CONSTITUTION OF MATTER, THE STANDARD MODEL

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INTRODUCTION

The concept of the atom as a building block of matter was envisioned by the Greeks around 440 BC. The discovery of the electron as a particle led to the development of the theory of the atomic nucleus in the early 20th century with the discovery of the protons and then the neutrons in 1932, collectively called nucleons. The neutrino joined the collection of particles to allow conservation of energy, momentum, and angular momentum in the process of radioactive decay. These four particles are still considered today as the main constituents of matter, and are the basis of numerous applications in engineering and science. However, it was soon discovered that these particles themselves are formed of even more elementary constituents. As probing of matter proceeded with higher magnification and smaller structures became apparent.

In 1936 physicists discovered the muons in cosmic rays followed by hundreds of particles which were discovered with the help of high energy accelerators in the 1960's and 1970's. Matter, from galaxies to nuclei, is composed of quarks and leptons. Quarks behave differently than leptons, and for each kind of matter particle there is a corresponding antimatter particle.

The Standard Model of Elementary Particles summarizes the current state of knowledge in particle physics. It is a quantum mechanical theory that includes the theory of strong interactions or Quantum Chromo Dynamics (QCD) and the unified theory of weak and electromagnetic interactions or the Electroweak force. Gravity is one of the fundamental interactions even though it is not part of the Standard Model. Its force carrier, the graviton is theoretical and has not yet been experimentally observed.

NUCLEAR STRUCTURE

In the fifties and sixties, experiments with particle accelerators showed that protons and neutrons are a part of a larger family of particles called hadrons. In the sixties the quark model of matter suggested that known hadrons, can be described by three quarks: up, down and strange.

At this scale, the common unit for length is the Fermi or femtometer (fm) in the SI system of units, which is about the size of the proton, where:

$$1 \text{ Fermi (fm)} = 10^{-15} \text{ m} = 10^{-13} \text{ cm.}$$

The common unit of energy is the electron volt (eV), which is the kinetic energy gained by an electron as it falls through a potential drop of 1 Volt. There:

$$1 \text{ eV} = 1.602\ 10^{-19} \text{ Joule.}$$

Today our understanding of the structure of matter covers a large scale in both dimension and energy. Larger excitation energies are associated with the tighter bound systems.

Table 1. Characteristic scales of the structure of matter.

Hierarchy	Example	Characteristic distance (cm)	Characteristic Energy	Relative size
Atom	Deuterium atom	10^{-8}	eV	1
Nucleus	U^{235} nucleus	10^{-12}	MeV	10^{-4}
Hadrons	Nucleons: protons, neutrons	10^{-13}	GeV	10^{-5}
Elementary Particles	Electron	$<10^{-16}$	-	10^{-8}
	Quark, up, down	$<10^{-17}$	-	10^{-8}

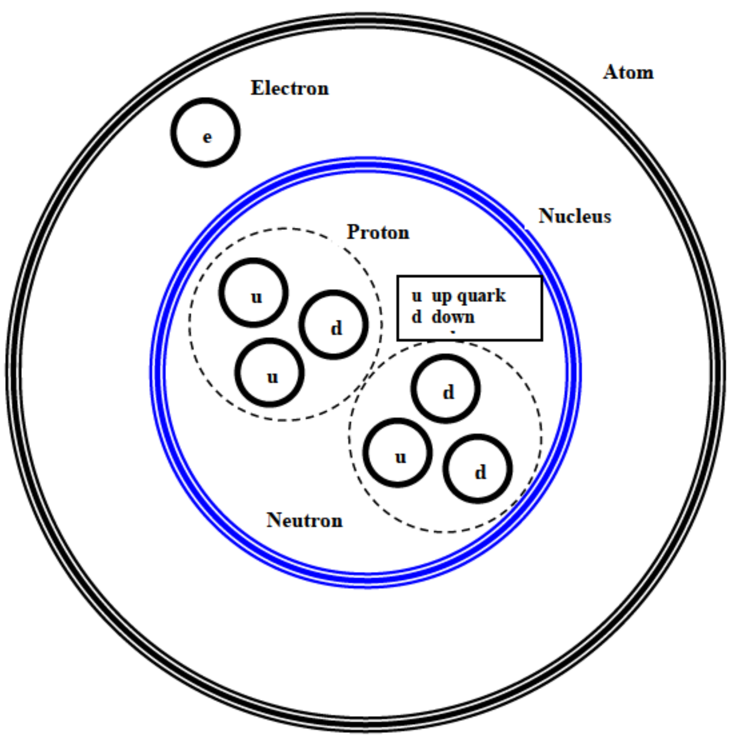

Figure 1. Schematic structure of the atom of a deuteron ${}_1D^2$. If the protons and neutrons were 1 cm in diameter, the quarks and electrons would be less than 0.01 mm in size and the atom would be 1 kilometer in size. Proton: 2 up and 1 down quarks. Neutron: 1 up and 2 down quarks,

PARTICLES ZOO

Lord Rutherford had shown in his experiments that the atom has a relatively small but massive nucleus. Quantum Theory made sense of atomic spectra and electron orbitals. Scattering experiments probed the constitution of the atom. The discovery of the neutron by Chadwick explained the occurrence of the nuclear isotopes. Protons, neutrons, and electrons provided a model for the building blocks of all matter.

Particle accelerators provided a tool to study the nucleus itself. They allowed physicists to resolve very small structures by producing particles with very high momentum and short wavelength. According to the De Broglie relation, the wavelength λ of the associated wave is inversely proportional to the momentum p of the particle:

$$\lambda = \frac{h}{p} = \frac{h}{mv} \tag{1}$$

where: h is Planck's constant.

Particle experiments studied collisions of high energy particles produced at accelerators. Large multi layered detectors would surround the collision point and each layer of the detector serves a separate function in tracking and identifying each of the many particles that are produced in a single collision.

Accelerator experiments revealed that the world of particles was rich. Many more particle types similar to protons and neutrons designated as baryons and a whole new family of particles called mesons was discovered. By the early 1960s a hundred or so types of particles had been identified leading to what became known as “the particles zoo.”

THE QUARK CONCEPT

The quark idea as a constituent of elementary particles has been confirmed and is a part of the Standard Model of Fundamental Particles and Interactions. New discoveries have shown that there are six types of quarks. They are given the odd names of up, down, strange, charm, bottom, and top, in order of increasing mass.

In 1964, the two physicists Murray Gell-Mann and George Zweig, independently suggested the idea that the neutrons and the protons and the newly discovered particles could be explained by a few types of yet smaller objects. Murray Gell-Mann in 1964 gave them the name: quarks. This is a nonsense word used by James Joyce in his novel: “Finnegan's Wake” in his exclamation: "Three quarks for Muster Mark!"

The quarks could explain all the observed baryons and mesons with just three types of quarks called up, down, and strange and their corresponding antimatter: the antiquarks. The interesting aspect of the concept was that the quarks had to be assigned electric charges of 2/3 and -1/3 in units of the proton charge. These charges had not been observed before. Quarks are not observed by themselves, so initially these quarks were considered as a mathematical artefact. High energy physics experiments have then convinced the high energy particle physicists that not only do quarks exist, but that there are six of them; three ordinary matter ones and their three antimatter counterparts.

