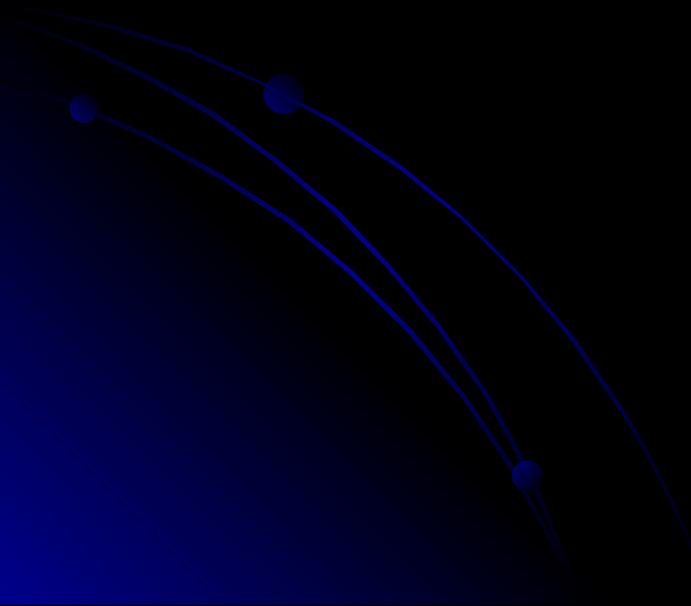


SCH4U1 Research Project

Subatomic Particles

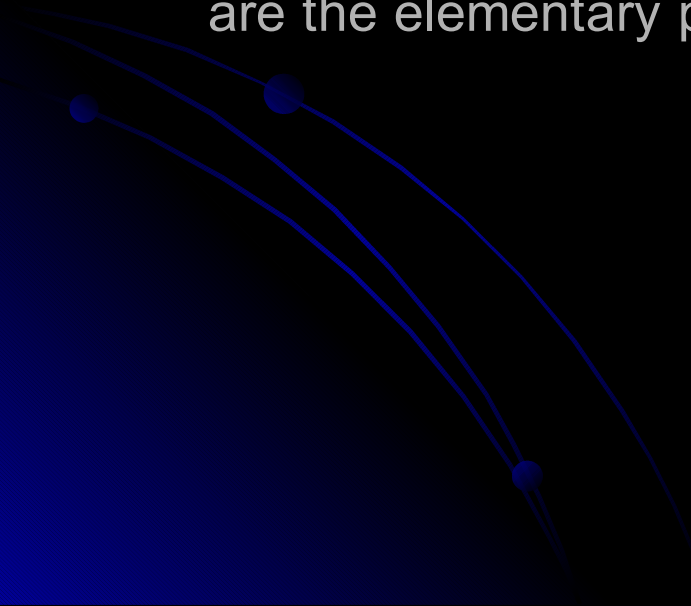
Fundamental Particles

Presented by: Amila De Silva



What are Fundamental Particles?

In particle physics and chemistry, an elementary particle or fundamental particle is a particle not known to have substructure (it is not made up of smaller particles). If an elementary particle truly has no substructure, then it is one of the basic particles of the universe from which all larger particles are made. In the modern theory of particle physics, the Standard Model, quarks, leptons and gauge bosons are the elementary particles.




Brief history of the Standard Model

460 - 370 B.C. - Democritus develops the theory that the universe consists of empty space and an (almost) infinite number of very small indivisible particles called atoms.

1898 - Joseph Thompson measures the electron, and puts forth his "plum-pudding" model of the atom - that the atom is a slightly positive sphere with small, raisin-like negative electrons inside.

1911-13 - Ernest Rutherford infers the nucleus as the result of the alpha-scattering experiment. Bohr develops a model of the atom with electron orbits at discrete radii.



