Interactions

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Interactions

Four types of interactions

Strong Interactions :

Responsible for forces between quarks and gluons and nuclear binding.

Electromagnetic Interactions :

Responsible for electric and magnetic forces.

weak Interactions :

Responsible for the instability of all but at least massive fundamental particles in any class

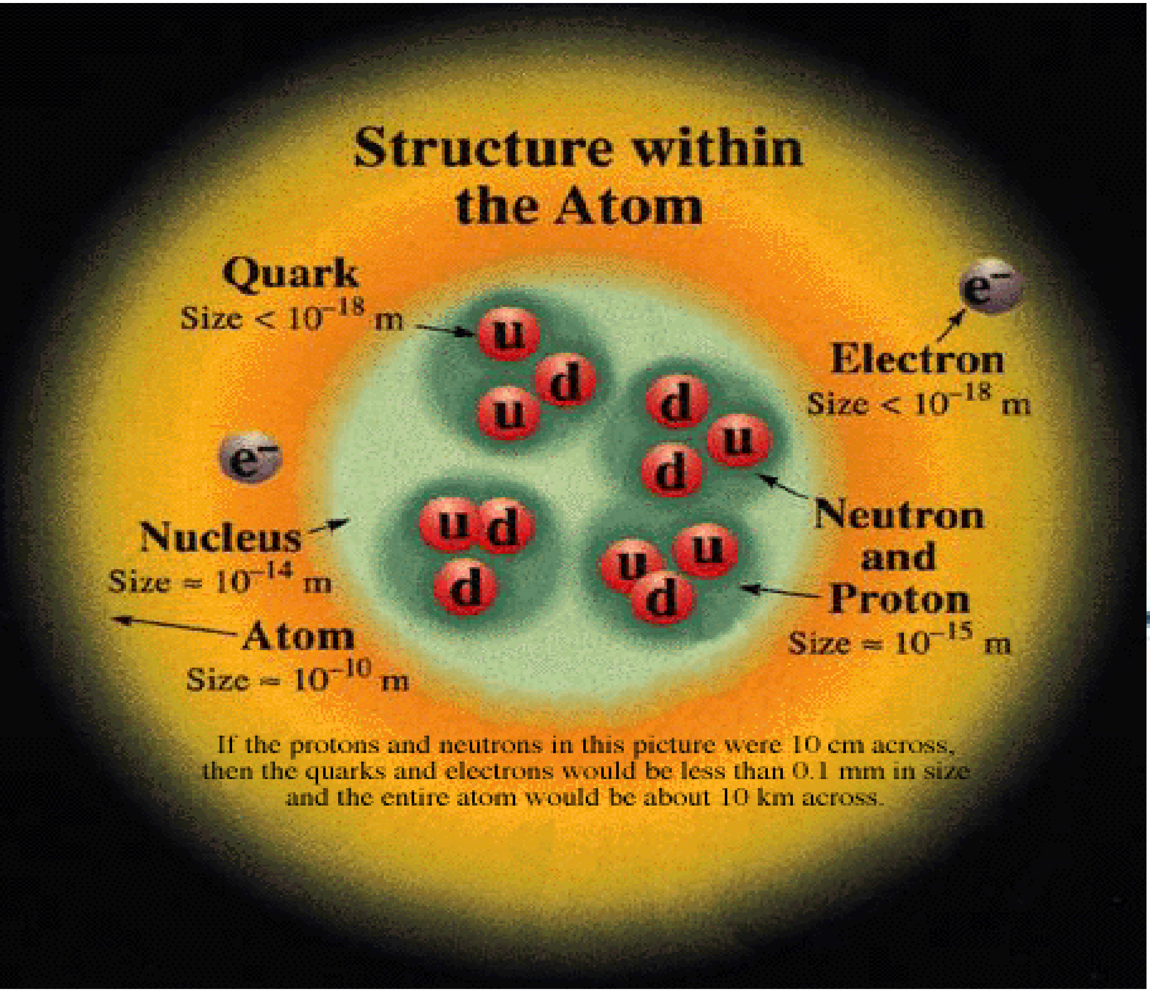
Gravitational Interactions :

Responsible for forces between any two objects due to their energy(which of course include their mass).

