SECTION 18: THE STRONG FORCE: TWO EXPRESSIONS

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Abstract

The exact origin of the strong force (holding compound atomic nuclei together) is not yet a completely settled matter. Some authors (Robert Oerter) attribute this force to the exchange of virtual mesons between protons and neutrons (as in the original theory of Yukawa), while others (Frank Close) claim this old model has been superseded by the modern theory of quantum chromodynamics (QCD), and attribute the binding between nucleons to a magnetic analog of the color charge, originating in the exchange of gluons between quarks (theory of Gell-Mann). Still others (Nicholas Mee), think both gluons and mesons play a role. My own view is that the original Yukawa model is correct (for the between-nucleon force), but the reader will have to make his own choice, and realize that not all experts would agree with me (or each other). (The binding of quarks within individual nucleons however, is generally agreed to be due to the Gell-Mann gluon exchange mechanism.)

This article has been translated into German by Valeria Aleksandrova: many thanks, Valeria!

http://www.pkwteile.de/wissen/die-starke-kraft-zwei-ausdruecke

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My reasons for preferring the original Yukawa model are several:
1) Yukawa's mathematics work, correctly predicting the mass of the exchanged mesons. If we deny the validity of this model, what are we to do with this mathematical structure and these mesons?
2) If the color-magnetism theory is correct, then all proton-neutron combinations should be equivalent, whereas we know that some are favored - the alpha particle, for example, and all combinations of even numbers of nucleons. There are also "magic numbers" of nucleons, combinations of special stability among the heavier nuclei. Finally, why do we not find isolated neutron-neutron pairings? The pion exchange model answers all these questions.
3) Because mesons carry both flavor and color charges, it is also possible that both effects are at work simultaneously (after all, gluons do attract each other, so if nucleons are sufficiently closely packed, there might be gluon-gluon attraction between nucleons as well as within nucleons). Mesons carry color-anticolor charges (always of the same color), so they can neatly substitute themselves for the color charge of a baryon's quark. Because they also carry flavor/anti-flavor charges (in this case not necessarily of the same flavor: d and anti- u, for example), they can just as neatly change a baryon's "u" quark into a "d" quark (and hence a proton into a neutron), or vice versa. A "magnetic" color effect, however, could not by itself change a quark's flavor. The exchange of mesons allows the neutron to satisfy

its natural tendency to undergo beta decay via a virtual reaction rather than an actual decay.
4) A true magnetic analog of the color charge is expressed as "asymptotic freedom" - the increasing freedom of movement of the quarks as they approach each other at the center of the baryon. Hence this is an inwardly directed "magnetic" effect, typical of the strong force, not a likely source of binding energy beyond the confines of the baryon. The symmetry-keeping role of the color charge is to permanently confine the fractional charges of the quarks to whole quantum charge units. While "asymptotic freedom" is completely understandable within this conservation context as a "local gauge symmetry" effect, the external binding of other baryons is not. (See: Frank Close: *The New Cosmic Onion*" Taylor and Francis 2007); (See: Robert Oerter: *The Theory of Almost Everything*. Penguin (Plume) 2006); (See: Nicholas Mee: *Higgs Force* The Lutterworth Press 2012); (See: Gross, Politzer, Wilczek: *Science:* 15 October **2004** vol. 306 page 400: "Laurels to Three Who Tamed Equations of Quark Theory.")

Introduction

The strong force has two structural levels of expression, quite different, one *within* the individual baryon (mediated by a Gell-Mann gluon exchange field carrying "color" charge from one quark to another), and a second *between* individual baryons (mediated by a Yukawa meson exchange field carrying "flavor" charge from one nucleon to another). While the internal gluon expression of the strong force consists of an interaction among three quarks carrying 3 "color" charges ("red/green/blue" or "red/green/yellow") exchanging a color-carrying gluon field, the strong force at the compound nuclear level consists of an interaction between two or more "nucleons" (protons and neutrons) carrying 2 quark "flavor" charges ("up, down"), exchanging a flavor-carrying meson field. The virtual gluon field is composed of color-anticolor charges, and the virtual meson field is composed of flavor-antiflavor charges, so the analogy is complete, except that the gluon field is massless while the meson field is massive. The massless gluon field nevertheless produces a short-range force field because unlike photons (the field vectors of the long-range electromagnetic force), the gluons attract each other (gluons have been compared to "sticky light").