Table 2. Charges of the quarks in units of a proton charge.

	Generation I	Generation II	Generation III
Quarks	Up u $\left(+\frac{2}{3}\right)$	Charm c $\left(+\frac{2}{3}\right)$	Top t $\left(+\frac{2}{3}\right)$
	Down d $\left(-\frac{1}{3}\right)$	Strange s $\left(-\frac{1}{3}\right)$	Bottom b $\left(-\frac{1}{3}\right)$

There are six flavors of quarks, where flavor means different kinds. The two lightest are called the up and down quarks. The third quark is called strange. It was named after the "strangely" long lifetime of the K particle, the first composite particle found to contain this quark. The fourth quark type, the charm quark, was named on a whim: It was discovered in 1974 almost simultaneously at both the Stanford Linear Accelerator Center (SLAC) and at Brookhaven National Laboratory (BNL). The fifth and sixth quarks were sometimes called truth and beauty in the past. The bottom quark was discovered at Fermi National Lab (Fermilab) in 1977, in a composite particle called Upsilon Y. The most elusive and massive quark, the top quark, was discovered at Fermilab in 1995 after its existence had been theorized for 20 years.

Quarks have the unusual characteristic of having a fractional electric charge, unlike the proton and electron, which have integer charges of +1 and -1 respectively. Quarks also carry another type of charge called color charge.

Each quark carries one of the three types of "strong charge," also called "color charge" that is totally unrelated to the colors of visible light. There are eight possible types of color charge for gluons. Just as electrically charged particles interact by exchanging photons, in strong interactions color charged particles interact by exchanging gluons. Leptons, photons, and W and Z bosons have no strong interaction and hence no color charge.

The reason that fractional electric charges like those of quarks have not been observed is that the quarks are never found separately, but only inside composite particles called the hadrons. There are two classes of hadrons: baryons, which contain three quarks, and mesons, which contain one quark and one antiquark. The sample hadron tables on the Standard Model chart give a few examples of the many known particles. Particles made from the first five quark types have been produced and studied at accelerator facilities.

Table 3. The Standard Model matter constituents and charge carriers showing the electron, muon and tau neutrinos.

Matter constituents Fermions			
Quarks	First generation	Second generation	Third generation

	Up u	Charm c	Top t
	Down d	Strange s	Bottom b
Leptons	Electron e^-	Muon μ^-	Tau τ^-
	Electron neutrino ν_e	Muon neutrino ν_μ	Tau neutrino ν_τ

Force carriers Bosons		
Photon γ	Gluon g	Bosons W^+ W^+ Z^0

TABLE OF SUBATOMIC PARTICLES

The two fundamental types of matter building blocks are the leptons, which include the electron and the neutrinos, and the quarks. These are thought to be point like particles smaller than 10^{-16} cm. Leptons and quarks have a spin of 1/2, which also classifies them as fermions. Since no excited states of quarks or leptons have been observed, they are thought to be elementary particles.

An attempt at classifying the constituents of matter classifies them into two major groups:

1. The elementary particles
2. The hadrons.

The elementary particles are not composed of any smaller particles, and represent the fundamental form of matter. The hadrons are composed of the quarks elementary particles.

Other terminologies for the different particles subfamilies are:

The leptons: or light weights family, contains the electron, the minus muon, the electron neutrino, the muon neutrino, the tau neutrino and their antiparticles.
The baryons: or heavy weights family, contains eight members including the proton and neutron in addition to six other particles, and their antiparticles.
The mesons family: does not have a separate family of antimesons
The massless bosons: include the graviton which remains undetected

Members of the leptons and the baryons families cannot transform from one family to the other, except through the agency of members of the mesons family.

Table 4. Table of the Subatomic Particles.

Family	Symbol	Name	Electric Charge	Mass (MeV)	Half Life (seconds)	Common Decay Products	Antiparticle
HADRONS							
Baryons (Strongly Interacting Fermions) Spin= half integral	p	proton nucleo	+e	938.26	stable		*p antiproton
	n	neutron nucle	0	939.55	stable (in nucleus) $7x\ 10^{2}$ (free state)	p, e, $^{*}\nu_e$	*n antineutron
	λ	lambda hyper		1115.6	$1.7x10^{-10}$	p, π^- p, π^0	$^{*}\lambda$ antilambda
	Σ^+	sigma plus hyperon	+e	1189.4	$0.6\ 10^{-10}$	p, π^0 n, π^+	$^{*}\Sigma^-$ anti sigma minus
	Σ^0	sigma zero hyperon	0	1192.5	$< 10^{-14}$	λ + radiation	$^{*}\Sigma^0$ anti sigma zero
	Σ^-	sigma minus hyperon	-e	1197.3	$1.2x10^{-10}$	n, π^-	$^{*}\Sigma^+$ anti sigma plus
	Ξ^-	xi minus casc hyperon	-e	1321.2	$0.9x10^{-10}$	λ, π^-	$^{*}\Xi^+$ anti xi plus
	Ξ^0	xi zero cascad hyperon	0	1314.7	$1.0x10^{-10}$	λ, π^0	$^{*}\Xi^-$ anti xi zero
Mesons (Strongly Interacting Bosons) Spin = 0	π^+	pion	+e	139.6	$1.8x10^{-8}$	μ^+, ν_μ	π^- pi minus
	π^-	pi minus	-e	139.6	$1.8x10^{-16}$	μ^-, $^{*}\nu_\mu$	π^+ pi plus
	π^0	pi zero	0	135.0	$0.7x10^{-8}$	radiation	π^0 pi zero
	κ^+	kaon	+e	493.8	$0.8x10^{-8}$	μ^+, ν_μ ,π^+, π^-	κ^- K minus
	κ^-	k minus	-e	493.8	$0.8x10^{-8}$	μ^-, $^{*}\nu_\mu$,π^-, π^0	κ^+ K plus
	κ^0	k zero	0	497.8	$0.7x10^{-10}$ (fast mode) $4x10^{-8}$ (slow mode	$\pi^+\pi^-$, $2\pi^0$ 3 π^0, $\pi^+\pi^-\pi^0$ π^+ μ^- $^{*}\nu_\mu$, π^+ e π^- $\mu^+\nu_\mu$, π^- e^+	$^{*}\kappa^0$ anti K zero
	* κ^0	anti K zero	0	497.8	$0.7x10^{-10}$ (fast mode) $4x10^{-8}$ (slow mode	$\pi^+\pi^-$, $2\pi^0$ 3 π^0, $\pi^+\pi^-\pi^0$ π^+ μ^- $^{*}\nu_\mu$, π^+ e π^- $\mu^+\nu_\mu$, π^- e^+	κ^0 K zero
	ω	omega	0	782.852	$6.6\ x\ 10^{-23}$		ω