Standard Model → theory of strong (QCD) + weak and EM interaction (electroweak).

It does not include the effects of gravitational interactions.

The effects are tiny under high energy physics situations. Eventually we seek a theory that also includes a correct quantum version of gravitational interactions but this is not yet achieved.



Strong Interactions

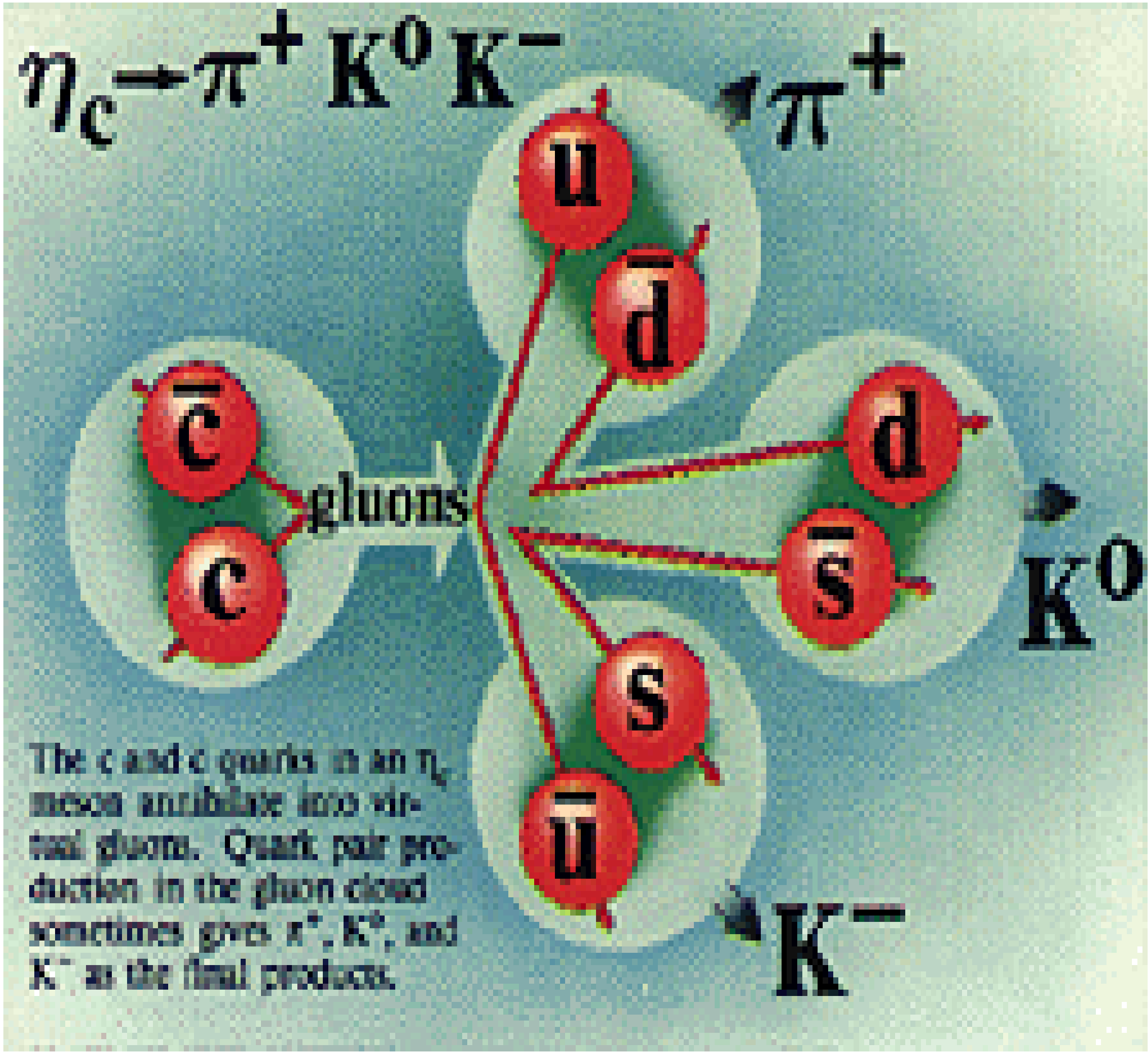
Fundamental strong interactions occur between any two particles that have color charge , that is, quarks, anti quarks and gluons.

