Elementary Particles and their Effect on the Evolution of Modern Physics

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Introduction

One of the primary goals in modern physics is to answer the question: "What is the Universe made of?". Often that question reduces to "What is matter and what holds it together?".

In particle physics, an elementary particle or fundamental particle is a particle whose substructure is unknown. Thus, it is unknown whether it is composed of other particles.

Today, more than 2000 hadron species have been discovered.

Timeline of particle discoveries

The inclusion criteria are**:**

* Elementary particles from the Standard Model**.**
* Antiparticles which were historically important to the development of particle physics, specifically the positron and antiproton**.**
* Composite particles which were the first particle discovered containing a particular elementary constituent, or whose discovery was critical to the understanding of particle physics.

Time	Event
1895	X-ray produced by Wilhelm Röntgen (later identified as photons)
1897	Electron discovered by J. J. Thomson
1899	Alpha particle discovered by Ernest Rutherford in uranium radiation
1900	Gamma ray (a high-energy photon) discovered by Paul Villard in uranium decay
1911	Atomic nucleus identified by Ernest Rutherford, based on scattering observed by Hans Geiger and Ernest Marsden
1919	Proton discovered by Ernest Rutherford
1932	Neutron discovered by James Chadwick (predicted by Rutherford in 1920)
1932	Antielectron (or positron), the first antiparticle, discovered by Carl D.

	Anderson (proposed by Paul Dirac in 1927 and by Ettore Majorana in 1928)
1937	Muon (or mu lepton) discovered by Seth Neddermeyer, Carl D. Anderson, J.C. Street, and E.C. Stevenson, using cloud chamber measurements of cosmic rays (it was mistaken for the pion until 1947)
1947	Pion (or pi meson) discovered by C. F. Powell's group (predicted by Hideki Yukawa in 1935)
1947	Kaon (or K meson), the first strange particle, discovered by George Dixon Rochester and Clifford Charles Butler
1955	Antiproton discovered by Owen Chamberlain, Emilio Segrè, Clyde Wiegand, and Thomas Ypsilantis
1956	Electron antineutrino detected by Frederick Reines and Clyde Cowan (proposed by Wolfgang Pauli in 1930 to explain the apparent violation of energy conservation in beta decay) At the time it was simply referred to as *neutrino* since there was only one known neutrino.
1962	Muon neutrino (or mu neutrino) shown to be distinct from the electron neutrino by a group headed by Leon Lederman
1964	Xi baryon discovery at Brookhaven National Laboratory
1969	Partons (internal constituents of hadrons) observed in deep inelastic scattering experiments between protons and electrons at SLAC; this was eventually associated with the quark model (predicted by Murray Gell-Mann and George Zweig in 1964) and thus constitutes the discovery of the up quark, down quark, and strange quark.
1975	Tau discovered by a group headed by Martin Per
1977	Upsilon meson discovered at Fermilab, demonstrating the existence of the bottom quark (proposed by Kobayashi and Maskawa in 1973)
1979	Gluon observed indirectly in three-jet events at DESY
1983	W and Z bosons discovered by Carlo Rubbia, Simon van der Meer, and the CERN UA1 collaboration (predicted in detail by Sheldon Glashow, Abdus Salam, and Steven Weinberg)
1995	Top quark discovered at Fermilab
1995	Antihydrogen produced and measured by the LEAR experiment at CERN
2000	Tau neutrino first observed directly at Fermilab
2011	Antihelium-4 produced and measured by the STAR detector; the first particle to be discovered by the experiment
2012	A particle exhibiting most of the predicted characteristics of the Higgs boson discovered by researchers conducting the Compact Muon Solenoid and ATLAS experiments at CERN's Large Hadron Collider