Gluons carry color-anticolor charges in any combination, except green-antigreen, which is doubly neutral, so there are 8 effective gluon field particles. Mesons are quark-antiquark pairs, which may carry the same or different flavor charges, but mesons always carry color charge in neutral combinations (such as red-antired).

Two particle charges unique to the quarks, "flavor" and "color", each produce a version of the strong force, expressed at different structural levels of the nuclear material. The color version of the strong force is expressed within the baryon, producing absolute quark confinement, while the flavor version of the strong force is expressed between nucleons in a compound atomic nucleus, producing a very powerful (but not absolute) nuclear binding force. The color version of the strong force serves symmetry and charge conservation; the flavor version of the strong force serves symmetry conservation via the less stringent "least bound energy" principle.

The Strong Force "Color" Charge (Gell-Mann and Zweig, 1964)

As noted above, there are three "color" charges which are exchanged between quarks by the "gluon" field; gluons are composed of a color-anticolor charge pair. The constant "round-robin" exchange of the massless gluons (at velocity c) from one quark to another is the strong force mechanism which binds the quarks together. There is a strong resemblance between color and electric charge, suggesting that the strong force gluon field is possibly derived directly from the electromagnetic field (see below).

Quarks are sub-elementary particles, as we know from their fractional electric charges which are either 1/3 or 2/3 of the unit charge carried by the truly elementary leptons such as the electron. Allowed quark combinations always sum to zero or unit leptonic values of electric charge: the proton is +1, the neutron 0, mesons are 0, +1 or -1. The symmetry which the strong force is protecting is this whole quantum unit of electric charge, the elementary leptonic charge, and whole quantum unit charges generally. If quarks were not confined as they are, there would be no way for permanent forms of matter to neutralize their partial electric charges, or other partial charges they may carry (such as color and identity - antiquarks would only cause annihilations). Symmetry could not be restored, and charge could not be neutralized or conserved (in permanent forms of matter), if individual quarks with partial charges roamed freely: immediate annihilation by antiquarks would be the only symmetry-conserving alternative. The strong force color charge and gluon field protects symmetry by confining these sub-elementary particles into whole quantum unit packages of charge which can be carried, cancelled, neutralized, or annihilated by the elementary unit anticharges of specialized alternative charge carriers such as the leptons and mesons. Given the absence of antimatter in our matter-only material universe, the role of the strong force color charge is to protect the quantum mechanical requirement of whole unit charge in the service of symmetry and charge conservation. (See: "Symmetry Principles of the Unified Field Theory: Part I"; and "Symmetry Principles of the Unified Field Theory: Part II".)

If one were to fracture an elementary leptonic particle into three parts, but require that when it became "real in time" it must retain its "virtual" leptonic character in terms of whole quantum units of charge, one would need a confining force with exactly the characteristics of the strong force as produced by the gluon field of the color charge. And just as the quark electric charges appear to be the remnants of a fractured lepton (or leptoquark), so the gluon field appears to be the remains of a fractured photon - "sticky light" - the divided field vector of a divided leptonic electric charge (which is probably why the gluons attract each other). Elsewhere we have noted that the ability to assume electrically neutral internal configurations (as in the neutron or neutral leptoquark) is the fundamental reason why the baryon must be a composite particle, if it is to break the symmetry of the primordial particle-antiparticle pairs.

(See: "The Origin of Matter and Information".)

The strong force (gluon field) represents a compromise between the necessity of cosmological symmetry-breaking and the requirement of quantum mechanical whole unit charge symmetry-keeping: the irresistible agenda meets the immovable principle. The force of the collision accomplishes the impossible, but via a compromise - the "virtual" fracturing of an elementary particle with the permanent confinement of its quarks and partial charges. Nature is indeed subtle - if not downright sneaky.