Gluons:

- Carrier particles.
- Responsible for binding force.
- Confines all color-charged particles to form hadrons.
- **Examples**
- Such as protons, neutrons and pions.
- Resulting hadrons have no color charge.

Strong Interactions
Gluons

The c and c bar quarks in an eta_c meson annihilate into virtual gluons. Quark pair production in the cloud gluon sometimes gives a Pi+ . K0, and K- as the final products.



Residual Strong Interactions

Residual strong interactions between the color-charge neutral hadrons are responsible for the strong nuclear force.

- The force that binds protons and neutrons together to form nuclei.
- It is responsible for nuclear fission and fusion processes.
- Responsible for rapid decay processes of many hadrons.
- It is of short range.
- It occur via exchange of mesons or because of two hadrons come close enough together that they overlap.
- It can be viewed as the exchange of mesons between the hadrons

Sample Bosonic Hadrons

Mesons $q\bar{q}$

Symbol	Name	Quark content	Electric charge	Mass GeV/c^2	Spin
π^+	pion	$u\bar{d}$	+1	0.140	0
K^-	kaon	$s\bar{u}$	−1	0.494	0
ρ^+	rho	$u\bar{d}$	+1	0.770	1
D^+	D^+	$c\bar{d}$	+1	1.869	0
η_c	eta-c	$c\bar{c}$	0	2.979	0

Properties of Interactions

- Spin is the intrinsic angular momentum of particles . It is given in units of h-bar(quantum unit of). H-bar = h/2pi = 6.58* 10^{-25}

GeV s = 1.05 * 10^{-34} Js.

Electric charges are given in units of the proton's charge. In SI units the electric charge of the proton is 1.60 * 10^{-19} coulombs

PROPERTIES OF THE INTERACTIONS

Property \ Interaction	Gravitational	Strong: Fundamental	Strong: Residual
Acts on:	Mass – Energy	Color Charge	See Residual Strong Interaction Note
Particles experiencing:	All	Quarks, Gluons	Hadrons
Particles mediating:	Graviton (not yet observed)	Gluons	Mesons
Strength relative to electromag for two u quarks at 10^{-18} m	10^{-41}	25	Not applicable to quarks
Strength relative to electromag for two u quarks at 3×10^{-17} m	10^{-41}	60	Not applicable to quarks
Strength relative to electromag for two protons in nucleus	10^{-36}	Not applicable to hadrons	20

Property \ Interaction	Weak (Electroweak)	Electromagnetic (Electroweak)
Acts on:	Flavor	Electric Charge
Particles experiencing:	Quarks, Leptons	Electrically charged
Particles mediating:	W^+ W^- Z^0	γ
Strength relative to electromag for two u quarks at 10^{-18} m	0.8	1
Strength relative to electromag for two u quarks at 3×10^{-17} m	10^{-4}	1
Strength relative to electromag for two protons in nucleus	10^{-7}	1

