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----- Preface

In this paper we approach the problem with a simple empirical observations of the fluctuations
Energy under vacuum, nuclei to higt atomic number, and nuclear interactions
That affect them, including the phenomena called cold fusion,

We are led to believe that the oscillations of the electrons induce fluctuations in energy nuclei. With changes in energy density of the core, density variations involving definition of space between quarks and production of Higgs bosons, which decay rapidly in Z ° bosons, W bosons decaying into
The problem of mergers and fission induced by cold nuclear phenomena, has been addressed in the first part of the article where they took into account nuclei with atomic number less than 4.
The central point is that it takes vortices of electrons and nuclei,
for nuclear reactions and mergers cold.
With simple analogy with what happens in the vortex elements, and elemental analysis, we can assume vortex structures with fairly ordered, with average temperatures
components of very similar.
At the center of the vortex, the nuclei components can have temperatures similar enough, we can assume a state BEC for nuclei in the center of the vortex.
In this case, we can assume that the fields axion produced by exchange between quarks of different nuclei in quasi-BEC and composed of photons super-luminal, may be in a state very excited,
very strong, and can have a range of microns.
The vortices then, can range from the size of microns to nano-meters ..
The same state is conceivable BEC is obtained from exchanges assionici very strong,
we can assume that trade even if the components of micrometric crystals, and in Mossbauer phenomenon ..
With this approach, very simply , we obtain results that confirm the observations made from the analysis of the behavior of nuclei with atomic number less than 4.

The results are the same, with a possible explanation of the phenomenon in the fullness of time decay alpha, beta and fission.
We use this empirical approximations for a rigorous mathematical analysis, according to the standard parameters, involves the use of 19 free parameters standard, +9 parameters for the oscillation energy vacuum quasi-standard + 7 parameters for the Higgs bosons,
+ 100 parameters for self-interaction with the Higgs fields.(SUSY semplice)

we must proceed with empirical experiments, for statistics calculated behavior.

---- First statistical section decay you weak and weak mergers and fissions weak.

The basic mechanism of the decays taken into consideration, is always to the lighting of an area of 10-18mt, such as to create virtual pairs of Z °, which fail to react with the quarks of the nuclei, and to change taste and electric charge to themselves., and in this case is being treated "implicit".

We can also predict that the Z °bosons are the pro duct of the decay of Higgs bosons, the interaction between electrons and quarks in a state TAU.

The Higgs bosons are neglected to simplify for the moment, even if they allow a much more detailed and comprehensive of the various nuclear phenomena and the phenomena of suppression of the particles produced in a vacuum.

In other articles, I propose a general empirical formula based on the energy density of nuclear and electronic, to calculate the probability of nuclear phenomena.

For simplicity, in this article is not addressed.

Processes -beta decay, alpha decay, mergers and cold fissions.

In the case of decay beta-, we can hypothesize a "excitation of a neutron" internal to the nucleus, with a decrease in density with lifting from the surface of the core.
Density change that leads to the decay
In the case of decay of the single neutron, with frequency of about 10 ^ .3 / sec,
We can think of a mechanism inside of a narrowing down quarks and one up quark, while the rest is down to the size of "normal,,,
with a narrowing internal to a radius of about 10 ^ -16 m.
We therefore density ratio in the neutron,
enough to have the frequency considered.

In the case of proton decay, we have some interesting ...

the same mechanism that we have applied neutron, leads us to considerations of a behavior different ending ..
If we shrink the up and down quarks inside to the 10 ^-17mt, (we are considering a proton ionized without the addition of stabilizing electron valence)
and we should also have a bulge down outwards, towards the 10 -13 m, with density ratio of about 10 ^ -16, and in this case we may have lighting frequency of the space of 10 ^ -18 mt necessary to the creation of pairs of Z ° virtual.
. We have the same rate of decay with the statistics of density and that of electron capture, considering the proton is ionized, or "normal, we obtain the calculated half-life
10^ +113 years .
Will not be easy to find experimentally, half-life of this frequency, but still within the parameters considered by the various theories.
Integrating the data that are present in the formulas, we could identify specific behaviors general decay of nuclei.
In cases of known natural decay by experimental observation, with a suitable calculation program, we could find the actual values of density, distance and other parameters in the two statistics, and build a model of the nucleus very precise.
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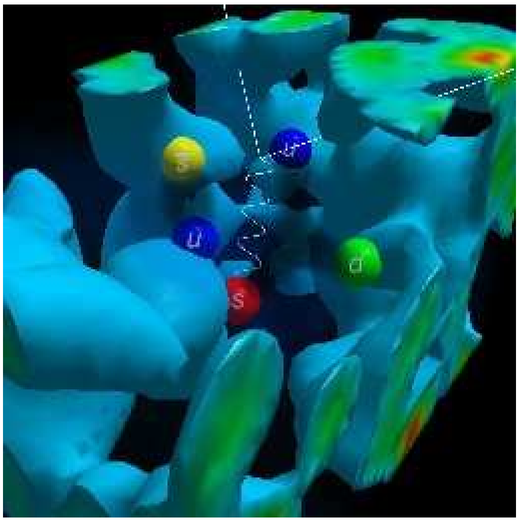

Fig.1-painted image of the interior of a proton. with phase "strangeness

We consider that enough small changes to the radius of the electron and the proton,
with minor variations of the rays of the nucleus and the electron, or with a neutron in the case of β - ,with a very small change of the relative densities, to have all the data corresponding to those actually found experimentally.,
The data cross the two aggregates, lead us to a very precise model of the nucleus and protons and neutrons and,
and could lead to much more simplified models of neutron and proton, with a greater understanding of the relationship between electro-weak force and strong nuclear force.
We may regard the quarks as composite particles, formed, in the case up, by two positron and an electron, joined together by neutrinos and antineutrinos, with bonding by strong forces of the Casimir vacuum,
particular asymmetries between spin and electric charge, and neutrinos, define a process of matter-antimatter annihilation very complex and with half-lives of about 10 +113 years
Down-in the case, we have two electrons and a positron, the differences in charge +2 / 3 and -1 / 3 are always derived from the composition asymmetries, asymmetries of CP violation.

