JETIR.ORG ISSN: 2349-5162 | ESTD Year : 2014 | Monthly Issue
JOURNAL OF EMERGING TECHNOLOGIES AND INNOVATIVE RESEARCH (JETIR)
An International Scholarly Open Access, Peer-reviewed, Refereed Journal

FUNDAMENTAL FORCES AND EXCHANGE PARTICLES

Subhash Chandra and I.D. Joshi
Department of Physics
Faculty of Science
Motherhood University Roorkee,
Haridwar, U.K

Abstract

All the physical interactions in the universe can be explained by one or more of the four fundamental forces: the strong force, electromagnetic force, weak force, and gravity (Pillitteri, 2017). It is quite interesting that many different events occur in the universe, yet only four forces are needed to describe them. It is even possible that only one force exists, and the four forces known today are just different manifestations of that same force. However as these forces cannot be explained by the any simpler interaction so called fundamental, all large scale forces that are experience can be explained by the microscopic, fundamental forces.

Introduction

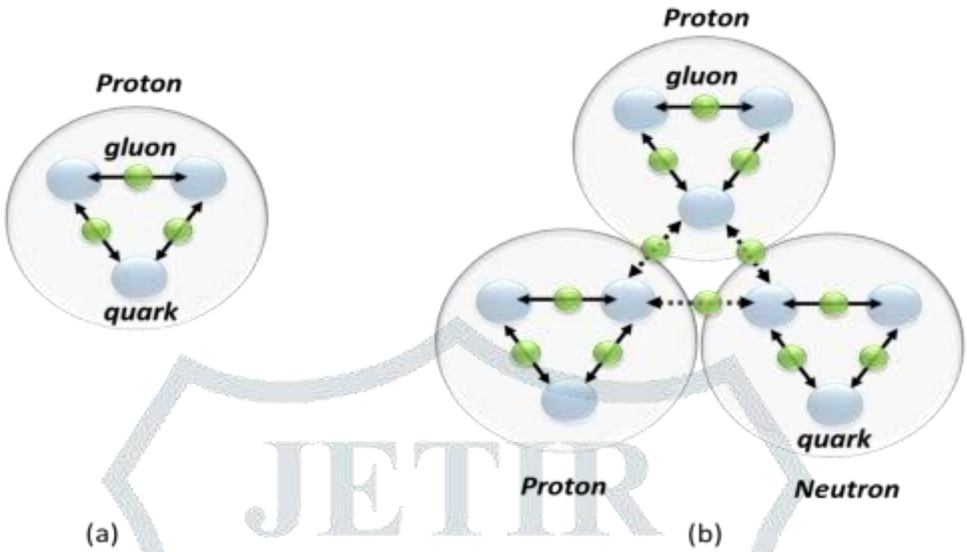
In order for one of these forces to act between two matter particles they need force-carrying particles. These force carrying particles are usually called 'exchange' particles since they are exchanged between matter particles. So the forces themselves are the result of the exchanging of particles. Some force carrying particles have a unique property that they don't carry mass at all, such as photon and gluons. So those particles aren't really matter they are the particles that allow matter to experience forces. Apart matter particles include quarks and leptons. The most significant difference between quarks and leptons is that quarks can experience the strong force while leptons cannot.

To understand various aspect of fundamental nature we need to gain knowledge of relation among various elementary forces and particles.

The strong force

It was believed that protons and neutrons were fundamental particles which could not be broken any smaller. Later scientists discovered that protons and neutrons can further be disintegrated in smaller particles, namely quarks and gluons where quarks are the matter particles and gluons are their exchange particles (M.GellMann, 1964). Quarks exchange gluons result in the strong forces, which is the strongest of the four fundamental forces (Pillitteri, 2017). The figure 1.1 (a) and (b) shows the exchange of gluons between quarks. When quarks exchange gluons, the quarks become bound together which forms nucleon (protons and neutrons). So nucleons are not fundamental particles at all. These particles (gluons and quark) are subjected to 'confinement' that is they can never be find in Free State. Each quark or gluon can come in a variety of "color state" which form the rule for possible combination of quark and gluon. Again the strong forces has very unique properties, they are short range, charge independent, highly spin dependent and so on. It is a unique property which allows quark and gluons to be only particles that can experience the strong force (Feynman, 1985).