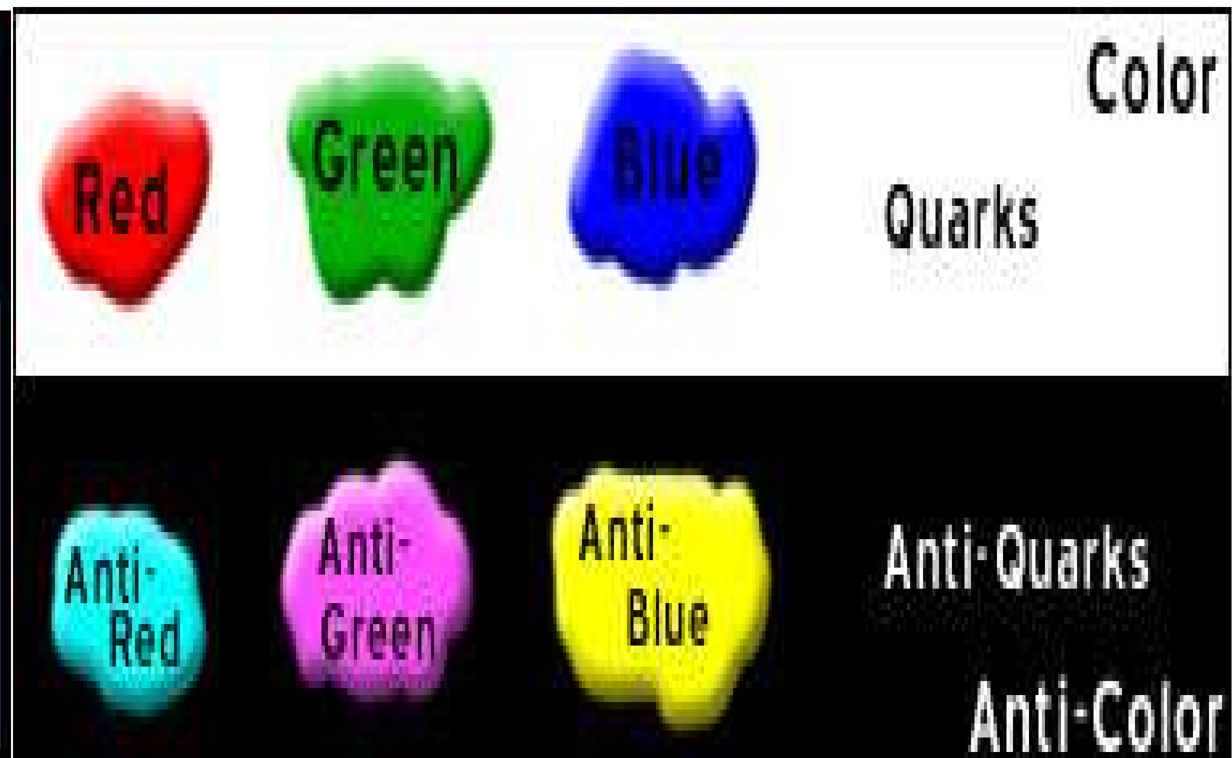
Theory of Color Charge

- It is only associated with strong interactions.
- The mathematics is of special unitary group SU(3).
- There are three possible color-charge for quarks. The meaning of 3 in SU(3).
- A three-quark state, with one of each color, is a color neutral state (color-singlet).this makes baryon.

Baryons qqq and Antibaryons $\bar{q}\bar{q}\bar{q}$

Baryons are fermionic hadrons.
There are about 120 types of baryons.

Symbol	Name	Quark content	Electric charge	Mass GeV/c^2	Spin
p	proton	uud	1	0.938	1/2
$\bar{p}$	anti-proton	$\bar{u}\bar{u}\bar{d}$	–1	0.938	1/2
n	neutron	udd	0	0.940	1/2
Λ	lambda	uds	0	1.116	1/2
Ω^-	omega	sss	–1	1.672	3/2



Color Neutrality

- All observed particles are color-neutral objects.
- Leptons have no color-charge inside, while hadrons have quarks and gluons.
- Quarks inside a hadron are bathed in a sea of gluons(responsible for binding force).
- Quarks continually emit and absorb gluons inside hadrons which can't be observed.
- Color charge is conserved in every such process.