Important to note that the model explains why a boson Z °, interacting with a quark, it changes strangeness,
The model also explains why the difference between quark and anti-quark is due to the internal presence of neutrinos with left chirality know and neutrinos with right-hand chirality.

2nd --- DECAY α

the alpha decay, which is believed to belong to the field of the strong force, and therefore should have no correlation with the weak decays, could have interesting explanations, and rientr are fully in the forms assumed for the decays "weak.

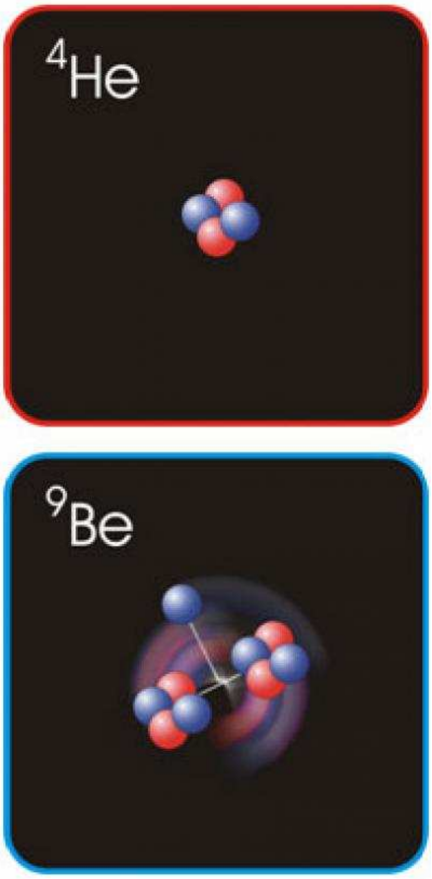

Fig.2-- pictorial view of a group of Be9

In unstable nuclei, chains of 2 protons and two neutrons, present inside the nucleus unstable, may vibrate and become detached from the rest of the core, and may illuminate the distance of 10-16cm, or less, and produce pairs of Z ° from the virtual empty.
The pairs interact with the 4 particles, and will change state and flavor, the transmuted into alpha-odd, then decay very rapidly in alpha, and the excess energy of 23 Mev produced by melting is used for the emission to the outside of the αparticles.

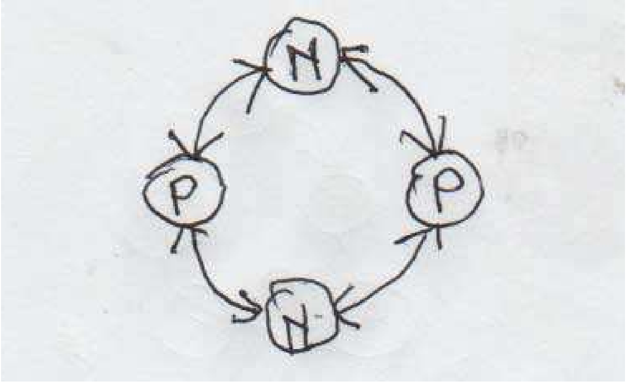

Fig.3 - excitation chain 2 protons and 2 neutrons inside the nucleus
With this mechanism, strange, α absorb and re-emit large amounts of energy drawn from the binding, and the two neutrons and two protons bound to alpha can transform the excess energy produced by their fusion) in enough energy to break away from the nucleus, and give normal alpha radiation ..

The two neutrons arriving at energies of over 1300 Mev, and at this point it has the identification of the space of 10-16cm and transformation into Ξ^-
I always get two protons to energies of 1300Mev transmuted into Ξ°