	J or Ψ	J particle	0	3096.66	1.0 10^{-10}		J or Ψ
	η	eta	0	548.8	< 10^{-16}	3 π^0. $\pi^0\pi^+\pi^-$ $\pi^+\pi^+$ + radiat radiation	η eta
ELEMENTARY PARTICLES							
Massless Bosons, Classons Spin = 1 $\hbar$	γ	photon	0	0	stable		(γ)
Spin = 2 $\hbar$	g	graviton	0	0	stable		(g)
Leptons (Weakly Interacting Fermions) Spin=1/2 $\hbar$	μ^-or μ^+	muon	-e	105.7	2.2 x 10^{-6}	e, ν_μ , $^*\nu_\mu$	μ^+or μ^-
	τ or τ^-	tau particles	-e		3.0 x 10^{-13}		
	ν_τ	tau neutrino		about 0	stable(?)		
	e^-	electron	-e	0.511	stable		e^+ positron
	ν_e	neutrino-electron	0	0	stable		$^*\nu_e$ antineutrino
	ν_μ	neutrino-muon	0	0	stable		$^*\nu_\mu$ mu antineutrino
	ν_τ	neutrino-tau	0	0	stable		$^*\nu_\tau$ tau antineutrino
Quarks	u	up	+2/3 e	310.177	stable		*u
	d	down	-1/3 e	310.177	stable		*d
	c	charm	+2/3 e	1481.9	?		*c
	s	strange	-1/3 e	504.868	?		*s
	t	top	+2/3 e	>51100	?		*t
	b	bottom	-1/3 e	5110	?		*b
Weakons	W^+, W^-	W particles	+e, -e,	81760	?		W^-, W^+
	Z^0	Z^0 particle	0	91980	?		

THE STANDARD MODEL

The standard model of elementary particle physics unifies the theory of electroweak interactions and quantum Chromo-Dynamics (QD). According to current conceptions, interactions are mediated by the exchange of vector Bosons. These are particles with spin 1. They are the photons in electromagnetic interactions. They are the gluons in strong interactions. They are the W^+, W^- and Z^0 bosons in weak interactions. The graviton is thought to mediate gravitational interactions.

Each of the interactions other than gravity is associated with a different type of charge: the electric charge, the weak charge, and the color or strong charge. A particle can be subject to a given interaction only if it carries its charge. The leptons and the quarks carry the weak charge. Quarks are electrically charged, as well as some leptons such as the electrons. The color charge is only carried by the quarks, but not by the leptons. Table 5 summarizes the properties of the three elementary interactions other than gravity.

Table 5. Forces of Nature according to the Standard Model.

	Gravity Force	Electroweak Force		Strong Force	
		Weak Force	Electromagnetic Force	Fundamental	Residual
Action target	Mass Energy	Flavor	Electric charge	Color charge	-
Experiencing particles	All	Quarks, Leptons	Electrically charged	Quarks, Gluons	Hadrons
Mediating particles	Graviton (unobserved)	W^+, W^-, Z^0	Photon γ	Gluons	Mesons

The W and Z Bosons have large rest masses of 82 and 92 GeV respectively. According to the uncertainty principle they can only exist for virtual times. The Heisenberg uncertainty principle relates the uncertainty in energy (E) and time (t) or the uncertainty in position (x) and momentum (p), through the Planck's constant ($\hbar$) as:

$$\begin{aligned} \Delta E\ .\ \Delta t &= \hbar = \frac{h}{2\pi} \\ \Delta p\ .\ \Delta x &= \hbar = \frac{h}{2\pi} \end{aligned} \tag{2}$$

The Planck's constant can be remembered through its product with the speed of light (c) as:

$$c.\hbar = 200\ [\text{MeV.fm}] \tag{3}$$

In fact, these particles exist in scattering high energy experiments virtually for very short times. The weak interaction therefore is of a very short range.

The rest mass of the photon is zero, correspondingly the range of the electromagnetic interaction is infinite.

The gluons, like the photons, have zero mass, but unlike the photons which carry no charge, they carry a *color* charge. Since they can interact with each other, this makes the strong interaction very short ranged.

QUANTUM MECHANICS

One of the tenets of modern physics is that atoms and the subatomic particles have wave properties. The Standard Model theory can mathematically describe the characteristics and interactions that are observed for these particles. Quantum Mechanics, where variables are broken into increments or parcels, is used to describe the physics of very small particles since some of their properties take on discrete values. For instance we can only find electric charges that are an integer multiples of the electron's charge.

The important quantum numbers of particles are:

1. Electric charge: Quarks may have $\pm\frac{2}{3}$ or $\pm\frac{1}{3}$ electron charges, but they only form composite particles with integer electric charge. All particles other than quarks have integer multiples of the electron's charge.

2. Color charge: A quark carries one of 3 color charges and a gluon $\frac{1}{2}\hbar$ carries one of 8 color-anticolor charges. All other particles are color neutral.

3. Flavor: Flavor distinguishes the quarks and the leptons from one another.

4. Spin: Spin is an important physical quantity. Large objects like the planets or marbles may have an angular momentum and a magnetic field because they spin. Since particles also appear to have their own angular momentum and small magnetic moments, this particle property was designated as spin. This could be misleading, since the particles are not actually spinning. Spin is quantized to half units of Planck's constant as: 0, $\frac{1}{2}\hbar$, $\hbar$ $\frac{3}{2}\hbar$, … .

CONSTITUTION OF MATTER

There are six types of particles including the electron, called leptons. The Standard Model accounts for the strong, weak, and electromagnetic interactions of the quarks and leptons, and thus explains the patterns of nuclear binding and decays.

In the Standard Model physicists have developed a theory that explains what the world is and what holds it together. It is a simple and comprehensive theory that explains all the hundreds of particles and complex interactions with only 6 quarks and 6 leptons; the best known lepton being the electron and force carrier particles, like the photon. The hundreds of particles are considered as made from a few fundamental particles: 6 quarks, 6 leptons, 6 antiquarks, 6 antileptons, and the force carriers.

All the known matter particles are considered as composites of quarks and leptons, and they interact by exchanging force carrier particles.

The Standard Model is a good theory with experiments that have verified its predictions, and all the particles predicted by this theory have been detected. However, gravity is not included in the Standard Model.

MATTER AND ANTIMATTER ANNIHILATION

In the standard model for every particle type there exists a corresponding antiparticle type. Particle and antiparticle have identical mass and spin but opposite charges. Some electrically neutral bosons such as the Z^0 are their own antiparticles.

Antiparticles look and behave just like their corresponding matter particles, except they have opposite charges. For instance, a proton is electrically positive whereas an antiproton is electrically negative. Gravity affects matter and antimatter in the same way because gravity is not a charged property and a matter particle has the same mass as its antiparticle.

