Unit 8. The Four Fundamental Forces of Nature

The Four Fundamental Forces of Nature are Gravitational force, Weak Nuclear force, Electromagnetic force and Strong Nuclear force. The weak and strong forces are effective only over a very short range and dominate only at the level of subatomic particles. Gravity and Electromagnetic force have infinite range. Let's see each of them in detail.

The Four Fundamental Forces and their strengths

1. Gravitational Force – Weakest force; but infinite range. (Not part of standard model)
2. Weak Nuclear Force – Next weakest; but short range.
3. Electromagnetic Force – Stronger, with infinite range.
4. Strong Nuclear Force – Strongest; but short range.

Gravitational Force

The gravitational force is weak, but very long ranged. Furthermore, it is always attractive. It acts between any two pieces of matter in the Universe since mass is its source.

Weak Nuclear Force

The weak force is responsible for radioactive decay and neutrino interactions. It has a very short range and. As its name indicates, it is very weak. The weak force causes Beta decay ie. the conversion of a neutron into a proton, an electron and an antineutrino.

Electromagnetic Force

The electromagnetic force causes electric and magnetic effects such as the repulsion between like electrical charges or the interaction of bar magnets. It is long-ranged, but much weaker than the strong force. It can be attractive or repulsive, and acts only

between pieces of matter carrying electrical charge. Electricity, magnetism, and light are all produced by this force.

Strong Nuclear Force

The strong interaction is very strong, but very short-ranged. It is responsible for holding the nuclei of atoms together. It is basically attractive, but can be effectively repulsive in some circumstances. The strong force is 'carried' by particles called gluons; that is, when two particles interact through the strong force, they do so by exchanging gluons. Thus, the quarks inside of the protons and neutrons are bound together by the exchange of the strong nuclear force.

Note : While they are close together the quarks experience little force, but as they separate the force between them grows rapidly, pulling them back together. To separate two quarks completely would require far more energy than any possible particle accelerator could provide.

Fundamental Force Particles

Force	Particles Experiencing	Force Carrier Particle	Range	Relative Strength*
Gravity acts between objects with mass	all particles with mass	graviton (not yet observed)	infinity	much weaker
Weak Force governs particle decay	quarks and leptons	W^+, W^-, Z^0 (W and Z)	short range	
Electromagnetism acts between electrically charged particles	electrically charged	γ (photon)	infinity	
Strong Force** binds quarks together	quarks and gluons	g (gluon)	short range	much stronger

Electroweak Theory and Grand Unification Theories (GUT)

There is a speculation, that In the very early Universe when temperatures were very high (the Planck Scale) all four forces were unified into a single force. Then, as the temperature dropped, gravitation separated first and then the other 3 forces separated. Even then, the weak, electromagnetic, and strong forces were unified into a single force. When the temperature dropped these forces got separated from each other, with the strong force separating first and then at a still lower temperature the electromagnetic and weak forces separating to leave us with the 4 distinct forces that we see in our present Universe. The process of the forces separating from each other is called **spontaneous symmetry breaking.**

- The weak and electromagnetic interactions have been unified under Standard Electroweak Theory, or sometimes just the Standard Model. (Glashow, Weinberg, and Salaam were awarded the Nobel Prize for this in 1979). [Unification of Weak forces except gravity]
- Grand unification theories attempt to treat both strong and electroweak interactions under the same mathematical structure. [Unification of Weak forces and strong forces] PS: Attempts to include gravitation in this picture have not yet been successful.
- Theories that add gravity to the mix and try to unify all four fundamental forces into a single force are called Superunified Theories.
- PS: Grand Unified and Superunified Theories remain theoretical speculations that are as yet unproven, but there is strong experimental evidence for the unification of the electromagnetic and weak interactions in the Standard Electroweak Theory. Furthermore, although GUTs are not proven experimentally, there is strong circumstantial evidence to suggest that a theory at least like a Grand Unified Theory is required to make sense of the Universe.

UPSC Prelims Question 2013

Qn: The known forces of nature can be divided into four classes, viz, gravity, electromagnetism, weak nuclear force and strong nuclear force. With reference to them, which one of the following statement is not correct?

1. Gravity is the strongest of the four
2. Electromagnetism act only on particles with an electric charge
3. Weak nuclear force causes radioactivity
4. Strong nuclear force holds protons and nutrons inside the nuclear of an atom.

Ans: 1