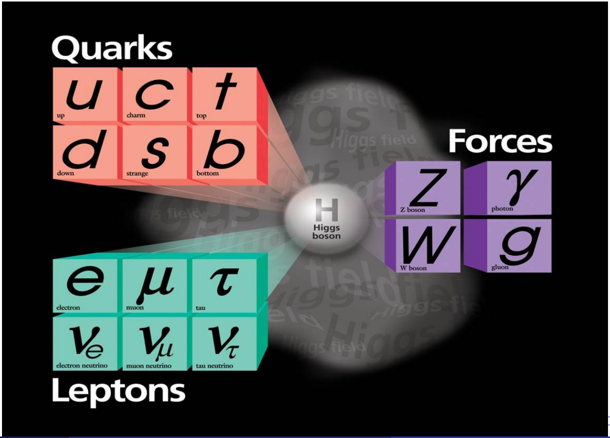
- Positron (1932), heavy electron (muon 1937) - name leptons
- 1941 Pauli (relat. field theory of elementary particles) -symmetry as a gauge principle to describe interaction (QED= U(1) symmetry).
- First order calculations in QED OK, then infinities ! Renormalization suggested (Bethe, Tomonaga, Schwinger, Feynman, Dyson 1947-1950)) - infinities hidden in mass and charge parameters.
- Yang-Milles (gauge) theory for isospin SU(2) 1954 - massless (vector) carries of forces ?? (name - gauge bosons)
- 1949 Strange particles discovered (Kaons)
- 1956 Parity non-conservation in weak interaction Yang, Lee, Wu...(parity transformation P leads to a mirror image). The argument of Pauli: since nature ”does not know” whether we observe it directly or through a mirror, mirror reflection invariance must hold and hence parity must be conserved. Landau - ”Space cannot be asymmetric”. I is. Over one night Landau found the

Particle Physics 1956-1975

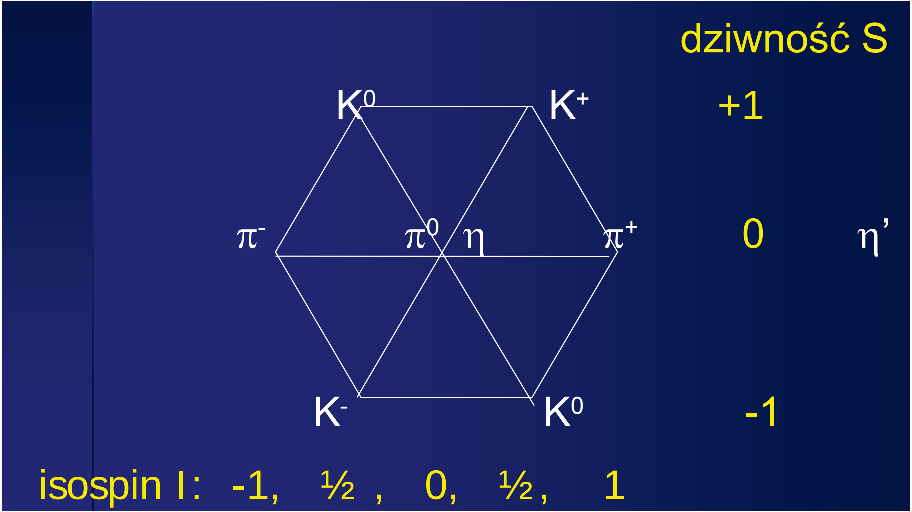
- Many particles discovered, mainly having strong interactions
- 1964 Classification led to Quark Model - Gell-Mann, Zweig
- 1961 Glashow - unification of electromagnetic and weak forces SU(2)xU(1) - electroweak interaction EW- gauge bosons $W^{\pm}$, Z expected
- 1964 Brout-Englert-Higgs mechanism for Yang-Mills theories (spontaneous symmetry breaking - mass generation of gauge bosons
- 1964 small CP violation in weak interaction observed
- 1967 Salam, Weinberg incorporated BEH mechanism to the EW interaction (only for leptons)
- 1971 d'Hooft, Veltman - EW theory is renormalized
- 1973 Gross, Wilczek, Politzer - QCD theory of strong interaction SU(3) color;colored quarks and gluons, asymptotic freedom
- 1973 Neutral current observed (means Z)
- 1974 - charm quark
- Standard Model SU(2)xU(1)x SU(3)