When a matter particle and antimatter particle meet, they annihilate into pure energy. For instance an electron and its antimatter a positron, initially at rest, undergo the annihilation reaction:

$$ {}_{-1}e^{0} + {}_{+1}e^{0} \rightarrow \gamma(0.51MeV) + \gamma(0.51MeV) \tag{4}$$

However, the electron and positron colliding at high energy can produce two B^0 and ${}^{*}B^0$ mesons via a virtual Z boson or a virtual photon within a gluon field.

$$ {}_{-1}e^{0} + {}_{+1}e^{0} \xrightarrow[or\,Z]{\gamma} {}^{*}\mathrm{bd} + {}^{*}\mathrm{db} \xrightarrow{\text{gluon field}} \mathrm{B}^{0} + {}^{*}\mathrm{B}^{0} \tag{5}$$

The reaction of Eqn. 4 has its inverse reaction in the pair-production process where gamma photons with an energy exceeding two electron rest masses or 2 x 0.51 = 1.02 MeV are converted in to a negative electron of mass 0.511 MeV and a positron of the same mass:

$$ \gamma(1.02\,MeV) \rightarrow {}_{-1}e^{0}(0.51MeV) + {}_{+1}e^{0}(0.51MeV) \tag{6}$$

One can see evidence for antimatter in bubble chamber photographs. A magnetic field in this chamber makes negative particles curve left and positive particles curve right, according to the cross product in Lorentz Equation describing the force on a particle of charge q and velocity $\overline{\mathrm{v}}$ in an electric field E and magnetic field $\overline{B}$:

$$ \overline{F} = q\overline{E} + \frac{q}{c}\overline{\mathrm{v}} \times \overline{B} \tag{7}$$

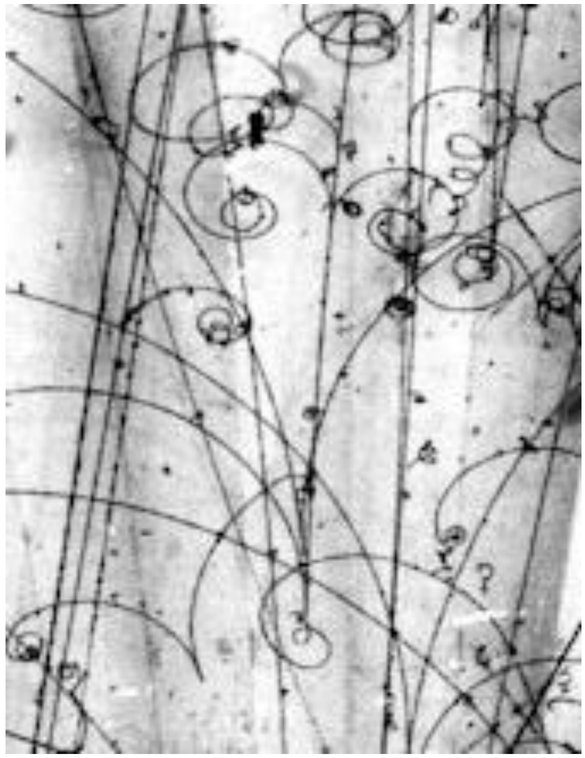

Figure 2. Bubble chamber tracks of electron-positrons pairs diverted in opposite directions along a magnetic field perpendicular to the page.

Many electron-positron pairs appear generated by gamma ray photons with an energy exceeding 1.02 MeV or two electron masses, which do not leave a trail, but are transformed into an electron positron pair. Positrons behave just like the electrons but curve in the opposite direction because they have the opposite charge.

A question that remains under investigation is if antimatter and matter are exactly equal but opposite, then why is there so much more matter in the universe than antimatter? It is suggested that there may exist other antimatter universes undetectable to us. If an antimatter and a matter universe would collide, a conflagration such as the Big Bang could be surmised to occur.

PARTICLES SPIN

Spin is the intrinsic angular momentum of particles. It is given in units of:

$$\hbar = \frac{h}{2\pi} = 6.58 \times 10^{-25} [\text{GeV.sec}] = 1.05 \times 10^{-34} [\text{Joule.sec}] \qquad (8)$$

which is the quantum unit of angular momentum.

Electric charges are measured in units of the proton's charge. In the SI system of units, the electric charge of the proton is 1.60 x 10^{-19} Coulombs.

The energy unit of particle physics is the electron volt (eV), the energy gained by one electron being accelerated in an electric field through a potential difference of one Volt. Masses are given in energy equivalent units of MeV or GeV where:

$$1 \text{ MeV} = 10^{6} \text{ eV} = 1.60 \times 10^{-13} \text{ Joule}$$

The mass energy equivalent of the proton is 938 MeV = 1.67×10^{-27} kg.

Quarks only exist in groups with other quarks and are never found alone. Composite particles made of quarks are called the Hadrons.

THE HADRONS

Although individual quarks have fractional electrical charges, they combine such that the hadrons have a net integer electric charge. Another property of hadrons is that they have no net color charge even though the quarks themselves carry color charge. A unique property of the Hadrons is that only a very small part of the mass of a hadron is due to the quarks in it.

Hadrons such as two protons can interact in high energy reactions producing an assortment of other hadrons plus very high mass particles such as the Z^0 bosons. Such events can yield clues in experiments in particle accelerators about the structure of matter:

$$p + p \xrightarrow{\text{quarks and gluons}} Z^0 + Z^0 + hadrons$$

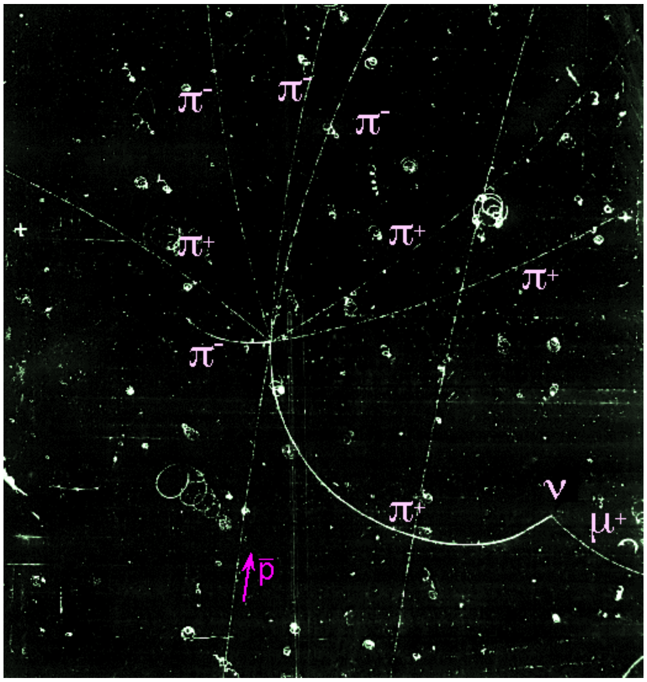

Figure 3. Bubble chamber photograph of an incoming antiproton and a stationary proton annihilation.

There are two classes of hadrons: the baryons and the mesons:

THE BARYONS

The baryons are fermionic hadrons which is made of three quarks qqq or three antiquarks. There exist about 120 different types of baryons. Because they are made of two up quarks and one down quark (uud), protons and are baryons, as well as the neutrons (udd).

Table 6. Baryons and antibaryons.

Name	Symbol	Quark composition	Electric charge	Mass energy equivalent [MeV]	Spin
Proton	p	uud	1	938	½
Antiproton	$^*p$	$^*u^*u^*d$	-1	938	½
Neutron	n	udd	0	940	½
Lambda	Λ	uds	0	1,160	½
Omega	Ω^-	sss	-1	1,672	1/2

THE MESONS

Mesons are bosonic hadrons composed of one quark q and one antiquark $^*q$ pair. There exist about 140 different meson types. An example of a meson is a pion π^+, which is made of an up quark and a down antiquark. The antiparticle of a meson has its quark and antiquark switched, so an anti-pion π^- is composed of a down quark and an up antiquark.