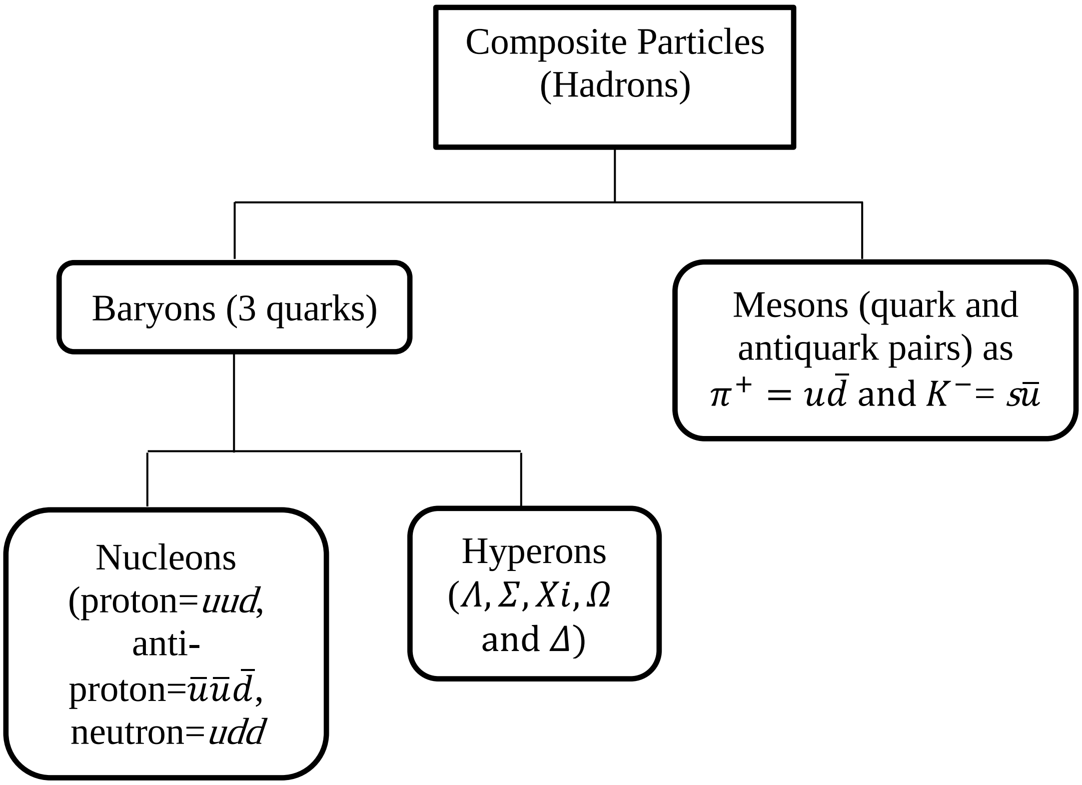

Figure 1: Schematic of Composite Particles.

The Standard Model

The Standard Model is a quantum field theory that describes the interactions between the fermionic quark and lepton fields through the exchange of gauge boson fields. It consists of two main parts: quantum chromodynamics theory (QCD) describing the strong interaction, and the electroweak theory (EW) unifying the description of the electromagnetic and the weak interactions. The gravitational interaction is left out of the description, because it has not yet been possible to successfully formulate a theory of quantum gravity, and furthermore, at present energies in high energy physics it is not important.

Table 1: The generations of quark and lepton.

Generation	1st	2nd	3rd
Quark	u d	c s	t b

A (Quarks)

Generation	1st	2nd	3rd
Lepton	ν_e e	ν_μ μ	ν_τ τ

B (Leptons)

Table 2: The summary of characteristics for quarks.

Fermions	Name	Mass	Electric Charge	Spin	Interaction
Quarks	Up	$2.3^{+0.7}_{-0.5}$ MeV/c^2	$+\frac{2}{3}e$	1/2	Electro-magnetism, Weak, Strong
	Down	$4.8^{+0.5}_{-0.3}$ MeV/c^2	$-\frac{1}{3}e$	1/2	
	Charm	1.275 ± 0.025 GeV/c^2	$+\frac{2}{3}e$	1/2	
	Strange	95 ± 5 MeV/c^2	$-\frac{1}{3}e$	1/2	
	Top (truth)	173.2 ± 0.9 GeV/c^2	$+\frac{2}{3}e$	1/2	
	Bottom (beauty)	4.18 ± 0.03GeV/c^2	$-\frac{1}{3}e$	1/2	

Table 3: The summary of characteristics for leptons.