The principle of "asymptotic freedom" (Gross, Wilczek, Politzer, 1973) illustrates the symmetry-keeping role of the strong force. As the quarks move apart, their partial charges increasingly threaten the symmetry-keeping function of whole quantum unit charges, and the strong force responds by strengthening its grip. Conversely, as the quarks move closer together, the threat to whole charge unit symmetry-keeping posed by the quark's partial charges diminishes, and the strong force relaxes (an expression of local gauge symmetry in the gluon exchange field of the strong force). (See: "Global vs Local Gauge Symmetry in the "Tetrahedron Model"".) If the quarks are squeezed together so closely that the original leptonic elementary configuration is completely restored (the "leptoquark"), the gluon field self-annihilates and the strong force vanishes. (The strong force vanishes when quarks are sufficiently compressed because the whole gluon field - being composed of color-anticolor charges in all combinations - sums to zero.) In this configuration a weak force leptonic decay is possible for the proton via the "X" IVB, with the emission of a leptoquark neutrino ("proton decay"). (See: "Proton Decay and the Heat Death of the Cosmos".)

The Strong Force "Flavor" Charge (Yukawa, 1934)

The role of the color charge is to protect charge invariance, charge conservation, and symmetry conservation by maintaining the integrity of whole quantum charge units; hence charge conservation and charge invariance explains the absolute character of the confinement of quark partial charges. Fundamentally, the conservation role of the flavor charge is to quantize and gauge the mass parameter of the elementary particles, whether leptons or quarks. In the virtual meson field expression of the strong force, binding nucleons in compound atomic nuclei, the role of the flavor charge also has a symmetry-keeping function, but with respect to bound vs free energy states rather than charge. The flavor charge in its virtual meson field expression can help reduce the amount of bound energy (mass) contained in the baryon ground state, while not violating the absolute parameters of charge conservation and invariance (electric charge, color charge, baryon number charge, spin).

It is the fact that we have two quark ground state flavor charges ("up-down"), that allows us to have two ground state baryons (neutron udd and proton uud+), which can share their virtual meson fields (uu, dd, u$\underline{d}$+ or $\underline{u}$d- (antiparticles underlined)), and so bond together by reducing their total bound energy content (the nuclear analog of chemical bonding). Because neutrons spontaneously decay into protons (half-life of about 15 minutes), and protons, given a sufficient energy boost, will revert to neutrons, we see that these two particles are in a real sense simply different electrically charged versions of one another. This close "family" relationship is the basic reason why these particles can form a combined "resonance" - the "nucleon". (The fundamental reason for the existence of the u,d quark dyad goes back to the necessity for an electrically neutral particle (with internal fractional charges that can sum to zero like the neutron) to break the symmetry of the primordial particle-antiparticle pairs. Added to this are quantum mechanical rules conserving charge, symmetry, and energy which require the fermions to be distinguishable one from another.)

It is remarkable what a variety of compound atomic nuclei can be produced by the exchange of a simple meson particle-antiparticle pair between proton and neutron (92 natural elements plus hundreds of isotopes). Another remarkable fact is that it requires the input of energy (as in the "Big Bang" or the interior of stars) to force these nucleons into such close proximity that they will actually bond. They will not bond spontaneously (unlike the gluons), but require some additional external coercion (to overcome the electrical repulsion between the protons). Hence the nucleosynthetic pathway conversion of bound to free energy is actually the role of gravitational symmetry conservation, not actually an "agenda" of the flavor charge, although we can see it as a role of their combination (flavor charge plus gravitational force). As noted elsewhere, the gravitational force is produced by the time dimension or historical entropy drive of matter. Therefore, the truly spontaneous stellar conversion of bound to free energy is ultimately a consequence of the temporal entropy drive of matter, eroding and vitiating the energy content of atoms via gravity and the nucleosynthetic pathway. Entropy increase and symmetry conservation work hand in hand.