Figure 1.1 *(a) Shows the proton contains three quarks bound together by exchange gluons. (b) Shows protons and neutrons are bound together as their quark exchange gluons. (This image is a simplification to show how quark exchange gluons to form bonds. Image shows one type of gluon and quark but they different in reality).*



The electromagnetic force

The second strongest fundamental force is the electromagnetic force, a combination of electric and magnetic forces. Almost about 100 times weaker than the strong force. This keeps the negatively-charged electrons orbiting the positively-charged nucleus of atom. The connectivity between electricity and magnetism was discovered through experiments of current carrying body which produces magnetic field as shown in the figure 1.2. According to quantum mechanics, an electromagnetic force occurs due to the exchange of photons, the particle of light. The photon in this process are considered as virtual photons because they cannot be produce in the laboratory.

Figure 1.2 *shows the relation between electric and magnetic field, wire carrying current (yellow) produces magnetic field (blue)*

The weak forces

The weak forces, also pronounced as the weak interaction, is very unique compared to electromagnetic and strong forces. These are mediated by different exchange particles known as W and Z bosons. This force differs from the others since the exchange particles involved are usually released from a single matter particles rather than transferred one particle to another as in case of strong forces. The weak forces cause quark or a lepton to transform into another particle. A quark converts into another quark by releasing a W of Z boson, similarly a lepton turns into another lepton (Pillitteri, 2017).

A very good example of weak interaction is beta decay a process through which a neutron is converted into a proton, here a down quark inside a neutron emits a W boson, and the emission cause the down quark to turn into up quark. The result is that the neutron turns into a proton. Meanwhile, the W boson decays into an electron and an antineutrino (a type of lepton). The resulting electron called beta particle as shown in the figure 1.3 below. The exploration of weak forces further with the help of particle accelerators have shown that high energies, bosons (W and Z) in weak interactions act similar as photons in electromagnetic forces, hence provides the evidence of unification of electromagnetic forces with weak forces into the electroweak force. Experiments also revealed that at high energies electroweak forces become stronger and the strong force become weaker. In theory the strong and electroweak forces also become unified experimentally yet to be observed (El Naschie, 2000; Poojary, 2015; Salam, 1980; T. H. Wu, 2015).

Figure 1.3 *Beta decay is a weak interaction where a neutron turns into a proton. W boson emitted, and a down quark turns in up quark.*

Gravity

Gravity is the weakest of the four fundamental forces. Gravitational force is practically negligible for the particles like protons and electrons, the other forces overwhelm it. Presently gravity is described by two different theories that don't agrees with each other. One is Einstein's general theory of relativity, which claims that gravity not a 'real' force like the other three fundamental forces; rather it is the result of the curvature of space-time induced by the presence of mass. The other theoretical framework is quantum mechanics, which predicts that the force of gravity is transmitted by an exchange particle called the graviton, yet not discovered. However the mathematical combination of general theory of relativity and quantum mechanics break downs, it does not produce any physical answer.

Elementary Particles

The first evidence of subatomic world came with the discovery of the electron by J.J Thomson in the year 1897, till 1918, Ernest Rutherford discovered the proton itself, later Chadwick in 1932 discovered the neutral particle called the neutron, and the picture of the atom seemed complete. Suddenly in 1936 new particle called the muon was discovered and soon more new particles start appearing form the study of cosmic rays. During 1950's scientists start building particles accelerators, which effectively accelerated protons (or electrons) and collide them together at very high speeds (Livingston, 2013; Van de Graaff, Trump, & Buechner, 1947; Wiedemann, 2015). The accelerator experiments helps in discovering new particles mostly in pairs, for electron they have positron with positive charge called antiparticle. Further Murray Gell-Mann surmised that the fundamental particles like the proton must be composed of even more fundamental particles called quark, initially three quarks was postulated later they grew to six.