Weak Interactions

- Weak interactions occur for all fundamental particles except gluons and photons.
- Weak interactions involve the exchange or production of W or Z bosons.
- Weak forces are very short-ranged.
- Conservation laws that are valid for strong and electromagnetic interactions, but broken by weak processes.

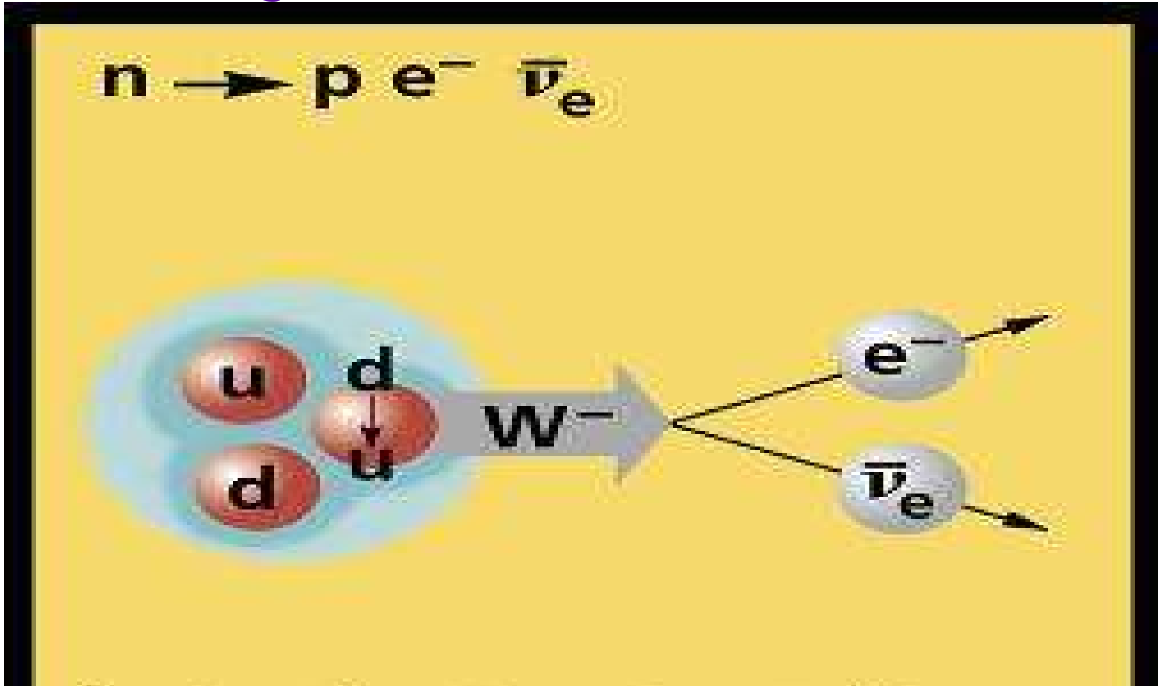
Weak Interaction Carrier Particles

The particles responsible for the weak interactions are W bosons and Z bosons.

W Bosons

- Its mass is 80 GeV/c^2 roughly equal to the mass of Bromine atom.
- Two types of W boson with electric charge +1 and -1.
- It is not a matter particles.
- The emition or absorption of W boson can only change the quark flavor. Like in β decay, that involve W bosons.

he weak interaction involves the exchange of the intermediate vector bosons, the W and the Z.