Brief history of the Standard Model

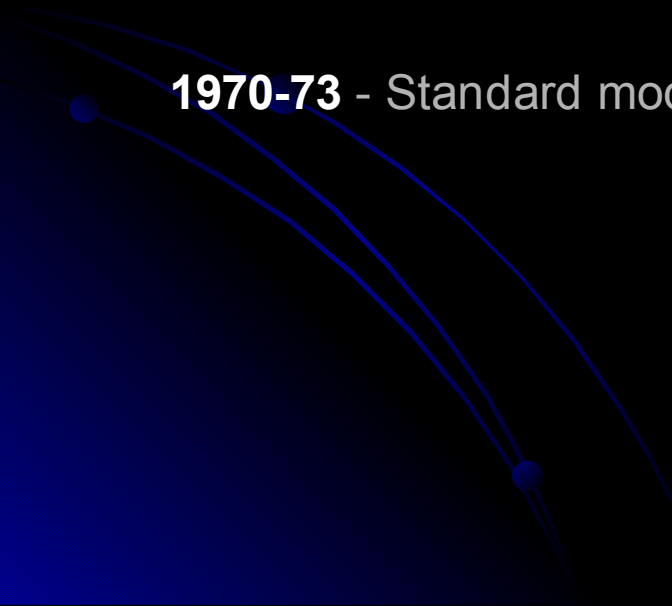
1925 - Heisenberg creates his uncertainty principle, which puts limits on the precision of experimentation

1926 - Erwin Schrödinger develops wave mechanics. Max Born gives a probability interpretation of quantum mechanics.

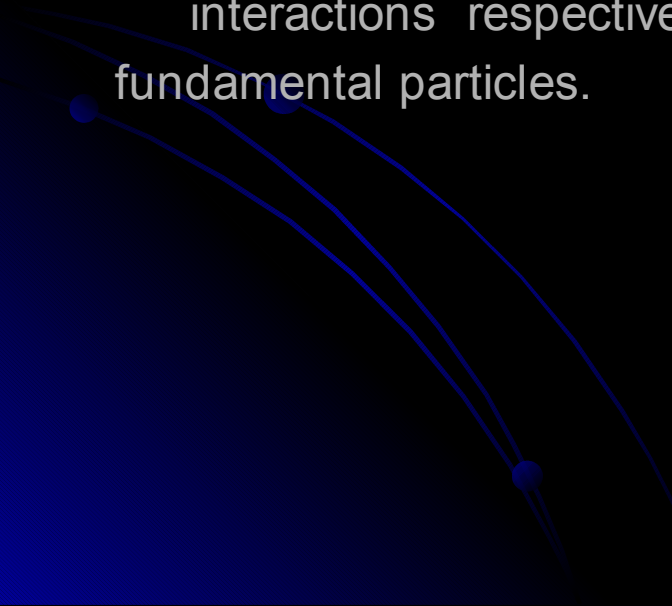
1932 - James Chadwick discovers the neutron.

1964 - Quarks are proposed by Murray Gell-Mann and George Zweig

1970-73 - Standard model of particle physics is developed



Types of Fundamental Particles

- In the modern particle theory there are 12 fundamental matter particle types and their corresponding antiparticles.
 - The matter particles divide into two classes: quarks and leptons. There are six particles of each class and six corresponding antiparticles.
 - In addition, there are gluons, photons, W and Z bosons, which are the force carrier particles responsible for strong, electromagnetic, and weak interactions respectively. These force carriers are also considered fundamental particles.
- 

Types of Fundamental Particles

The 12 fundamental particles are divided into three generations of four particles each. Six of the particles are quarks. The remaining six are leptons, three of which are neutrinos, and the remaining three of which have an electric charge of -1 : the electron and its two cousins, the muon and the tau lepton.

	I	II	III	
Leptons	u	c	t	γ
	d	s	b	g
	ν_e	ν_μ	ν_τ	Z
	e	μ	τ	W
Quarks				Force Carriers
Three Generations of Matter				