There are four major categories of fundamental particles of physics: Brutinos, Neutrinos, Matter, and Photons. Brutinos are small, spherical, elastic particles which make up an ether gas which in turn responsible for the creation of universe. Neutrinos are nuclear sized particles, travels mostly in linear paths at a speed slightly greater than the speed of light, but some are forced into circular paths, which makes matter. The basic unit of matter is a single neutrino orbiting in closed path. This is called an elementary matter particle. Matter interacts with other matter by absorbing, a close elliptic ring of brutinos which are moving at the speed of light. Butrinos which are not in elliptical ring spread uniformly over one length of a harmonic wave, this harmonic wave is called a photon (Brown, 2019).

THE GRAVITION

In speculative theories of quantum gravity, the graviton is a hypothetical fundamental particle that mediates the force of gravitation in the framework of quantum theory. The mass of the graviton is approximately $7.7 \times 10^{-23}\ ev/c^2$, and the wavelength would be $\lambda_g = 1.66 \times 10^{17} m$. The graviton is spherical, smooth, elastic particle which makes up everything physical in the universe, according to the kinetic particle theory of physics. It is the unique particle form which all matter, radiation, and neutrinos are made.

THE PHOTON

The photon is very ''modern' particle, having more in common with the W and Z bosons. In the discovery of photon the first contribution was made by Planks to explain blackbody spectrum for the electromagnetic radiation emitted by a hot object. He assumed that electromagnetic radiation is quantized having energy $E = h\nu$. Later Einstein give more radical view, argued that quantization was a feature of the electromagnetic field itself and explain photoelectric effect. Then came Compton showing that the light scattered form a particle at rest is shifted in wavelength concluding that light behaves as a particle, on subatomic scale. The particle was called the photon.

THE MESONS

The force that bind the nucleon together in the nucleus must be more powerful than the force of electrical repulsion. Such force we do not observed in the everyday life as it is very short rang and called as strong force. The theory of strong forces was proposed by Yukawa, he assumed that the proton and neutrons are attracted to one another by some short of field, just as electron is attracted to nucleus by an electric field. The field must be quantized and act as quantum particle whose exchange would account for the strong force. The mass of such quantum particle was nearly about 300 times that of electron, or about a sixth the mass of a proton. As its mass fell between the electron and the proton, the particle came to known as the meson (meaning 'middle-weight').

THE ANTIPARTICLES

The theory of relativistic quantum mechanics provide a troubling feature: for every positive-energy solution ($E = +\sqrt{p^2c^2 + m^2c^4}$) it admitted a corresponding solution with negative energy ($E = -\sqrt{p^2c^2 + m^2c^4}$). This reveals that for every kind of particle there must exist a corresponding antiparticle, with the same mass but opposite electric charge. The union of special relativity and quantum mechanics, then leads to a pleasing matte/antimatter symmetry. However matter and antimatter cannot coexist for long – if a particle meets its antiparticle, they annihilate.

THE NEUTRINOS

Nuclear beta decay was not following the law of conservation of energy and creating the problem. Then it was suggested that another particle was emitted along with the electron, a silent accomplice that carries off the 'missing energy'. It has to be electrically neutral, to conserve charge and called as neutrino. Various experiments were performed to prove the existence of neutrino.