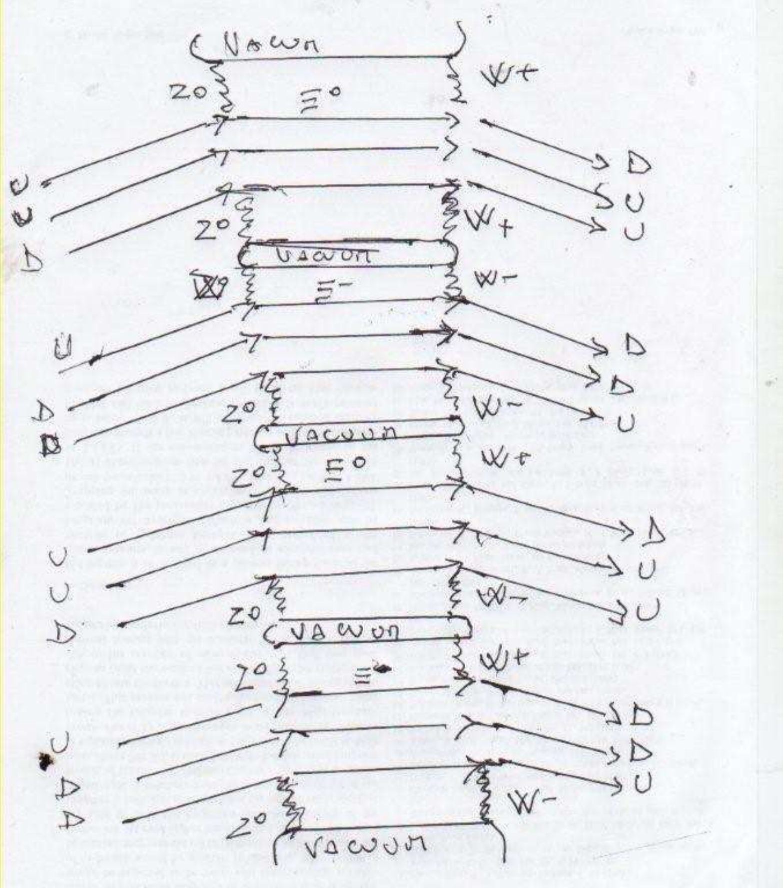

Fig.4-chain internal diagram P + N + P + N bonding with α

decay in Ξ°· 10-10 sec, for the particular conditions of bond already happened blend together in alpha He4 glued weak.with a strong emission of energy due to the mass defect,. and are detached from the core, according to the following reactions

$N + Z^* \longrightarrow \Xi^-$
$P + Z^* \longrightarrow \Xi^\circ$
$2\,\Xi^\circ + 2\,\Xi^- \longrightarrow 4N\varepsilon^{**}$(xi strange particle still in nucleo)
$4N\varepsilon^{**} \longrightarrow He4$
formulas reaction

$4\Xi^{\circ-} + 4W^{\mp} \longrightarrow 4He$

The energy produced by the fusion of the particles, approximately about 23 Mev, is returned to the core, and the alpha is emitted to de-energize the core.
We could also explain and fission of nuclei, always with discovery mechanisms lighting of interior spaces in the nuclei, including complex chains of neutrons and electrons, with the variables already described.
It is also possible a different reaction, perhaps less likely,
possible but as far as I know.
Only laboratory tests and measures addressed, can
Confirm the phenomena, and identify the weights of the various possibilities.

3a --- decay and induced fission in nuclei of iron, thorium, carbon and other elements

The greater stability of nuclei to high atomic number, makes possible a large amount of decays "simultaneous, with protons and neutrons in the nucleus with energy exchanged with the vortices electronic, and arriving to transmute the nucleus in an element in rapid decay, with fission final destroys the vortex electronic

We may have reactions in the chain of nucleons, with intermediate stages strange, and Xi-Xi ° Previous analyzed for alpha phases.

We may also have different reactions in the quark inside the nucleus, up and down quarks present in pairs of nucleons with change of flavor, with an intermediate step in sigma, $\Sigma°$, chain to 2 different chain to 4 of decay .α

The tiles and nucleons are "excited over 1300Mev with the whirlpools of electrons.

The electrons in the vortex around the cores have an electromagnetic behavior similar to the "normal electron capture, but in this case do not produce illumination of space and production of Z° their task is exhausted with the transfer of electromagnetic energy to the nucleus with photons axions ..

We can in some way, and inject induce behaviors of the vortex, chains of millions, of electrons outside the nucleus, with appropriate electromagnetic fields or sonic.

And produce chains of many millions of electrons, united to spin, in vortex around the cores

We have then excitation of protons that can define a space of 10-19 m between pairs of neutrons and protons, and are able to produce Z ° bosons that change flavor to interacting nuclei