Since a meson consists of a particle and an antiparticle, it is quite unstable. The kaon κ^+ meson lives much longer than most mesons, which is why it was designated as “strange” and it gave this name to the strange quark, one of its components.

Table 7. Some types of mesons as bosonic hadrons.

Name	Symbol	Quark composition	Electric Charge	Mass equivalent [MeV]	Spin
Pion	π^+	$u\,^*d$	+1	140	0
Kaon	K^-	$s\,^*u$	-1	494	0
Rho	ρ^+	$u\,^*d$	+1	770	1
B zero	B^0	$d\,^*b$	0	5,279	0
Eta c	η_c	$c\,^*c$	0	2,980	0

THE LEPTONS

There exist six leptons, three of which have electrical charge and three of which do not have a charge. They appear as point like particles without an internal structure. The best known lepton is the electron e^-. The other two charged leptons are the muon μ, which was discovered in 1936, and the tau τ particles, which are charged like electrons but have a larger mass and were discovered in 1975. They differ from the electron only in that they are more massive.

The other leptons are the three types of neutrinos ν. They have no electrical charge, very little mass, and they are hard to detect. There is one type of neutrino corresponding to each type of electrically charged lepton. For each of the six leptons there is an anti lepton with equal mass and opposite charge.

Quarks only exist in composite particles with other quarks, whereas leptons are solitary particles. An animal world analogy is to think about the quarks as elephants which can be found as a herd, the charged leptons as independent cats with associated neutrino fleas, which are very hard to see.

For each lepton there is a corresponding antimatter anti lepton. The anti electron has the special name of positron.

LEPTONS DECAYS

The heavier leptons, the muon and the tau, are not found in ordinary matter. This is because when they are produced they very quickly decay into lighter leptons. Sometimes the tau lepton will decay into a quark, an antiquark, and a tau neutrino.

Electrons and the three kinds of neutrinos are stable and thus they can be observed.

Whenever a heavy lepton decays, one of the particles it decays to is always its corresponding neutrino. The other particles could be a quark and its antiquark, or another lepton and its antineutrino.

Some types of lepton decays are energetically possible and some are not. In order to explain this, the leptons are classified into three lepton families: the electron and its electron-neutrino, the muon and its muon-neutrino, and the tau and its tau-neutrino. The number of members in each family remains constant in a decay: a particle and an antiparticle in the same family cancel out to make the total of them equal zero.

LEPTON CONSERVATION

The terms “electron number,” “muon number,” and “tau number” are used to refer to the lepton family of a particle. Electrons and their neutrinos have an electron number of +1, positrons and their antineutrinos have an electron number of -1, and all other particles have an electron number of 0. The muon number and the tau number operate analogously with the other two lepton families.

Although leptons are solitary, they are always loyal to their families. For leptons, the electron number, muon number, and tau number are always conserved when a massive lepton decays into smaller ones.

In the following muon decay, the electron, muon and tau numbers are conserved:

$$\mu \rightarrow \nu_\mu + {}_{-1}e^0 + {}^*\nu_e$$

muon $\rightarrow$ muon neutrino+electron+electron antineutrino

		(9)
Eletron number	$0 \rightarrow 0 + 1 + -1$	
Muon number	$1 \rightarrow 1 + 0 + 0$	
Tau number	$0 \rightarrow 0 + 0 + 0$	

These and other conservation laws define whether or not a given lepton decay is possible.

NEUTRINOS

Neutrinos are a type of lepton. Since they have no electrical or strong charge they almost never interact with any other particles. Most neutrinos pass right through the Earth without substantially interacting with it.

Neutrinos are produced in many interactions, particularly in particle decays. It was through a careful study of the process of radioactive decay that the neutrino's existence was hypothesized. In a radioactive nucleus, a neutron at rest with zero momentum decays, releasing a proton, an electron and an antineutrino:

$${}_0n^1 \rightarrow {}_1H^1 + {}_{-1}e^0 + {}^*\nu_e \qquad (10)$$

Internally within the neutron a down quark changes to an up quark, and with the intermediary of a virtual or mediating W$^-$ boson results into an electron and an electron antineutrino:

$${}_0n^1(\text{udd}) \xrightarrow{W^-} {}_1H^1(\text{udu}) + {}_{-1}e^0 + {}^*\nu_e \qquad (10)'$$

Since the charge of the up u quark is +2/3 and the charge of the down d quark is –1/3, the charge of the neutron is:

$$+ 2/3 – 1/3 – 1/3 = 0,$$

whereas the charge of the proton is:

$$+ 2/3 – 1/3 + 2/3 = 1.$$

Because of the law of conservation of momentum, the resulting products of the decay must have a total momentum of zero, which the observed proton and electron clearly do not possess. Therefore, one needs to infer the presence of another particle with appropriate momentum to balance the event. An electron antineutrino conserves momentum and its occurrence was confirmed experimentally.

Neutrinos were produced in great abundance in the early universe and rarely interact with matter. It is believed that they are numerous in the universe. Their small mass but large numbers are thought to contribute to the total mass of the universe and could explain the presence of the dark matter that is thought to affect its expansion.

FORCES AND INTERACTIONS

The forces holding the elementary particles building blocks of matter together are due to the underlying interactions of the particles. These interactions come in 4 types: gravitational, electromagnetic, strong, and weak.

Gravity is the most familiar force but it is not included in the Standard Model because its effects are imperceptible in particle processes and the theoreticians are still trying to account for it, possibly through String Theory.

Electromagnetic forces are familiar and are responsible for binding the electrons to the nucleus to form electrically neutral atoms. Atoms combine to form molecules or crystals because of electromagnetic effects due to their charged substructure. Most common forces, such as the support of the floor or friction, are due to the electromagnetic forces in matter that resist displacement of atoms or electrons from their equilibrium positions in the materials.

In particle processes, the forces are described as due to the exchange of particles. For each type of force there is an associated force carrier particle. The carrier particle of the electromagnetic force is the photon. Gamma ray is the name given to a photon resulting from a nuclear transition.

At distances much larger than the size of an atomic nucleus, the remaining two forces have only small effects, so they are not noticed in everyday life. However, they are depended upon for the existence of all the components from which the world is made of, and for the decay processes that make some types of matter unstable.

The strong force holds the quarks together to form hadrons. Its force carrier particles are called gluons because they so successfully glue the quarks together. The binding of protons and neutrons to form nuclei is a residual strong interaction effect due to their strongly interacting quark and gluon constituents. The leptons have no strong interactions.

The weak interaction force is the only process in which a quark can change to another type of quark, or a lepton to another lepton. It is responsible for the fact that all the more massive quarks and leptons decay to produce lighter quarks and leptons. This is the reason why stable matter contains only electrons and the lightest two up and down quark types. The carrier particles of weak interaction are the W and Z bosons. Beta decay of nuclei was the first observed weak process: in a nucleus where there is sufficient energy for a neutron to become a proton giving off an electron and an electron antineutrino. This decay changes the atomic number of the nucleus and consequently its chemical nature. Beta rays was the name given to the emerging electrons.

Table 8. Properties of the Interactions and the forces of nature.