Flavor charges apparently exist to quantize and regulate, scale, or "gauge" the mass of quark and leptonic elementary particles, an energy conservation role. Flavor charges are associated with and identify the specific masses of quark and leptonic elementary particles. Inasmuch as massive particles must have an associated temporal entropy drive and gravitational field, we can say that the symmetry conservation "agenda" of the flavor charge (if any) is revealed only through the temporal entropy drive which is naturally associated with massive particles - including their gravitational field (which produces time), with all its consequences for the release of bound to free energy in stars and other astrophysical phenomena (as well as radioactivity, particle and proton decay).

In contrast to the rather passive character of the flavor charge, the color charge of the strong force clearly has an "agenda" of quark confinement in the service of symmetry and charge conservation, through the protection of whole quantum charge units. The flavor charge of the strong force also has an "agenda" of symmetry conservation, but not through charge conservation, rather through the release of bound to free energy via gravity-assisted nucleosynthesis, achieving a "least bound energy" configuration for compound atomic nuclei.

The "Nucleon"

The "nucleon" is a combined state of both the proton and neutron, a "resonance" of these particles. Because in the combined state the baryons can share their load of "parasitic" virtual mesons, a significant reduction of their total bound energy is possible. This reduced energy is the "binding energy" of the atomic nucleus released in nuclear fusion (representing the amount of energy that must be replaced if the bond is to be broken and the proton/neutron made whole and free again). The quark composition of the proton is "uud+", while that of the neutron is "udd". The exchange of a (virtual) meson particle-antiparticle pair, ud+ or ud- (antiparticles underlined), changes a proton into a neutron and vice versa. If two protons and two neutrons combine, they can position themselves at the corners of a tetrahedron in which all partners are equidistant. In the tetrahedral configuration meson exchange is especially efficient, as each proton has two equidistant neutrons to play the round-robin exchange game with, and vice versa (apparently our penchant for playing catch is of ancient origin). This 4-baryon tetrahedron is the alpha particle or helium nucleus, an especially tightly bound and favored nuclear configuration (the "brick" of the nucleosynthetic pathway), and it is easy to see why. The exchange of mesons between neutron and proton is exactly the "sharing of differences" that epitomizes the third stage of the General Systems model. It leads directly to the 4x3 tetrahedral bonding of the alpha particle (4 nucleons each of 3 quarks), and thence to the carbon atom - 3 alpha particles each of 4 nucleons; and so on up the nucleosynthetic pathway to oxygen and beyond, in alpha particle increments. (See: "The Fractal Organization of Nature".)

The "nucleon" can also be seen as a state of higher symmetry than either the proton or neutron alone - the analog of a unified force symmetry state, but expressed at the particle level of baryons. This symmetry was originally given the name of "isospin" symmetry, and was thought to characterize a global gauge symmetry of the strong force which was insensitive to local "spin" differences ("up" or "down") among the baryons. In this case the meson (or "Yukawa") exchange field formed a local gauge symmetry "current" or field vector which carried and effected "spin" transformations among the baryons, but without changing the underlying binding principle of the strong force.

Local changes in the "isospin" symmetry (changing "up" spin to "down" spin) leaves the strong force unaltered when protons and neutrons are interchanged. The name derives from assigning a completely imaginary or fictitious state of "spin" to the nucleon ("up" for the proton and "down" for the neutron). This theoretical spin state is isotropic (invariant) insofar as the strong force is concerned, whether it is in the up or down "phase". When the quark model was developed by Gell-Mann and Zweig, the "up" and "down" designations were retained for the quark ground state "flavors". The superseded isospin model of the strong force was then applied to the actual (rather than virtual) weak force transformations of neutrons to protons. Like the strong force, the weak force is also a short-range force with massive field vectors, the IVBs. Also like the strong force, meson exchange occurs in weak force baryon transformations, but as mediated by the IVBs. (See: "The 'W' IVB and the Weak force Mechanism".) (See: James Trefil: *The Moment of Creation*. Macmillian (Collier) 1983.)