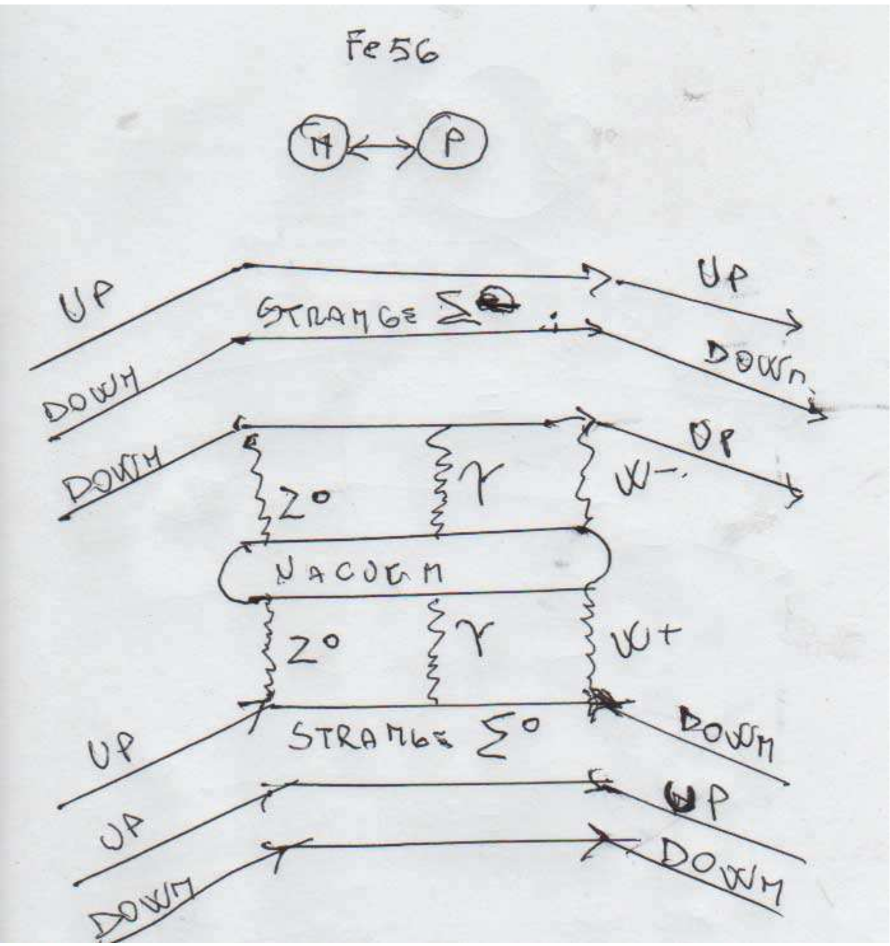

Fig.5-- chain diagram 2 inner core Fe56

In the particular case of Fe56 we 6 protons, neutrons and 6, which interagis cone together to form Σ°

The internal quark 6 protons and 6 neutrons interact with the Z ° bosons produced by the illumination of spaces 10 ^-17cm between the nucleons., And start the reactions that lead to the protons to become N., and neutrons in P

The core of Fe56, is subjected to 12 transformations strange, $6\Sigma^\circ + 6\Sigma^\circ$ and turns into nucleus Fe46 * (+12 s) strange unstable ..

To a chemical, it may be similar to a core of CA56.

The core of strange Fe (46 +12 * (under the shares it energy decays of $12\Sigma^\circ$ decade with fission, in times in the order of 10-20 sec.,

SUBTRACTION with energy of about 43 MeV, or 0.0046 amu mass increase of the final components of the reaction

obtained at the expense of energy we put into the system to produce chains of electrons.

W bosons $^-$ are annihilated each other and reabsorbed by the gaps of the vacuum energy and we have no emission of particles and energy outward beyond the fission products itself.

We could have a chain with 16 neutral strange particles, in this case, we have a group with similar characteristics argon 56

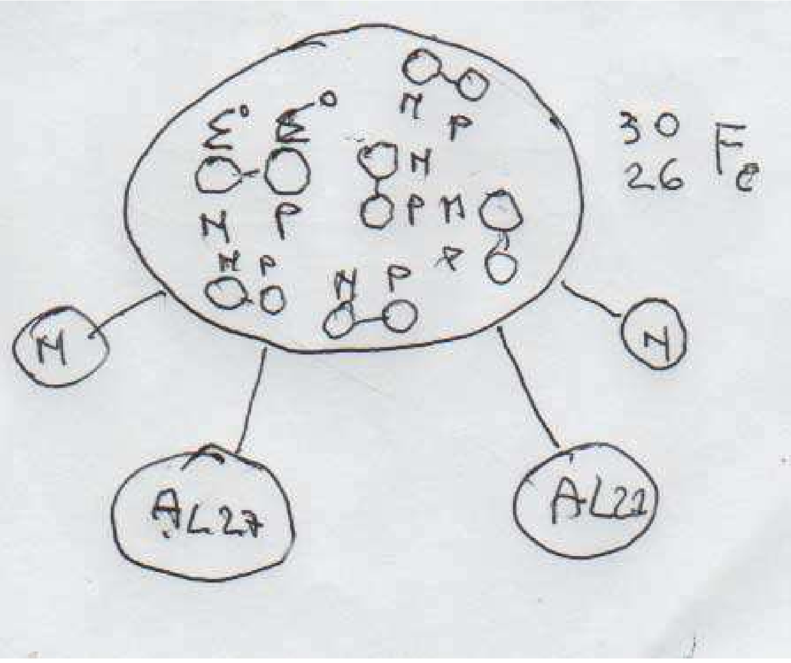

Fig 6 ----- fission of the nucleus of Fe56 in 2 AL27 + 2 N

$$Fe56 + 12(Z^\circ *) \longrightarrow Fe^*46(12\Sigma^\circ)$$

$$Fe^*46(12\Sigma^\circ + 12W^\pm) \longrightarrow 2Al27 + 2\,N$$

In the case of Fe57, we have 2 +3 N AL27

We may have in complex nuclei with atomic number> 18, including the case of Fe56,