	Gravitational Force	Electroweak		Strong Force	
		Weak Force	Electromagnetic Force	Fundamental	Residual
Action	Mass/Energy	Flavor	Electric charge	Color change	-

Particles experiencing force	All	Quarks, Leptons	Electrically charged	Quarks, Gluons	Hadrons
Mediating particles	Graviton (postulated)	W^+, W^-, Z^0	Photons γ	Gluons	Mesons
Strength relative to electromagnetic force					
Two up quarks at $1x10^{-18}$ m	10^{-41}	0.8	1	25	Inapplicable to hadrons
Two up quarks at $3x10^{-17}$ m	10^{-41}	10^{-4}	1	60	Inapplicable to hadrons
Two protons in nucleus	10^{-38}	10^{-7}	1	Inapplicable to hadrons	20

The processes of alpha decay and fission result from the breakup of a massive nucleus into smaller nuclei. This occurs when the sum of the masses of the smaller nuclei is less than the mass of the parent nucleus. This is a residual strong interaction effect. The strong binding of color neutral protons and neutrons to form nuclei is due to the residual strong interactions between their color-charged constituents. It is similar to the residual electrical interaction which binds electrically neutral atoms to form molecules. It can also be viewed as the exchange of mesons between the hadrons.

QUARKS CONFINEMENT IN MESONS AND BARYONS

The quarks and gluons cannot be isolated and they are confined in color neutral particles called the hadrons. This confinement or binding results from multiple exchanges of gluons among their color charged constituents. As the color charged particles of quarks and gluons move apart, the energy in the color force between them increases. This energy eventually is converted into additional quark antiquark pairs. The quarks and antiquarks then combine into hadrons which are the particles seen to emerge. Two types of hadrons have been observed in nature: mesons q, *q and baryons qqq.

MATTER GENERATIONS

Both quarks and leptons exist in three distinct sets. Each set of quark and lepton charge types is called a generation of matter with charges of +2/3, -1/3, 0, and -1 as one goes down each generation. The generations are organized in order of increasing mass.

All visible matter in the universe is made from the first generation of matter particles: up quarks, down quarks, and electrons. This is so because all second and third generation particles are unstable and quickly decay into stable first generation particles.

Table 9. Generations of matter.

	Generation I	Generation II	Generation III
Quarks	Up u	Charm c	Top t
	Down d	Strange s	Bottom b
Leptons	Electron neutrino ν_e	Muon neutrino ν_μ	Tau neutrino ν_τ
	Electron $_{-1}e^0$	Muon μ	Tau τ

The higher generations of matter decay quickly, are rarely observed, and do not make up any of the stable matter around us. When the muon was discovered the physicist I. I. Rabi asked the question: “So why do we have generations of matter at all?”

It is not known why there are only three generations. There possibly are more of them and one cannot rule out the possibility that there are yet more quarks and leptons that were not yet discovered. Another possibility is that quarks and leptons are not fundamental, but are made up of even more elementary particles whose composite particles we observe as quarks. String Theory tries to address this issue only theoretically, since it cannot be verified experimentally at the current state of knowledge.

FORCES AND INTERACTIONS

The universe exists because the fundamental particles interact. These interactions include attractive and repulsive forces, decay, and annihilation.

There are four fundamental interactions between particles, and all forces in the world can be attributed to these four interactions including friction, magnetism, gravity, and nuclear decay.

A force is considered as the effect on a particle due to the presence of other particles. The interactions of a particle include all the forces that affect it, but also include the decays and annihilations that the particle might undergo.

Most people use the terms “force” and “interaction” interchangeably, although they are different. For instance, we call the particles which carry the interactions: force carrier particles.

If we observe two people standing on an ice pond and one person moves their arm and is pushed backwards. A moment later, the other person grabs an invisible object and is driven backwards. Even though we cannot see a ball thrown from one person to the other, one can assume that one person threw a ball to the other person because we see its effect on him.

All interactions which affect matter particles are due to an exchange of different force carrier particles. These particles are like balls tossed between matter particles.

What we normally think of as forces are nothing but the effects of force carrier particles on matter particles.

The analogy can only explain repulsive forces and gives no hint of how the exchange of particles can result in attractive forces.

Attractive forces occur in everyday life, such as magnetism and gravity, and so we generally take it for granted that an object's presence can just affect another object without necessarily touching each other.

The force of one particle acting on another can be attributed to the exchange of force carrier particles. A particular force carrier particle can only be absorbed or produced by a matter particle which is affected by that particular force. Electrons and protons have electric charge, so they can produce and absorb the electromagnetic force carrier, the photon. Neutrinos have no electric charge and they cannot absorb or produce photons.

ELECTROMAGNETIC FORCE

The electromagnetic force causes like-charged objects to repel and oppositely-charged objects to attract. Many common forces, such as friction and magnetism, are caused by the electromagnetic force. As an example, the force that keeps a person from falling through the floor is the electromagnetic force which causes the atoms making up the matter in the floor and the person's feet to resist displacement.

The carrier particle of the electromagnetic force is the photon γ. The photons of different energies span the electromagnetic spectrum of gamma rays, x rays, visible light, microwaves and radio waves.

Photons have zero mass at the present state of knowledge and travel at the speed of light c, which is in a vacuum about 3×10^{10} cm/sec, or 186,000 miles / second.

RESIDUAL ELECTROMAGNETIC FORCE

Neutral atoms usually have the same numbers of protons and electrons and the positive protons cancel out the negative electrons.

Even though they are neutral, what causes them to form molecules is that the charged parts of one atom can interact with the charged parts of another atom. This allows different atoms to bind together, an effect designated as the residual electromagnetic force.

In this case the electrons in one atom or a molecule are attracted to the protons in the other atom, and vice versa, even though the atoms are electrically neutral.

Thus, the electromagnetic force is what allows atoms to bond and form molecules, allowing the world to stay together. The structures of the world exist because protons and electrons possess atractive opposite charges.

THE STRONG FORCE

The strong force holds quarks together to form hadrons, so its carrier particles are whimsically called gluons because they so tightly glue the quarks together.

The quarks make up the protons and neutrons in the nucleus. The quarks have an electromagnetic charge, and they also have an altogether different kind of charge called the color charge. The force between color charged particles is very strong, so this force is called the strong force.

The color charge behaves differently than the electromagnetic charge. The gluons themselves have a color charge, unlike the photons which do not have an electromagnetic charge. While the quarks have a color charge, composite particles made out of quarks have no net color charge and they are color neutral. Consequently, the strong force only takes place on the really short distance level of quark interactions, making them invisible in everyday's life.

COLOR CHANGE

The quarks and gluons are color charged particles. Just as electrically charged particles interact by exchanging photons in the electromagnetic interactions, color-charged particles exchange gluons in the strong interactions.

Table 10. Color and anti-color charges.

Quarks, color	Red	Green	Blue
Antiquarks, Anti-color	Anti-red	Anti-green	Anti-blue
Gluons	Eight combinations of color and anti-color.		

When two quarks get close to one another, they exchange gluons and create a very strong color force field that binds the quarks together. The force field gets stronger as the quarks get further apart. Quarks constantly change their color charges as they exchange gluons with other quarks.