Particle Generations

First generation

electron: e^-

• electron-neutrino: ν_e

• down quark: d

• up quark: u

Second generation

muon: μ^-

• muon-neutrino: ν_μ

• strange quark: s

• charm quark: c

Third generation

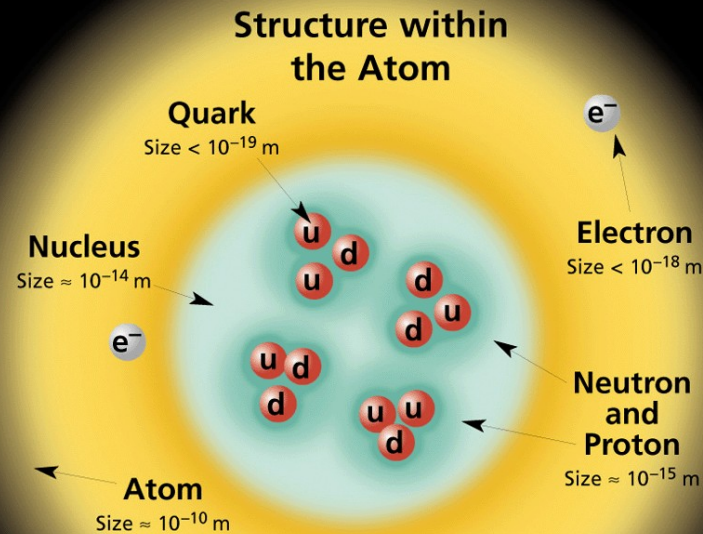
tau lepton: τ^-

• tau-neutrino: ν_τ

• bottom quark: b

• top quark: t

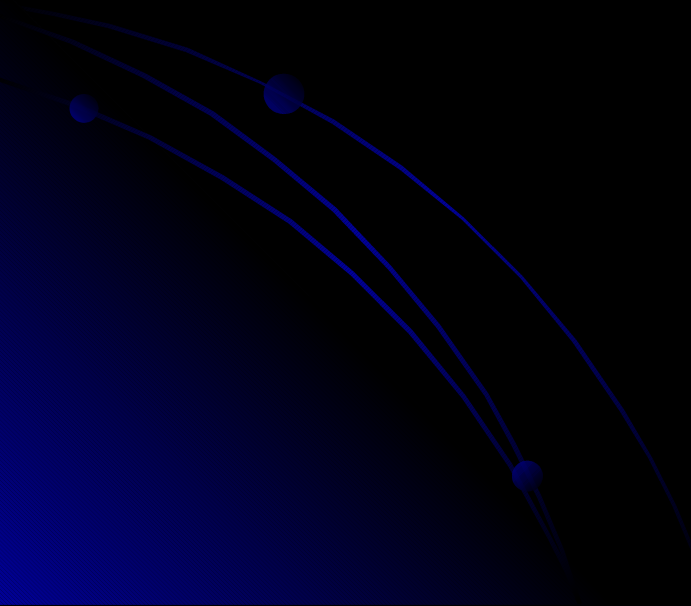
Example: Atomic Structure of He



If the protons and neutrons in this picture were 10 cm across, then the quarks and electrons would be less than 0.1 mm in size and the entire atom would be about 10 km across.

Quarks Part 1

Presented by: Krishna Eydatoula



What are Quarks?

➤ Quarks are one of the two basic constituents of matter (the other one is the leptons). They are the only fundamental particles that interact through all four of the fundamental forces.

➤ The word “quark” was borrowed by Murray Gell-Mann from the book *Finnegans Wake* by James Joyce, where seabirds give "three quarks", akin to three cheers. The names of quark flavours (up, down, strange, charm, bottom, and top) were also chosen arbitrarily based on the need to name them something that could be easily remembered and used.

➤ Quarks possess several important properties, which are

- ✓ Flavour
- ✓ Colour
- ✓ Spin
- ✓ Confinement

These parameters define the behaviour of each quark and consequently the properties of all particles composed of quarks.

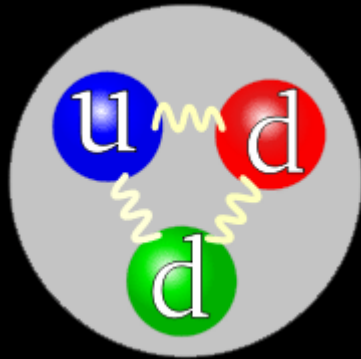
Quark Properties - Flavour

The term "flavour" was first used in the quark model of hadrons in 1968. A name for the set of quantum numbers related to isospin, hypercharge and strangeness is said to have been found on the way to lunch by Murray Gell-Mann and Harald Fritzsch when they passed a Baskin-Robbins advertising 31 flavours.