THE QUARKS

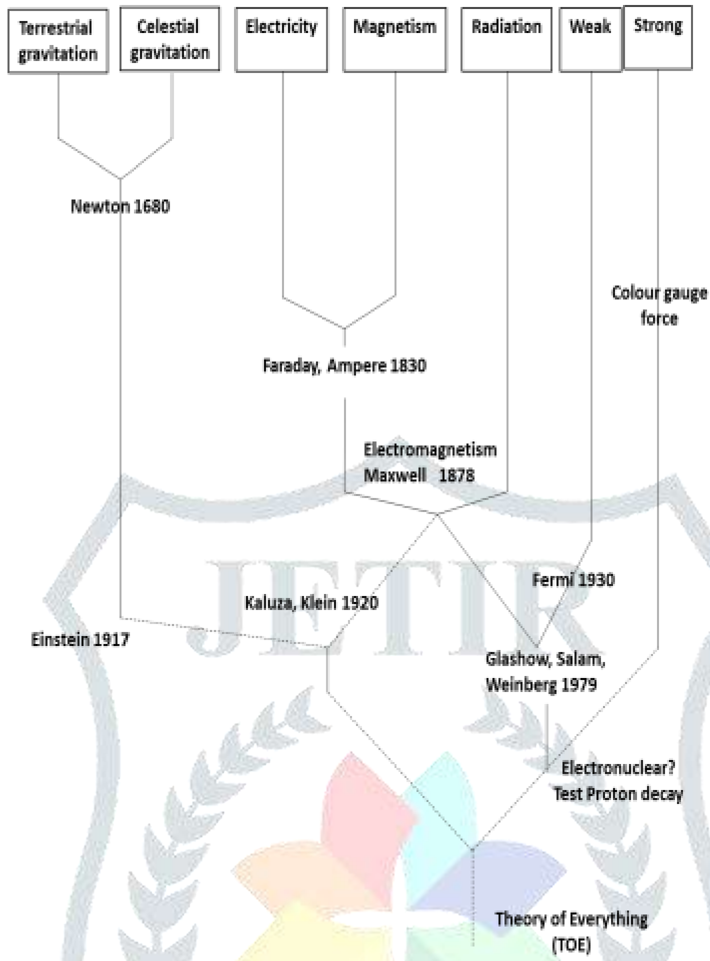
Gell-Mann introduced the so called Eightfold way to arranged the baryons and mesons into a geometrical patterns, according to their charge and strangeness. These patterns proposed that all hadrons are composed of even more elementary constituents, which were called as quark. There were two composition rules: every baryon is composed of three quarks (and every antibaryon is composed of three antiquarks) while every meson is composed of a quark and an antiquark. Experiments has shown six 'flavors' of quarks classified by charge strangeness (S), charm (C), beauty (B), truth (T), up (U) and down (D) (Friedman, 2001; M.Gell-Mann, 1964).

Unification of Forces and Standard Model

Firstly Galileo gives the idea of "celestial" gravity then Isaac Newton asserted that "terrestrial" gravity was the same as "celestial" gravity. Newton introduce a new fundamental constant of nature, G, which characterizes the strength of the gravitational force. The force was always attractive and long range. Next unification of fundamental forces was electromagnetism- the 'force of life'. Faraday and Ampere unified the electricity and magnetism giving the electromagnetism.

Then Maxwell unified the electromagnetism with optics. After this Einstein gives his Idea of Special Theory of Relativity which was unification of space and time and generalization of gravity. Now come the nuclear forces mainly of two types the so-called "weak" and "Strong". Glashow and Salam unify electromagnetism and weak nuclear forces with the idea that both these forces have spin-one messengers (exchange particles) and are "gauge" forces. Figure 1.4 shows the history of unification of physical theories.

Figure *Shows the history of unification of physical theories.*



At present all elementary entities plus all forces of nature (except for gravity) can be present in a symmetric pattern shown in the table 1.1. This table comprise the 'Standard Model' of the elementary particles. All the particles of the standard model are known to exist directly. The standard model corresponds to the gauge symmetry SU (3) x SU (2) x U (1), where the electroweak gauge messengers W^{+}, W^{-}, Z^{0}, γ^{0}. Where W^{+}, W^{-}, Z^{0} are massive, with three helicities $\pm\hbar$, 0 each while γ^{0} has zero rest-mass (and therefore just two helicities $\pm\hbar$). Strong nuclear gauge messengers are eight (electrically) neutral massless gluons of spin $\hbar$ (helicities $\pm\hbar$). There is no spontaneous symmetry breaking here.

***Table 1.1** Shows the standard model of particle physics. All matter is made out of three kinds of elementary particles: leptons, quarks, and mediators.*

	FERMIONS (matter particles)			BOSONS (force carriers)	
QUARK	Up (u) Down (d)	Charm (c) Strange (s)	Top (t) Bottom (b)	Gluon (g) Photon (γ)	Higgs boson (H)
LEPTON	Electron (e) Electron neutrino (ν_e)	Muon (μ) Muon neutrino (ν_μ)	Tau (τ) Tau neutrino (ν_τ)	Z boson (Z^0) W boson ($W^\pm$)	

References:

Aaboudd, M., Aad, G., Abbott, B., Abdallah, J., Abeloos, B., Abidi, S. H., Abreu, H. (2018). Measurement of the W-boson mass in pp collisions at s√= 7TeV with the ATLAS detector (vol 78, 110, 2018). *The European Physical Journal C*, *78*(898).