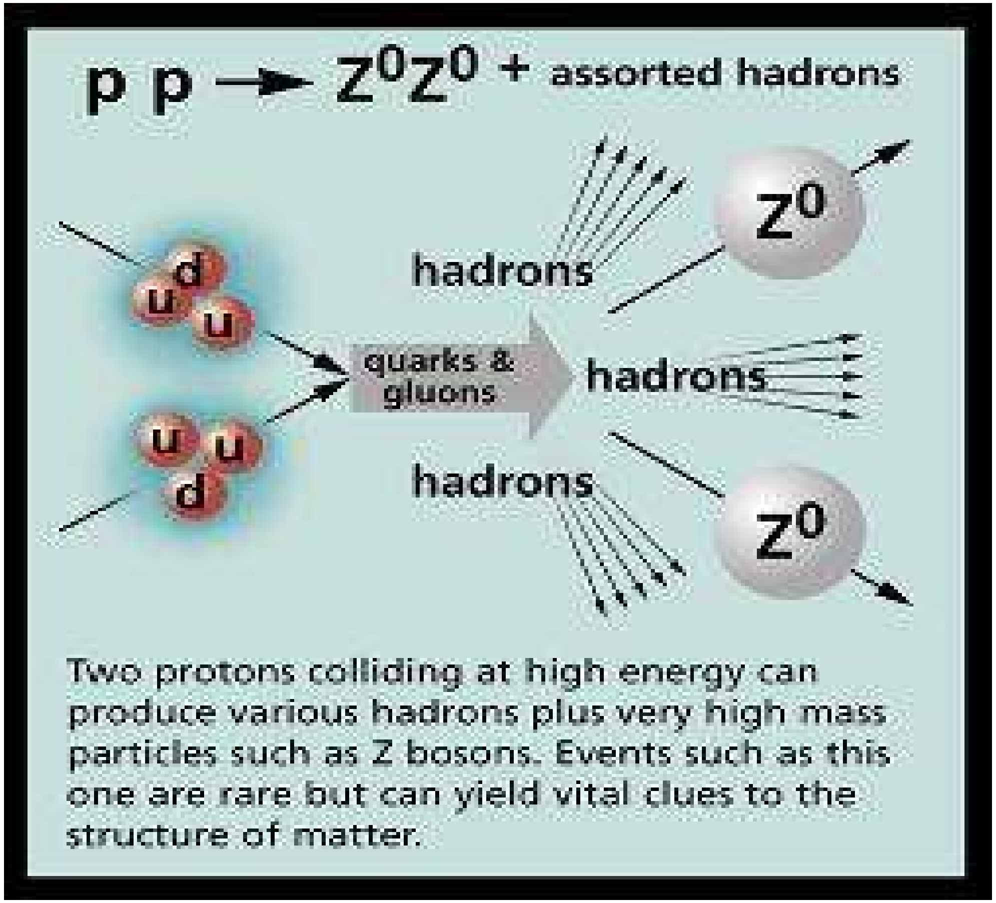


A neutron decays to a proton, an electron, and an antineutrino via a virtual (mediating) W boson. This is neutron β decay.

Weak Interaction Carrier Particles

Weak interaction carrier particles

Z Bosons



Processes involving Z-bosons are called

"neutral current processes" are even more

elusive than W-boson effects.

Its mass is about 91 GeV/c^2 or roughly

the same as an Zirconium atom.

It have no electric charge and no

distinguishable quantum number so the

antiparticle of Z boson is a Z boson.

It is produced by colliding electron and positron beams

with just the right energy to make a single Z are the

main object of study for the linear collider at SLAC.

It decay to produce either quark and anti-quark or lepton and anti-lepton

Weak interaction discoveries

The discovery of the W and Z particles in 1983 was hailed as confirmation of the theories which connect the weak force to the electromagnetic force in electroweak unification

- The weak interaction acts between both quarks and leptons.
- The strong force does not act between leptons.
- Leptons have no color, so they do not participate in the strong interactions.
- Neutrinos have no charge, so they experience no electromagnetic force, but all of them join in the weak interactions.

References

- An introduction to the Standard Model of Particle Physics by W.N. Cottingham and D.A Greenwood.
- Modern Elementary Particle Physics by Gordon Kane.
- Gauge Theories of the Strong, Weak, and electromagnetic Interactions by Chris Quigg.
- Quarks and Leptons, an introductory Course in Modern Particle Physics by Francis Halzen and Alan D.Martin.
- Force and Interaction on the Internet. http://www2.slac.stanford.edu/vvc/theory/interactions.ht