There exist three color charges and three corresponding anti-color or complementary color charges. Each quark has one of the three color charges and each antiquark has one of the three anti-color charges. Just as a mix of red, green, and blue light yields white light, in a baryon a combination of red, green, and blue color charges is color neutral, and in an antibaryon anti-red, anti-green, and anti-blue is color neutral too.

The mesons are color neutral because they carry combinations such as red and anti-red.

Since gluon emission and absorption always changes color, and color is a conserved quantity, gluons can be thought of as carrying a color and an anti-color charge. There are nine possible color anti-color combinations and one might expect nine different gluon charges. The mathematics works out that there are only eight such combinations.

It must be noted that color charge has nothing to do with the visible colors, it is just a convenient naming convention for a mathematical system physicists developed to explain their observations about the quarks in the hadrons.

QUARK CONFINEMENT

Color-charged particles are not found individually. The color-charged quarks are confined in groups with other quarks as hadrons composites which are color neutral.

The Standard Model theory of the strong interactions reflected the evidence that quarks combine only into baryons or three quark objects, and mesons which are a quark and anti-quark objects, but not, for example, four-quark objects.

Only baryons with three different colors and mesons with color and anti-color are color neutral. Particles such as ud or uddd that cannot be combined into color neutral states are never observed.

COLOR FORCE FIELD

The quarks in a given hadron exchange gluons at a high frequency. For this reason, physicists talk about the color force-field which consists of the gluons holding the bunch of quarks together.

If one of the quarks in a given hadron is pulled away from its neighbors, the color force field stretches between that quark and its neighbors. In so doing, more and more energy is added to the color force field as the quarks are pulled apart. At some point, it is energetically cheaper for the color force field to snap into a new quark antiquark pair:

$$^{*}cc \xrightarrow{Snapping} {}^{*}cd + {}^{*}dc \tag{11}$$

In the process, energy is conserved because the energy of the color force field is converted into the mass of the new quarks, and the color force field can relax back to an un-stretched state.

The quarks cannot exist individually because the color force increases as they are pulled apart.

GLUONS EMISSION BY QUARKS

Color charge is always conserved. When a quark emits or absorbs a gluon, that quark's color must change in order to conserve color charge. For instance, suppose a red quark changes into a blue quark and emits a red and anti-blue gluon. The net color is still red.

This is so because, after the emission of the gluon, the blue color of the quark cancels with the anti-blue color of the gluon. The remaining color then is the red color of the gluon.

The quarks emit and absorb gluons very frequently within a hadron, so there is no way to observe the color of an individual quark. Within a hadron, on the other hand, the color of the two quarks exchanging a gluon will change in a way that keeps the bound system in a color-neutral state.

RESIDUAL STRONG FORCE

The strong force binds the quarks together because the quarks have a color charge. This does not explain what holds the nucleus together, since positive protons repel each other with the electromagnetic force, and the protons and neutrons are color neutral.

What holds the nucleus together is that the strong force between the quarks in one proton and the quarks in another proton is strong enough to overwhelm the repulsive electromagnetic force between the protons.

This is called designated as the residual strong interaction, and it is what glues the nucleus together.

THE WEAK FORCE

There exist 6 kinds of quarks and 6 kinds of leptons. However, the stable matter of the universe appears to be made of the two least massive quarks: the up u quark and the down d quark, the least massive charged lepton; the electron, and the neutrinos.

Weak interactions are responsible for the decay of the massive quarks and leptons into lighter quarks and leptons. When fundamental particles decay, it is observed that the vanishing particle is replaced by two or more different particles. Although the total of mass and energy is conserved, some of the original particle's mass is converted into kinetic energy, and the resulting particles always have less mass than the original particle that decayed.

The only matter that is stable is made up of the smallest quarks and leptons, which cannot decay any further, suggesting an irreversible process increasing the entropy of the universe.

FLAVOR CHANGE

Flavor changes are due to the weak interaction. When a quark or lepton changes type such as a muon changing into an electron, it is said to change flavor.

The carrier particles of the weak interactions are the W^+, W^- particles, which are electrically charged and the Z particles which are neutral.

THE ELECTROWEAK FORCE

The Standard Model has united the electromagnetic interactions and the weak interactions into one unified interaction under the unified electroweak theory.

Physicists had long suspected that the weak forces were closely related to the electromagnetic forces. They eventually discovered that at very short distances of about 10^{-18} meters, the strength of the weak interaction is comparable to that of the electromagnetic one.

On the other hand, at thirty times that distance or 3×10^{-17} m, the strength of the weak interaction is a factor of 10^{-4} that of the electromagnetic interaction. At distances typical for quarks in a proton or a neutron at 10^{-15} m the force is even smaller.

The conclusion is that the weak and the electromagnetic forces have essentially equal strengths. That is because the strength of the interaction depends strongly on both the mass of the force carrier and the distance of the interaction. The difference between their observed strengths is due to the large difference in mass between the W and Z particles, which are very massive, and the photon, which has no mass.

GRAVITY FORCE

Gravity is one of the fundamental interactions, but the Standard Model does not include it. This is still an unanswered problem in physics that String Theory tries to answer.

The theorized gravity force carrier particle: the graviton, has not been experimentally observed. It is predicted to exist and may someday be observed.

The effects of gravity are extremely small in most particle physics situations compared to the other three interactions, so theory and experiment can be compared without including gravity in the calculations, resulting in the Standard Model working without having to include gravity.

FERMIONS AND BOSONS

PAULI'S EXCLUSION PRINCIPLE

The quantum particle properties can be used to classify the particles that are observed. At one time, physicists thought that no two particles in the same quantum state could exist in the same place at the same time. This is called the Pauli Exclusion Principle, and it explains many chemical interactions.

However, it has been since discovered that a certain group of particles do not obey this principle. Particles that do obey the Pauli Exclusion Principle are called fermions, and those that do not are called bosons.

Fermions do not share the same locations and also seek them as far as possible from each other. On the other hand, bosons share the same positions.

The nucleus of an atom is either a fermion or boson depending on whether the total number of its protons and neutrons is odd or even, respectively. This causes some strange behavior in certain atoms under unusual conditions, such as cryogenic He.

Table 11. Comparison of the properties of the fermions and the bosons.

Fermions Odd A		Bosons Even A	
Particle	Spin	Particle	Spin
Lepton	1/2	Force carriers Postulated graviton	1 2
Quark	1/2		
Baryons (qqq)	1/2 , 3/2 , 5/2, …	Mesons (*qq)	0, 1, 2, …

FERMIONS

A fermion is any particle that has an odd half-integer spin such as: 1/2, 3/2, 5/2, … . Quarks and leptons, as well as most composite particles, like protons and neutrons, are fermions.

An unexplained consequence of the odd half-integer spin is that the fermions obey the Pauli Exclusion Principle and therefore cannot coexist in the same state at the same location and at the same time.

Table 12. Fermions include the quarks and the leptons.