a possible branching different rationale, with formation of chains α

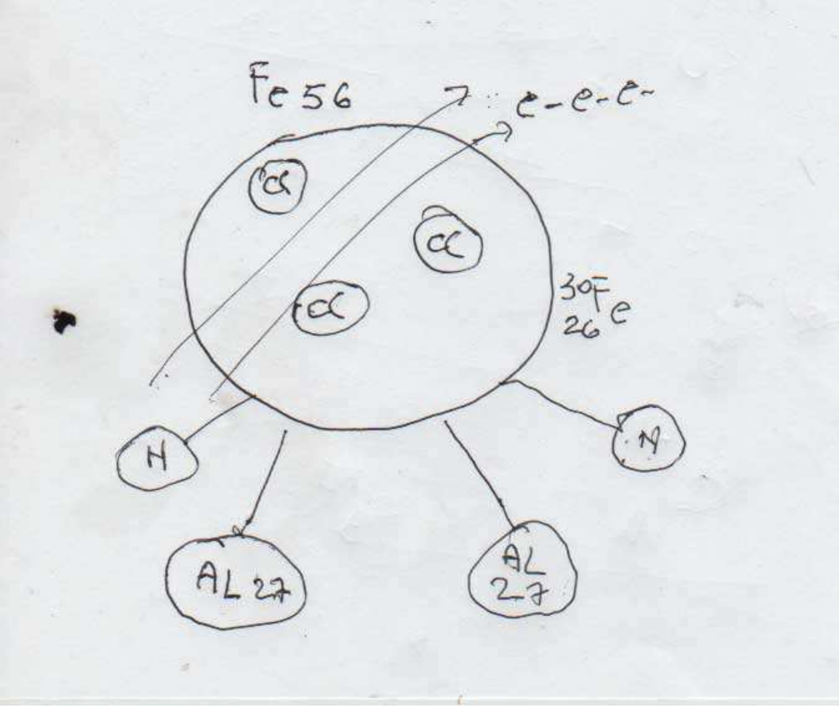

Fig 7 --- alpha chains in Fe 56

The energy produced by 'gluing 3 α weak internal produces the fission of the nucleus

We could also have a different channel of transmutation, with the formation of 4-chain alpha-phase delta

In this case, we would phase where 4 alpha phase delta produce a core with characteristics similar to argon 56, with fission into 4 parts and we get the immediate reaction in 2AL27 + 2N
We note that in the case of fission of
Fe56 —>Al27+ AL27 + 2N
to balance the mass defect endothermic, we must address in the iron core, at least 43 MeV of energy.
The reaction in 2 +2 N AL27 seems to be the most favorable for the need less energy.
Other reactions

Fe56-———> 3O16 +He4 +4N
With input power over 80Mev
Or

Fe54 ———> 3O16 + He4 + 2N

Fe54-———> 2O16 +Ne20 +2N
With input power over 78Mev
In addition, no emission of neutrons,

Fe56 ———> 2O16 +2B12
With beta-decay in 10 milliseconds B12 into C12

Input of energy beyond 52Mev,
this reaction could be the basis for the enormous carbon emissions observed in volcanic reactions

For many experiments, these processes of cold-induced fissions, we produce neutrons, which have a sconcert behavior.
They seem to have channeled trajectories or affected by electromagnetic radiation, very difficult for normal neutrons.
Possible explanation.
Protons can get a lot of energy by electromagnetic vortices of electrons, and can become omega-
In this case, if they do not interact with other nuclei, in 10 ^ -10 seconds, decay into neutrons, with subtraction of energy from the environment for about 0.8 Mev.
But I'm afraid of being strange negatively charged, and thus affected the Influence of electromagnetic fields, and maintain the trajectory affected after the conversion into neutrons normal
Equation

$$H+3(Z\,^*)+\text{ energy}(0.8\text{ Mev}) \text{–>} \Omega^- \text{–>} N$$

This equation explains the behavior of neutrons detected channeled
In different experiments by mr. Carpinteri and Mr. Cardone.
Normally, the free protons, in environment, can have phase strange Xi,
acquire from the environment about 0.5 Mev, which then decay into protons when ricedono.

$$H+2(Z\,^*) +0.5\text{ Mev} \text{—>} \Xi^\circ \text{——>} P +0.5\text{ Mev}$$

4a-transformations and mergers electro-weak induced in nuclei of carbon, thorium and other nuclei.

In many experiments, we reactions of carbon-based, strangely "energy.
The decays are very rapid, similar to those of the strong force, and differ in some respects from those observed in normal nuclei, are different because the conditions inside a core of Fe 56 are different from those so far studied, and observed

these inexplicable results with a mechanism of carbon nuclei quite complex, but similar to the previous explicate for iron., in this case the quarks pass in phase strange $\Sigma^\circ\ *$ reactions with

$$P + Z^\circ \text{——>} \Sigma{*}^\circ$$
$$N +Z^\circ \text{——>} \Sigma{*}^\circ$$

These reactions involving may be only one part,

$$C12 +4(Z^\circ{*}) \text{———>} C^*(4p+2\Sigma^\circ+2\,\Sigma^\circ +4\,n)$$

Or completely involve the C12 core
$C(12\ \Sigma{*}^\circ)$ decays to C12 with time in the order of 10 ^ .10 sec with the mechanism of resorption of W without producing emission of energy.

The core strange thus produced, has neutral charge, and allows a fusion very likely with a core of C12. normal if it is able to interact within the time allowed by the decay.

$$C^*(12\Sigma^{*\circ}) = C^*12$$
$$C^*12 + C12 \longrightarrow Mg24^*$$

MG24 * decays in the manner already illustrated hereinabove in MG24 and emits the energy resulting from the mass defect with a cascade of photons widest spectrum of energy.

$$Mg24^* \longrightarrow Mg24 + \Sigma\gamma\,(1.4\ \text{Mev})$$

C12	12.	6	98.9	0 +	Stable	
MG24	2 3.985	12th	78.99	0 +	Stable	

the core of the C12 * strange neutral nuclei can fuse with other elements, having charge neutral and thus have a great chance to transmute and produce a number of elements with important energy production ..

