Interactions and Fields

In <u>classical physics</u>, interaction at a distance is described by a potential. Under the influence of the potential, particles follow smooth, continuous trajectories.

In <u>quantum mechanics</u>, the defined trajectory is replaced by a probability distribution, derived from a wave function. The interaction is still considered as a smooth, continuous potential.

<u>Quantum field theory</u> describes interactions at very small distances. The quantum nature of the interaction makes it necessary to abandon the continuous potential model, and we must regard the interaction as being propagated by individual quanta (bosons) which are specific to the type of interaction. (This is known as *second quantisation*.)

In modern field theories, we have the fundamental forces transmitted by the exchange of bosons (particles of spin 0, 1, 2, …).

Two basic types of fundamental field can occur – ones in which the fermions act as sources of the field and the bosons act simply as propagators, and ones in which both the fermions and the bosons themselves act as sources.

An example of the former is electromagnetism, where electric charge (on an electron for example) is a source and the boson is the photon, which is neutral.

The four fundamental forces are electromagnetism, the weak force responsible for nuclear beta decay, the strong (nuclear) force and gravity. Their properties are given in the table.

Interaction	Source	Field quanta Particle	spin	mass	Strength
Strong	"colour" (carried by quarks and gluons)	gluon g	1	0	~1 at large distance <1 at small distance
Electromagnetism	charge (carried by e,μ,τ and quarks)	photon γ	1	0	$\sim 10^{-2}$
Weak	all leptons and quarks	$W^{\pm}$,Z	1	80-90 GeV/c²	$\sim 10^{-13}$ @10^{-15} m $\sim 10^{-2}$ @10^{-18} m
Gravity	energy density	Graviton G	2	0	$\sim 10^{-38}$

Interaction	Source	Field quanta Particle	spin	mass	Strength
Strong	"colour"	gluon	1	0	~1 at large distance
Electroma					
Weak	quarks				m $\sim 10^{-2}$ @10^{-18} m
Gravity	energy density	Graviton G	2	0	$\sim 10^{-38}$

<u>Gravity</u>, of great importance between macroscopic bodies (like us and the earth) is too weak to play an important rôle between fundamental particles. We will only make one remark – that the spin of the graviton (2) is related to the fact that there is only positive mass, so dipole radiation is not a possibility.

Interaction	Source	Field quanta Particle	spin	mass	Strength
Stro…					…distance …distance
Electro…	…and quarks)				…2
Weak	all leptons and quarks	$W^{\pm}$,Z	1	80-90 GeV/c^2	~10^{-13} @10^{-15} m ~10^{-2} @10^{-18} m
Gravity	energy density	Graviton G	2	0	~10^{-38}

The short range of the weak interaction (and hence its name) is related to the mass of its bosons. (At very short distances, it is no weaker than electromagnetism.) Note that all fermions experience the weak interaction.

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Strong	"colour" (carried by quarks and gluons)	gluon g	1	0	~1 at large distance <1 at small distance
Electromagnetism	charge (carried by e,μ,τ and quarks)	photon γ	1	0	~10^{-2}
Wea…					…$^{-15}$ m …$^{-18}$ m
Gravi…		…G			

Electromagnetism is the everyday force responsible for chemistry, solid state physics, friction and the stability of atomic matter in general.

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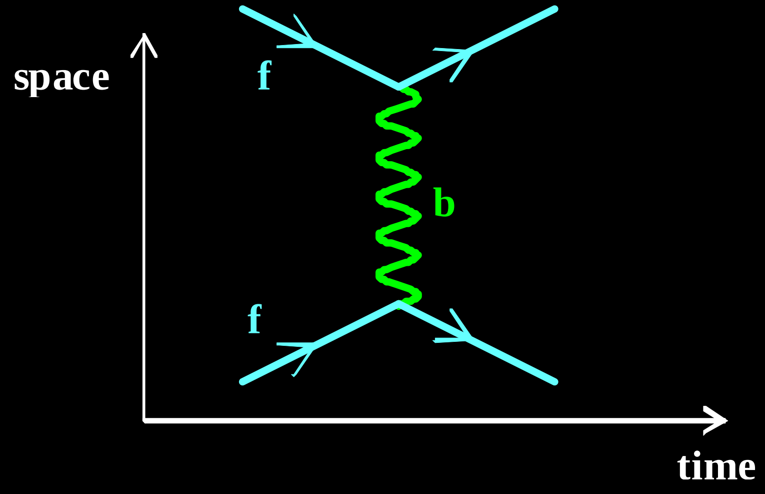
Strong	"colour" (carried by quarks and gluons)	gluon g	1	0	~1 at large distance <1 at small distance
El…					…$^{-2}$
					…10^{-15} m …10^{-18} m
					…$^{-38}$

The reason for the "strong charge" being given the name of "colour" will be revealed later - it has nothing to do with the normal colour of an object! The strong interaction was originally postulated to bind protons (and neutrons) together in nuclei against the large electromagnetic repulsion. We now know that this is a second-order effect similar to the Van der Waal's (electromagnetic) force which binds neutral covalent molecules in solids. The proton and neutron (and all hadrons) are "colourless" or colour neutral.

- Quantum picture of Coulomb's Law

Feynman Diagrams

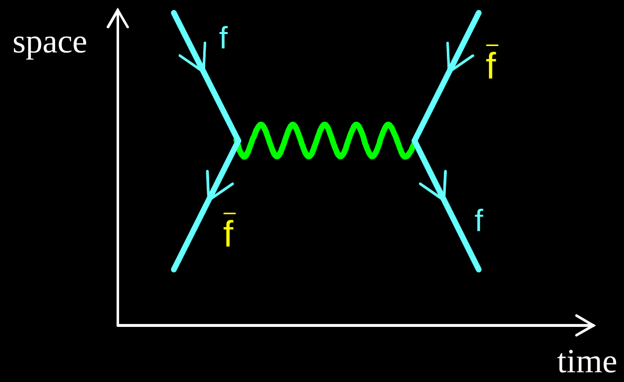
- **In the classical limit, considered emission and absorption of many photons**
- **At very high energies**
  - **Time of interaction very short**
  - **Process dominated by exchange of single quantum**
- **Process can be represented by space-time diagram (Feynman diagram)**



Used for calculating scattering amplitudes:

Specific rules for each line and vertex in diagram

Rotating a Feynman diagram reveals another, intimately related process:



"Fermion going backward in time" ≡ normal antifermion

Above is fermion-antifermion annihilation

e.g. $e^+e^- \xrightarrow{\text{annihilation}} \gamma \longrightarrow e^+e^-$