Aamodt, K., Quintana, A. A., Achenbach, R., Acounis, S., Adamová, D., Adler, C., … Ahammed, Z. (2008). The ALICE experiment at the CERN LHC. *Journal of Instrumentation*, *3*(08), S08002.

Alitti, J., Ambrosini, G., Ansari, R., Autiero, D., Bareyre, P., Bertram, I. A., … Bourliaud, M. (1992). An improved determination of the ratio of W and Z masses at the CERN pp collider. *Physics Letters B*, *276*(3), 354–364.

Arnison, G., Albrow, M. G., Allkofer, O. C., Astbury, A., Aubert, B., Bacci, C., … Bezaguet, A. (1986). Intermediate-vector-boson properties at the CERN Super Proton Synchrotron collider. *EPL (Europhysics Letters)*, *1*(7), 327.

Aßmann, R. (2002). Review of ultra high-gradient acceleration schemes, results of experiments.

Brown, J. M. (2019). The mechanical theory of everything. In *World's Greatest Architect* (p. 287). https://doi.org/10.7551/mitpress/7949.003.0019

Brüning, O., & Rossi, L. (2020). High-luminosity Large Hadron Collider. *CERN Yellow Reports: Monographs*, *10*, 1.

Buchmüller, O. (2008). LHC detectors: commissioning and early physics. In *Journal of Physics: Conference Series* (Vol. 110, p. 12015). IOP Publishing.

Collaboration, ALICE. (2021). Unveiling the strong interaction among hadrons at the LHC. *Nature*, *590*(7844).

Collaboration, ATLAS. (n.d.). Technical Design Report, CERN–LHCC 99–14 (May 1999); CMS Collaboration, Technical Proposal, CERN– LHCC 94–38 (December 1994); S. Dawson, D. Dicus, C. Kao, and R. Malhotra.

Das, D. (2009). ϒ production in STAR. *The European Physical Journal C*, *62*(1), 95–98.

Dijkstra, H., Nakada, T., Hilke, H. J., & Ypsilantis, T. (1995). *LHCb Letter of Intent*, *LHCb Collaboration*. CERN-LHCb-95-001.

Durr, S., Fodor, Z., Frison, J., Hoelbling, C., Hoffmann, R., Katz, S. D., Lippert, T. (2008). Ab initio determination of light hadron masses. *Science*, *322*(5905), 1224–1227.

El Naschie, M. S. (2000). On the unification of the fundamental forces and complex time in the E(∞) space. *Chaos, Solitons and Fractals*, *11*(7), 1149–1162. https://doi.org/10.1016/S09600779(99)00185-X

Epelbaum, E., Hammer, H.-W., & Meißner, U.-G. (2009). Modern theory of nuclear forces. *Reviews of Modern Physics*, *81*(4), 1773.

Evans, L. (2007). The large hadron collider. *New Journal of Physics*, *9*(9), 335.

Evans, L. (2009). The LHC machine. *Proceedings of Science*.

Evans, L., & Bryant, P. (2008). LHC machine. *Journal of Instrumentation*, *3*(08), S08001.

Fabjan, C. W. (2008). ALICE at the LHC: getting ready for physics. *Journal of Physics G: Nuclear and Particle Physics*, *35*(10), 104038.

Feynman, R. P. (1985). QED: The Strange Theory of Light and Matter Princeton University Press. *Princeton*, *New Jersey*, p15.

Francis, A., Green, J. R., Junnarkar, P. M., Miao, C., Rae, T. D., & Wittig, H. (2019). Lattice QCD study of the H dibaryon using hexaquark and two-baryon interpolators. *Physical Review D*, *99*(7), 74505.