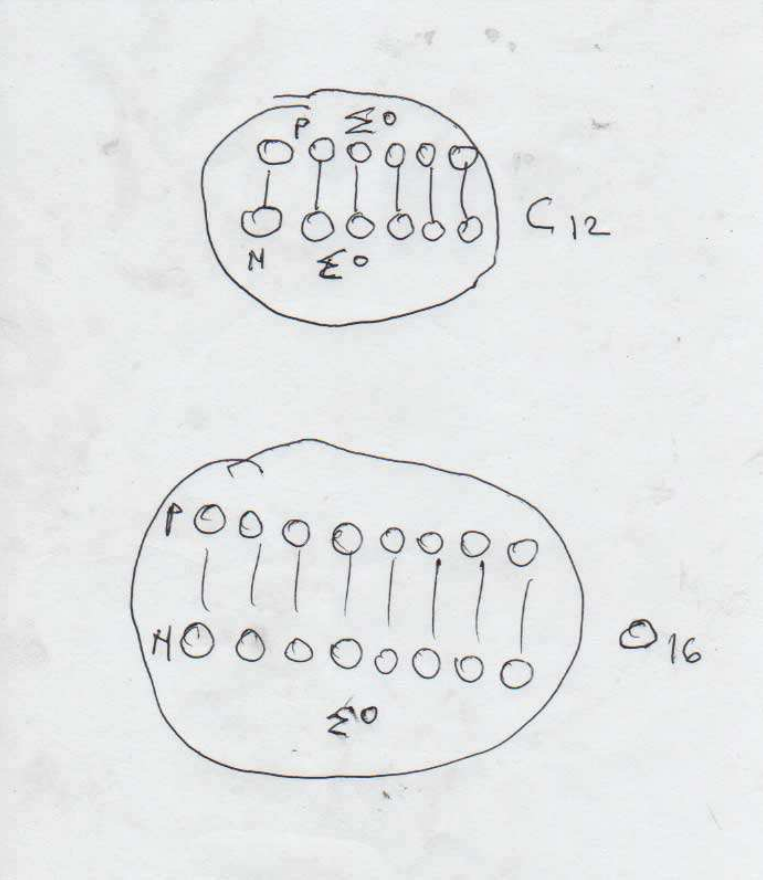

Fig.8-- formation of nuclei with neutral strange passage Σ° *

We also have interesting reactions involving oxygen., And that are based completely transform O16 $O^*(16\ \Sigma^{*\circ})$ a neutral particle
In some cases we observe a energization of nuclei OH-, with vortices electronic around the nucleus of O16, detachment of the H radical,

and transformation with strange decay of the nucleus of O16
for the particular conditions of the experiments, we have a good chance that the nuclei strange neutral O16 *, for the particular conditions of the experiments,
in times of 10-10 sec, can meet and melt easily, at low temperatures with the following reactions;

O16*strange + O16 ——> S32*strange ——> S32 + fotoni (16.5 Mev)

S32	31.9721	16th	95.02	0 +	Stable
O16	15.9949	8	99,762	0 +	Stable

If the core is not strange O16 * in the time of 10-10 sec other nuclei decays into O16 normal, with no power output.
find also other strange fusions involving aluminum nuclei, nuclei of sodium and chlorine and silicon.
We have the possibility that the excess energy due to the fusion, is emitted photons with axions, and nuclei of oxygen or carbon, act as a receiving antenna, and fission in alpha.
In the case of O16 -----> 4 He4 with energy endo-energy of about 4 Mev

- a different possibility, which concerns' energy emitted by fusion of complex nuclei,

with photons assionici,
but most likely the carbon nuclei have the best chance to be absorbing photons assionici.,
we could have triple fission track, with the fission of a nucleus of C12 in 3 neutral strange nuclei 4He * sn and training with Triple track of alpha

C12 ——> 3 He4*sn ——> 3He4

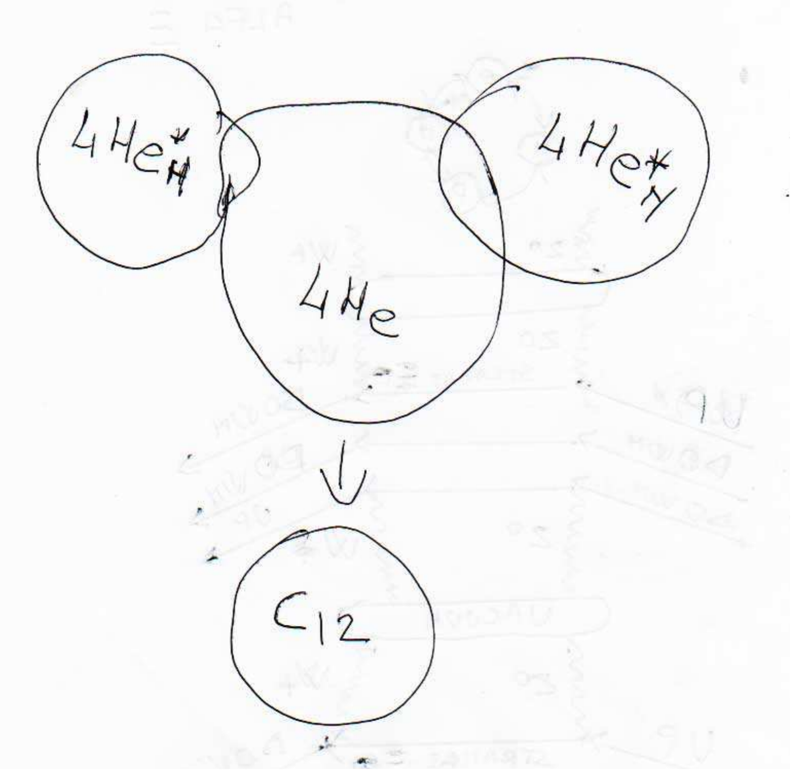

Fig .9-triple track of 4 He, fission of C12
The fission reaction C12 in 3 alpha,

may also be described in

C12+ (12W) ——> 3 He4

Reaction endo-energy obtained at the expense of energy immes know in the core of C12 with photons assionici., Of about 7.3 MeV, obtained by fusion of nuclei in cold fusion reactions.
This reaction is very likely in cold fusion in living organisms