Quarks Spin=1/2				Leptons Spin=1/2			
Flavor		Mass [GeV]	Electric Charge	Flavor		Mass [GeV]	Electric charge
Up	u	0.003	2/3	Electron neutrino	ν_e	$<1.0\times10^{-8}$	0
Down	d	0.006	-1/3	Electron	e	0.000511	-1
Charm	c	1.3	2/3	Muon neutrino	ν_μ	<0.0002	0
Strange	s	0.1	-1/3	Muon	μ	0.106	-1
Top	t	175	2/3	Tau neutrino	ν_τ	<0.02	0
Bottom	b	4.3	-1/3	Tau	τ	1.7771	-1

BOSONS

Bosons are those particles which have an integer spin such as: 0, 1, 2, ... The force carrier particles are bosons, as are those composite particles with an even number of fermion particles like the mesons. The postulated graviton force carrier is presumed to have a spin of 2.

Table 13. Bosons including the force carriers and integer spin particles.

Unified electroweak Spin =1			Strong color Spin=1		
Name	Mass [GeV]	Electric charge	Name	Mass [GeV]	Electric charge
Photon γ	0	0	Gluon g	0	0
W^-	80.4	-1			
W^+	80.4	+1			
Z^0	91.187	0			

PARTICLE DECAYS

The strong, electromagnetic, and weak interactions cause the particles to undergo decays.

WEAK DECAYS

Only the weak interactions can cause the decay of the fundamental particles into other types of particles. Particle types are referred to as “flavors.” The weak interaction can change a charm flavor quark into a strange flavor quark while emitting a virtual W boson. Only the weak interaction via the W boson can change flavor and allow the decay of a truly fundamental particle.

ELECTROMAGNETIC DECAYS

The neutral pion π^0 is a *qq meson. As an example of an electromagnetic decay, is the quark and the antiquark in the pion annihilating into two photons.

STRONG DECAYS

The η_c particle is a *cc meson and can undergo a strong decay into two gluons which emerge as hadrons.

Table 14. Interaction mediators and end result.

Interaction	Mediator	End Result
Strong	Gluon	Color change No electric charge change
Weak	W^+or W^-	Electric charge change No color change

The strong force carrier particle, the gluon, mediates decays involving color changes. The weak force-carrier particles, W^+ and W^-, mediate decays in which particles change flavor and electric charge.

DARK ENERGY, DARK MATTER AND NEUTRALINOS

In the static model of the Universe, all the heavenly bodies are at fixed distances from one another. But given the gravitational attraction between these bodies what keeps them from collapsing into each other? The answer should be a cosmos pervading repulsive force, “dark energy,” which acts as antigravity repulsive force holding everything in place.

The discovery by the astrophysicist Hubble in 1927 that the Universe is not static but that the galaxies are flying away from each other at a rate proportional to the distances between them, suggests a dynamic Universe. The concept of the repulsive force was no longer needed. However the rate of expansion was found to be slower than could be predicted from the visible matter. So the concept of dark matter and dark energy has to be reintroduced in the dynamic model of the Universe.

As scientists probe deeper into the Universe, they have come to believe that the bulk of it consists of an invisible substance: dark matter. This dark matter even though predicted theoretically to explain the expansion of the Universe, is hard to detect. While the Antarctic muon and neutrino detector might detect dark matter indirectly, an experiment called Zeplin, tried to detect what could be the essence of dark matter in the form of neutralinos. The neutralino is a prime candidate in the so-called zoo of subatomic particles that are thought to be the source of dark matter.

Leading the effort is the UK Dark Matter Collaboration, which conducted an experiment designated as Zeplin I, below more than 1 kilometer below the Earth's surface at the Boulby's mine. The result remains negative.

Neutralinos would belong to the family of particles designated as Weakly Interactive Massive Particles, or Wimps. They rarely interact with other forms of matter, and are accordingly hard to detect. Once in a while, a neutralino undergoes a collision with a conventional atom, which scientists are trying to detect in the Zepelin experiment. Zepelin I is a vat of liquid xenon weighing 10 kgs. If a neutralino collides with a xenon atom in the detector, a flash of light is expected to be emitted from the recoiled xenon atom. The shape and speed of the light pulse would identify the colliding particle as a neutralino.

Larger detectors are in the planning stage. Their goal is to improve the probability of neutralinos detection by a factor of 100.

Some theoreticians believe that neutralinos accumulate at the center of the Earth trapped by gravity. As their density increases, they would collide, annihilating each other and giving off neutrinos. The neutrino detection experiments for neutrinos coming from the center of the Earth would be an indication of dark matter annihilation.

In 1997 the Hubble space telescope captured by chance the light from the farthest supernova ever observed. It exploded 11 billion years ago. A team under Adam G. Reiss at the Telescope Science Institute in Baltimore analyzed the brightness of the light from the supernova. An intricate chain of reasoning led to the conclusion in April of 2001 that dark energy indeed exists.

The implications are staggering. Are there other universes right around us? Can we travel to those other universes using say, wormholes? Can dark matter be used as an energy supply on Earth or for space travel and colonization? Will life on Earth escape its aged and vulnerable Earth to spread in space and time using dark energy and matter as its energy source? This is a cosmological fertile field of study for the new generation of engineers and scientists. One can only dream about the vast implications of the existence of dark matter.

SUPER STRING THEORY

Two pillars of twentieth theory physics are Quantum Mechanics and General Relativity. Each theory works nicely within its own realm. Quantum mechanics deals with the small scale of elementary particles, and General Relativity covers the large scale of gravitational forces. However, when it comes to studying the behavior of a cosmological object that is small in size but really massive, such as a black hole, the two theories cannot be reconciled.

String theory is an attempt at reconciling these two theories. It possesses two important tenets:

1. Everything in the universe is composed of an unimaginably small loop of string.

A proton is composed of three of these strings. An electron is composed from just one string. Nothing can be smaller than a string, and everything is built out of strings. Each of these strings is so infinitesimally small that they appear as particles. This is thought to be the reason we have not noticed them before. It does not seem possible to be able to detect them with our existing technology. We can infer their existence only theoretically.

2. String Theory suggests a 10-dimensional universe:

Our everyday world is three-dimensional. With special relativity, including time, it can be considered as 4-dimensional. The other six dimensions are considered as curled up inside the other four. The analogy is looking at a garden hose. From a distance, it appears one-dimensional. Upon close inspection, it is in fact two-dimensional since in fact it is cylindrical with an axial dimension and a radial dimension. In 1919, the mathematician Theodor Kaluza introduced the concept of a universe of more than 4 dimensions. Michael Green and John Schwartz in 1984 suggested that String Theory could resolve the conflict between Quantum Mechanics and General Relativity.

This theory is still surrounded with controversy. String Theory may provide a Theory of Everything; the Holy Grail of our understanding of the Universe.

DISCUSSION

The Standard Model answers many of the questions of the structure and stability of matter with its six types of quarks and six types of leptons for a total of 12 elementary particles, and the 4 force types.

However the Standard Model leaves many other questions unanswered concerning the reason for the existence of three types of quarks and leptons of each charge, the possible existence of some pattern to their masses, the existence of more types of particles and forces to be discovered at yet higher-energy accelerators, whether or not the quarks and leptons are really fundamental particles or the existence of a still smaller substructure, how can the gravitational interactions be included in the model, and what particles, possibly the neutrinos and antineutrinos, form the dark matter of the Universe.

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