Fermions	Name	Mass	Electric Charge	Spin	Interaction
Leptons	e	0.51 MeV/c^2	-1	1/2	Electromagnetism, Weak
	ν_e	< 2 eV/c^2	0	1/2	Weak
	μ	105.66 MeV/c^2	-1	1/2	Electromagnetism, Weak
	ν_μ	< 0.19 MeV/c^2	0	1/2	Weak
	τ	1776.99^{+29}_{-26} MeV/c^2	-1	1/2	Electromagnetism, Weak
	ν_τ	< 18.2 MeV/c^2	0	1/2	Weak

Table 4: The summary of characteristics for Gauge Bosons.

	Name	Force	Coupling	Mass (GeV/c^2)	Electric Charge	Spin
Gauge Bosons	photon (γ)	EM	10^{-2}	0	0	1
	W boson	Weak	10^{-13}	80.4	±1	1
	Z boson	Weak	10^{-13}	91.2	0	1
	gluon (g)	Strong	1	0	0	1

In addition to the quarks and leptons, there are basic elementary particles which transmit the four fundamental forces, called "gauge bosons" which summarized in figure 2;

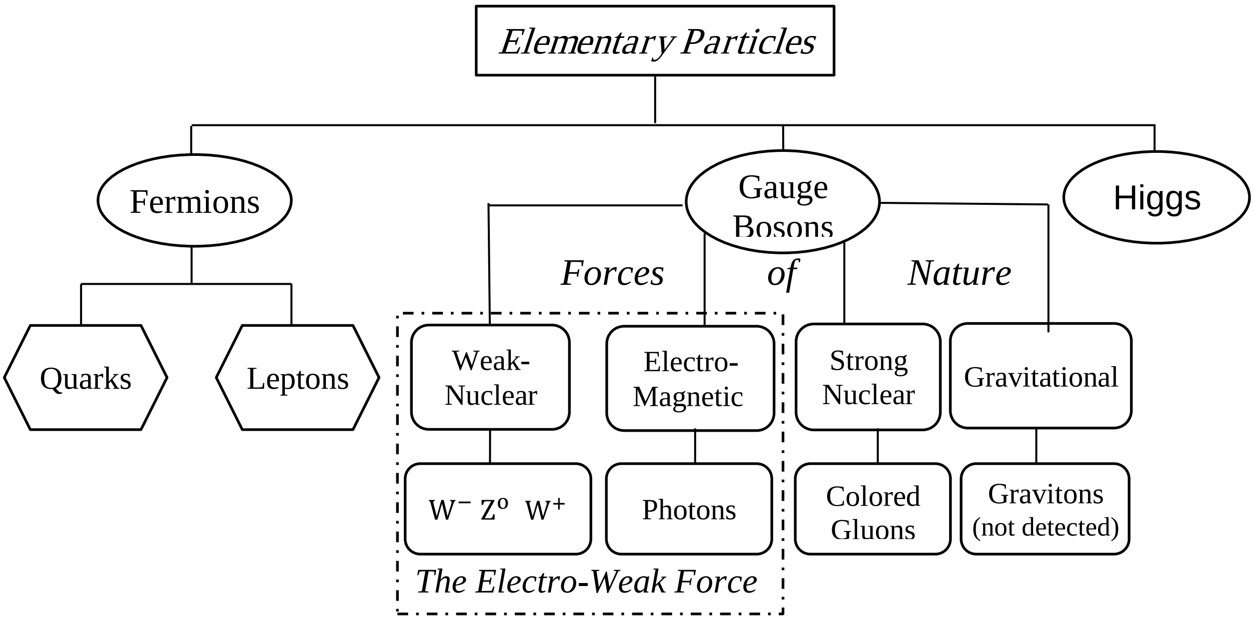

Figure 2: Schematic of elementary particles depending on coupling force.

Asymptotic Freedom and Confinement

when two quarks are close together, the force is relatively weak, or in very high-energy reactions, quarks and gluons interact very weakly, this is asymptotic freedom, which states that the interaction strength α_s between quarks becomes smaller as the distance between them gets shorter.

The other kind is confinement, it occurs when two quarks are move farther apart, then the force becomes much stronger. Because of this, it would take an infinite amount of energy to separate two quarks.