Possible traces of experimental decays of C12 in 3 alpha, are the tracks in CR39 detected by Pam Boss

5th - single neutron decay
The mechanism of the decay of the neutron is more complicated than the single beta decay-observed in complex nuclei.
In this particular case are the three quarks to excite each other to define a space of 10 ^ - 16 cm, and the pairs of virtual Z ° thus produced, lead to a decline in the neutron proton complex mechanism.

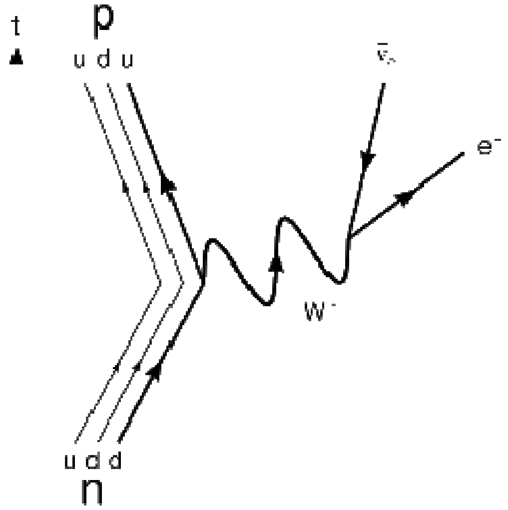

Fig.10-diagram of Feynmann decay – β
. N ——> P + e^-+ $\nu\varepsilon^-$

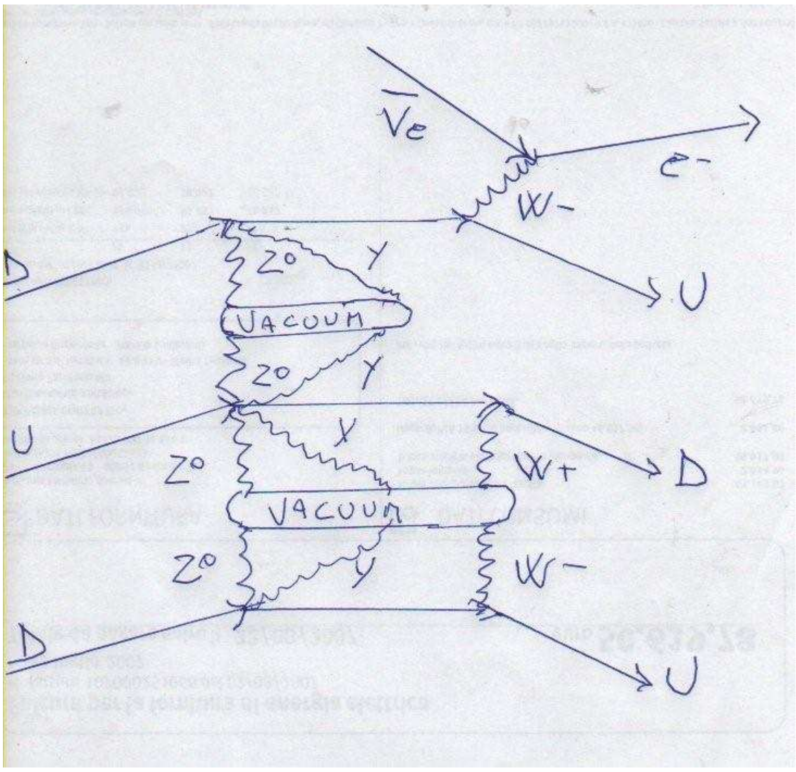

Fig.11-beta-decay

Free neutrons decay times of about 15 minutes, with a reaction to complet

down +Z° ——> s+ fotone +W- ——> up + e^- + $\nu\varepsilon^{-}$
up + Z° ——> s + fotone + W+ ——> down

The mechanism of decay could be practically similar to the above, in this specific case are the three quark excited to each other, up to define a space of 10 ^ - 16 cm, and the pairs of Z ° virtual thus produced, lead to decay the neutron into a proton with a mechanism similar to the previous one. compressed but in times of about 10 ^ -23 seconds.

N ——> p + e^- + $\nu\varepsilon^{-}$

6a-proton decay single

A mechanism of self-excitation may occur in individual protons, but only allows the internal energy of the illumination between the down and alternatively one of the two up quark, and is not achieved the possibility of emission of a W + free normally.
In addition, the continuous exchange of photons assionici, does not produce appreciable entropy.
.