The Complexity of Matter

Local gauge symmetry operating at multiple levels of nuclear, atomic, and molecular organization is epitomized in the neutral, quiescent nature of the cold, crystalline, ground state of atomic matter, the state we normally occupy that is so life-friendly. Because it is our normal, habitual state, we become thoroughly accustomed to it and forget how remarkable it really is. The heavy elements of which we are composed are very strange particles indeed: the nuclear material is composed of baryons containing 3 colored quarks of two flavors, bearing partial electric charges which are confined by a massless gluon field exchanged at velocity c. Baryons (in normal matter) in turn consist of two species, protons and neutrons, bound (in compound atomic nuclei) by a virtual meson field exchanged between baryons, which reduces both to a common denominator of least bound energy - the androgynous "nucleon". This fantastically complex nucleus is in turn surrounded by a cloud of electrons (leptonic alternative charge carriers) bound to the nucleus (and each other) by a massless field of exchanged photons. These electric and magnetic fields will, in turn, allow the creation of molecules and a further hierarchy of chemical structure, information, and complexity.

Nor is this all: these particles and fields are surrounded by (and engender) clouds of virtual particles which contribute to their interactions and total bound energy. Elementary particles carry various conserved charges such as electric, color, identity, and spin, including partially conserved charges such as the local quark "flavor" charges. There are neutrinos associated with each elementary particle (neutrinos function as alternative charge carriers for "identity" or "number" charge); and while all charges are balanced by alternative charge carriers rather than antiparticles, antimatter is nevertheless abundantly present in the gluon and meson fields, and in the clouds of virtual particles. The photon is its own antiparticle. The whole atomic complex is set within the regulatory metric and entropic fields of spacetime and gravitation, and subject to the exotic transformation fields of the weak force IVBs which can create, destroy, or transform elementary particles, and elevate portions of the material system above the ground state of electromagnetic symmetry to a higher symmetry level of force unification: electroweak force unification (baryon transformations, lepton creation and destruction), or even the GUT symmetry level (baryon creation and destruction). (See: "The Higgs Boson and the Weak Force IVBs".)

The incredible complexity of matter beggars our understanding, and yet in its ground state it is perfectly well behaved and predictable (in its gross characteristics), a benevolent condition necessary to our evolution and survival. The meson exchange field of the strong force succeeds in reducing the energy level of most heavy atomic nuclei to a quiescent ground state. Radioactive decay is not a common phenomenon in our ordinary elements - one has to look rather hard to find it, as the Curies discovered. The local activity of the meson field provides us with a (mostly) non-radioactive spectrum of stable heavy elements capable of producing and sustaining life - which itself is a whole new level and hierarchy of biological information and extreme complexity, built upon the electron shell and delicate bonding chemistry of carbon atoms. At the top of this biological order, humans are building yet another new information domain of abstract and symbolic thought patterns, imagination, languages, culture, science, mathematics, art, and mechanical and technological systems, including computer languages and the internet, enabling us to begin to comprehend the grand hierarchy of information systems of which we are composed. (See: The Information Pathway.)

Calculating Strong Force Interactions

See the link below (or Google search "amplituhedron") for intriguing recent advances in the formal methodology for calculating the probabilities of strong force interactions between gluons - until now, exceedingly difficult due to the great strength of this force and the fact that gluons, unlike photons, attract each other. It is especially interesting (from the point of view of this website and the "Fractal Organization of Nature") that tetrahedrons are the basic geometric form used in this mathematical formalism.

https://www.simonsfoundation.org/quanta/20130917-a-jewel-at-the-heart-of-quantum-physics/

Links:

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References

Close, Frank: *The New Cosmic Onion*. Taylor and Francis 2007
Gross, D. J. and F. Wilczek. **1973**. *Ultraviolet Behavior of*

Non-Abelian Gauge Theories. Phys. Rev. Lett. 30: 1343.
Gross, Politzer, Wilczek: *Science:* 15 October **2004** vol. 306 page 400: "Laurels to Three Who Tamed Equations of Quark Theory."
Mee, Nicholas: *Higgs Force*. The Lutterworth Press 2012
Oerter, Robert: *The Theory of Almost Everything*. Penguin (Plume) 2006
Politzer, H. D.. **1973**. *Phys. Rev. Lett*. 30: 1346
Wolchover, N. 17 Sept. 2013. "A Jewel at the Heart of Quantum Physics". *Quanta Magazine*

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