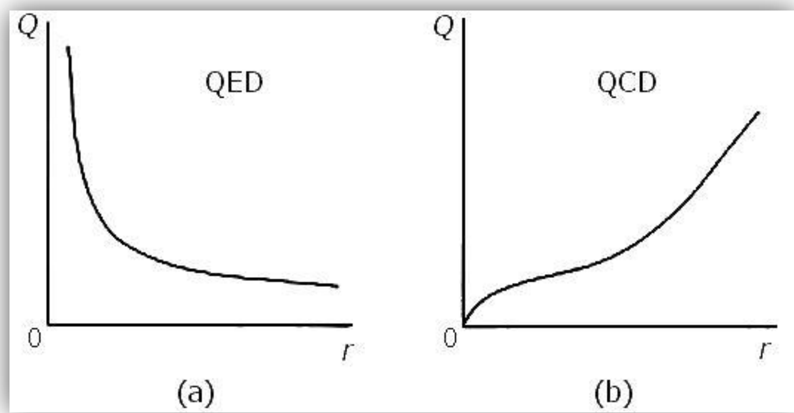

Figure 3:
(a) The apparent strength of an electrical charge as a function of the distance from which it is viewed.
(b) The apparent strength of the color charge on a quark.

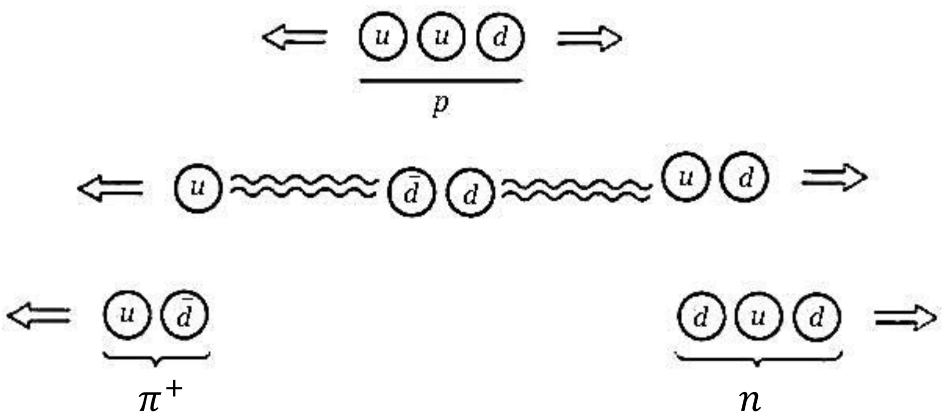

Figure 4: **A** possible scenario for quark confinement

The Potential of QCD

The potential between two quarks should consist of a Coulomb-like part and a confining part and it is taken to be of the form:

$$V_s = -\frac{4}{3}\frac{\alpha_s}{r} + kr \qquad (1)$$

The elementary estimate of k from size of hadrons: r ~ 1 fm and k ~ 1 GeV/fm, then from the derivative of eq. (1); the force between two quarks at large distance is:

$$F = |dV/dr| = k = 1.6 \times 10^{-10} \text{ J}/ 10^{-15} \text{ m} = 160{,}000 \text{ N} \qquad (2)$$

The Effect on the evolution of modern physics

* The electromagnetic and weak forces have been unified into one electroweak force as shown in figure 2. It is the aim of theoretical physicists to unify all forces into one Grand Unified Theory. Much progress has been made towards this goal, but it is gravity, although very well described by General Relativity, that is proving hardest to incorporate.

* Also there is Higgs boson H^0, which is a boson with no spin, electric charge, or color charge. Higgs boson plays a unique role in the Standard Model, by explaining why the other elementary particles, except the photon and gluon, are massive. In particular, the Higgs boson would explain why the photon has no mass, while the W and Z bosons are very heavy. Elementary particle masses, and the differences between electromagnetism and the weak force, are critical to many aspects of the structure of microscopic (and hence macroscopic) matter. In electroweak theory, Higgs boson generates the masses of the leptons

(electron, muon, and tau) and quarks. As the Higgs boson is massive, it must interact with itself. The mass of it is 125.9 ± 0.4 GeV.

* According to consensus among cosmologists, dark matter is composed primarily of a not yet characterized type of subatomic particle. The search for this particle, by a variety of means, is one of the major efforts in particle physics today.