The following are the flavour quantum numbers :

- Baryon number: $B = \frac{1}{3}$
- Isospin, which has value $I_z = \frac{1}{2}$ for the up quark and value $I_z = -\frac{1}{2}$ for the down quark.
- Strangeness (**S**): **+1** for the strange antiquark. This is a down-type quark.
- Charm (**C**): **+1** for the charm quark. This is an up-type quark.
- Bottom (beauty), **B'**: **+1** for the down-type bottom antiquark.
- Top (truth), **T**: **+1** for the up-type top quark.
- Hypercharge: $Y = B + S + C + B' + T$
- Electric charge: $Q = I_z + Y/2$

Quark Properties - Colour

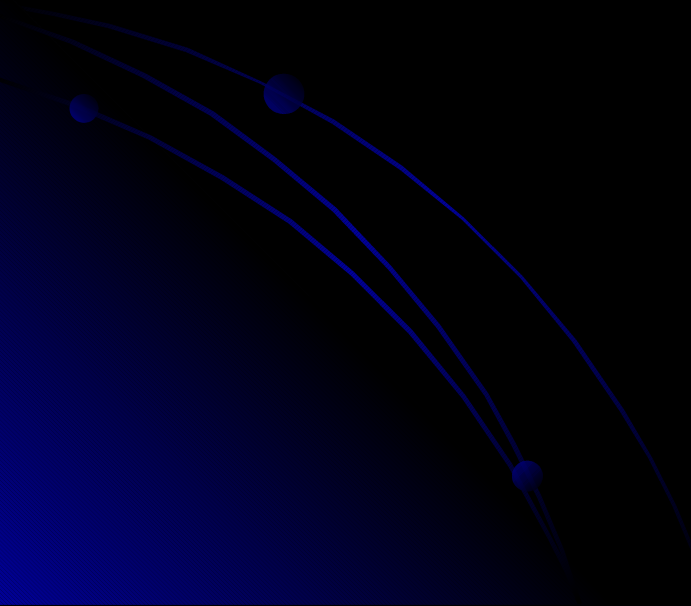


Since quarks are fermions, the Pauli exclusion principle implies that the three valence quarks must be in an antisymmetric combination in a baryon. However, the charge $Q = 2$ baryon, Δ^{++} (which is one of four isospin $I_z = 3/2$ baryons) can only be made of three up quarks with parallel spins. Since this symmetric under interchange of the quarks, it implies that there exists another internal quantum number, which would then make the combination antisymmetric. This is given the name "*colour*", although it has nothing to do with the perception of the frequency (or wavelength) of light, which is the usual meaning of colour.

Colour is a gauged $SU(3)$ symmetry. Quarks are placed in the fundamental representation, 3, and hence come in three colours (red, green, and blue).

Quarks Part 2

Presented by: Eugene Solodkin



Quark Properties - Spin and Confinement

Spin:

In the quark model one builds mesons out of a quark and an antiquark, whereas baryons are built from three quarks. Since mesons have integer spins and baryons have half-integer spins, the quark model implies that quarks are fermions. Further, the fact that the lightest baryons have spin-1/2 implies that each quark can have spin $J = 1/2$. The spins of excited mesons and baryons are completely consistent with this assignment.