Today

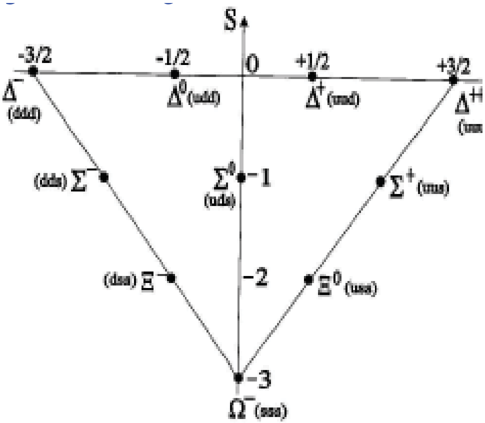
1983 W/Z gauge bosons discovered - very heavy (80/90 GeV)!- very short range $10^{-18}m$
Fundamental particles - quarks and leptons, and carriers of interactions (bosons)- photon, W+,W-,Z , gluons
and Higgs boson



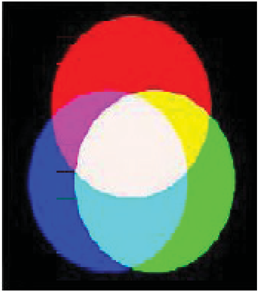
Quark diagram (octet) - Isospin vs Strangeness



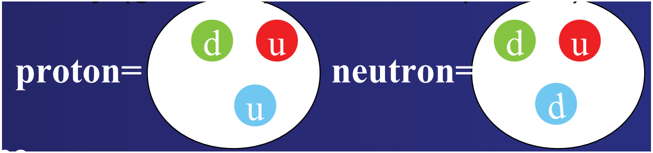
Discovery of Omega - a way to quantum chromodynamics



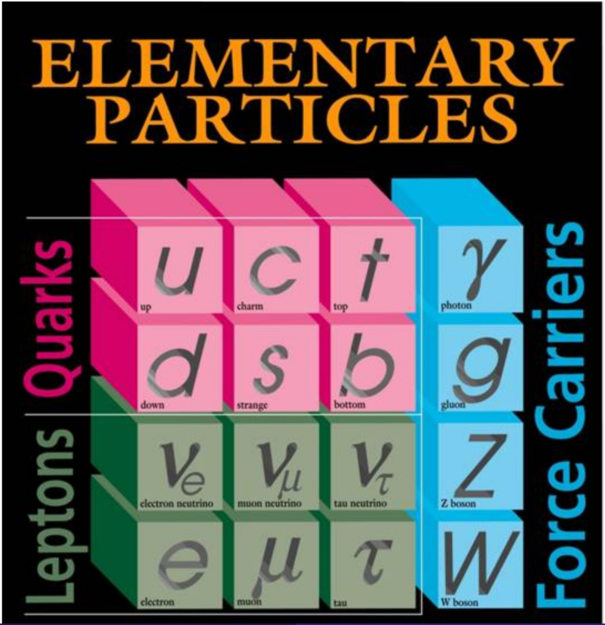
Hadrons- bounds states of colored quarks- barions (qqq) and mesons (q $\bar{q}$)- are colorless!



Proton and neutron and light quarks



Why 3 generation?



Year 1964

→ LHC 4.07.2012

Higgs-like particle with mass125 -126 GeV

observed by ATLAS+CMS (+Tevatron)

BROKEN SYMMETRY AND THE MASS OF GAUGE VECTOR MESONS*

F. Englert and R. Brout
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(Received 26 June 1964)

BROKEN SYMMETRIES, MASSLESS PARTICLES AND GAUGE FIELDS

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Received 27 July 1964

26.06.1964

27.07.1964

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BROKEN SYMMETRIES AND THE MASSES OF GAUGE BOSONS

Peter W. Higgs
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(Received 31 August 1964)

GLOBAL CONSERVATION LAWS AND MASSLESS PARTICLES*

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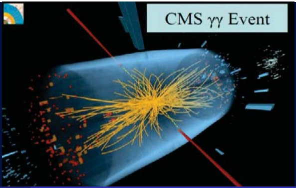
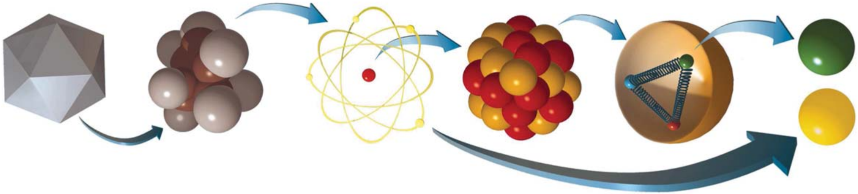
(Received 12 October 1964)

12.10.1964





$< 10^{-18}$ m