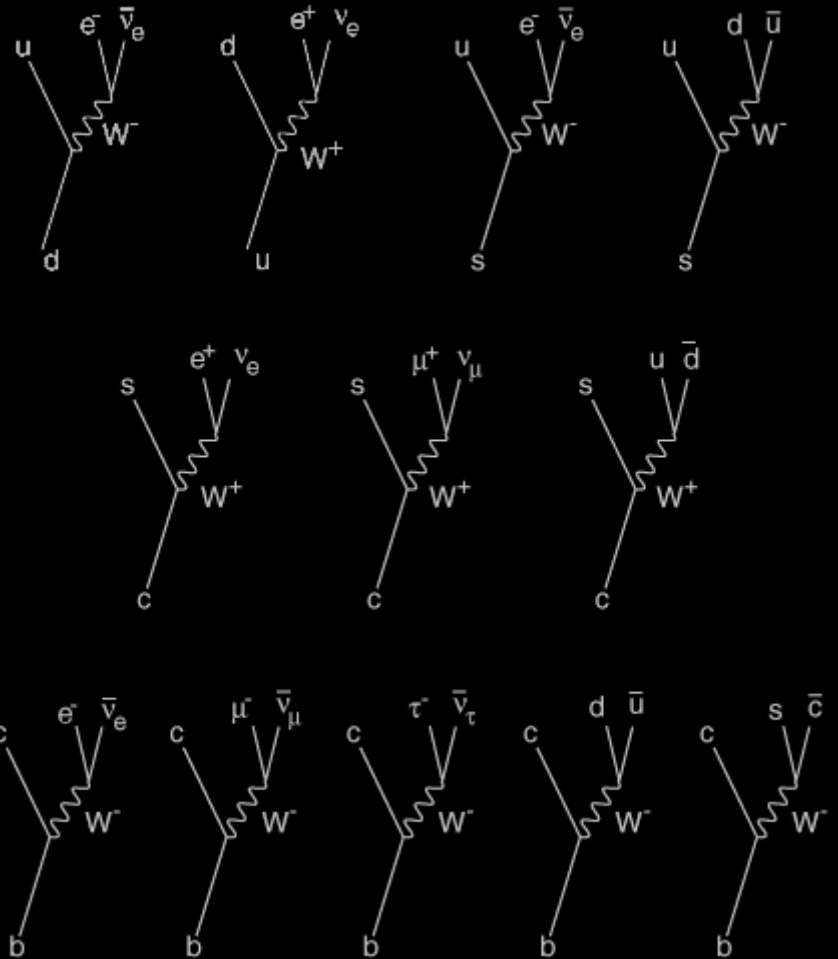
Confinement:

Confinement is a property, which states that individual quarks are not seen because they are always confined inside subatomic particles called hadrons (e.g., protons and neutrons). An exception is the top quark, which decays so quickly that it does not hadronize, and can therefore be observed more directly via its decay products.

Quark Transformations

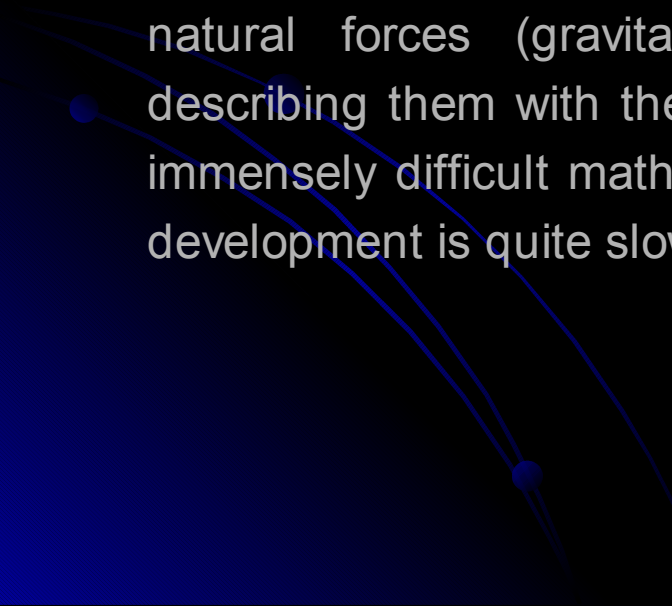
The decay of hadrons by the weak interaction can be viewed as a process of decay of their constituent quarks. There is a pattern of these quark decays: a quark of charge $+2/3$ (u, c, t) is always transformed to a quark of charge $-1/3$ (d, s, b) and vice versa. This is because the transformation proceeds by the exchange of charged W bosons, which must change the charge by one unit. The general pattern is that the quarks will decay to the most massive quark possible, leading to the pattern

$$t \rightarrow b \rightarrow c \rightarrow s \rightarrow u \leftrightarrow d$$



Conclusion

Despite the success of the Standard Model, many physicists still do not find it satisfactory as it cannot provide a sufficient mechanism to combine quantum mechanics with the theory of general relativity. Hence many other theories of matter emerge. The most promising at present seems to be the string theory, which proposes that all matter is build from one-dimensional extended objects (strings) rather than the zero-dimensional points (particles) that are the basis of the Standard Model of particle physics. Due to this modification string theory appears to be able to "unify" the known natural forces (gravitational, electromagnetic, weak and strong) by describing them with the same set of equations. However, because of the immensely difficult mathematics involved, the progress of the string theory development is quite slow.



THE END