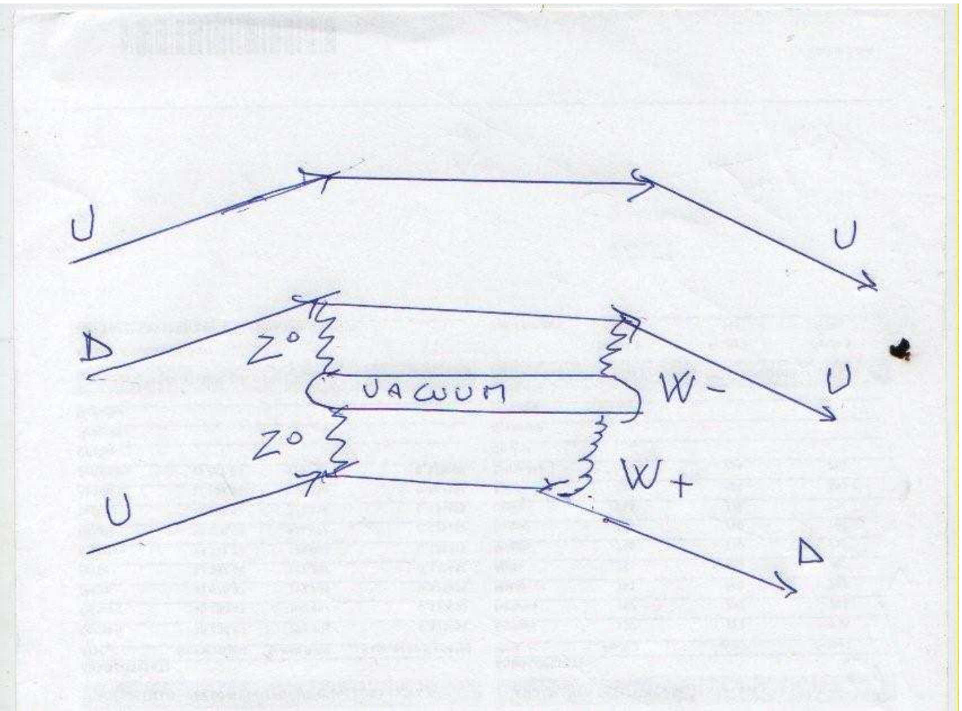

Fig .12. The proton is stable and can not decay into neutron

We have a possible decay of a proton into a neutron without interaction with electrons, as we have shown, with a reaction that relates to another external element, a neutrino.

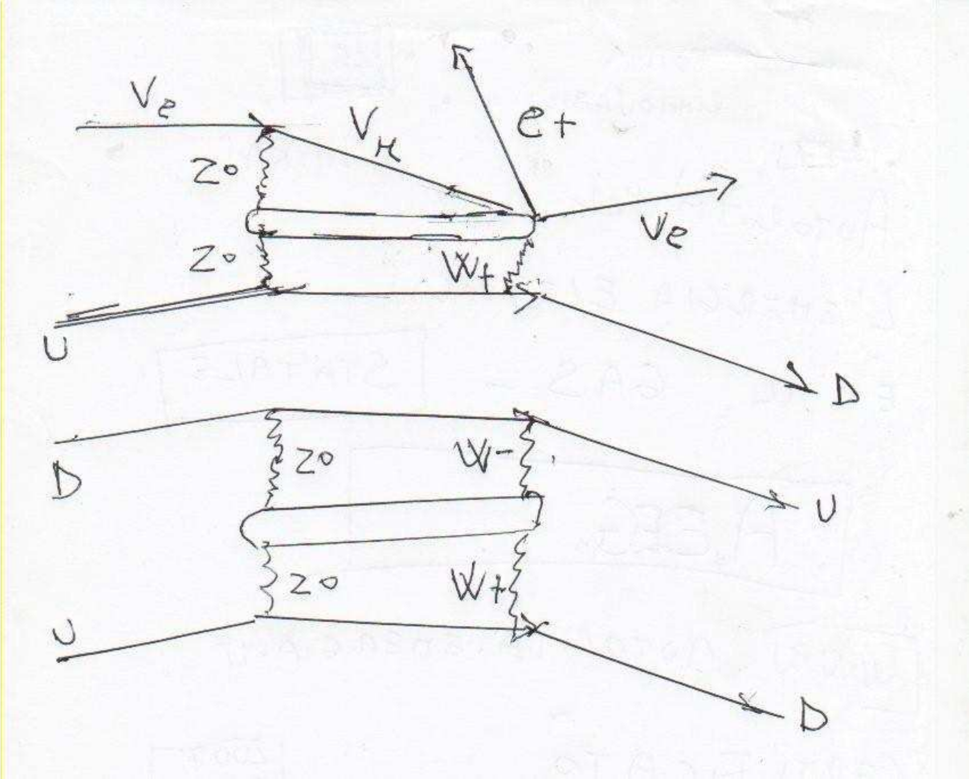

Fig.13. interaction of proton and neutrino

final reaction
P + Ve ------ → N + e+ + Ve

The reaction has extremely small cross sections.

Single proton decay in positron
For this phenomenon, we hypothesize mechanisms more complex lighting with energy states very unlikely the proton, which could decay into and $^+$ + Neutral pion., With a time course longer than 15 minutes, we are certainly more than the 10 +33 years, probably over 10 years +113.

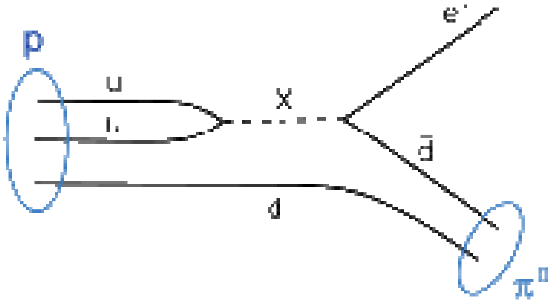

Fig.14-example of proton decay photons in e $^{+e}$

In the case of the proton, the decay time with empirical formulas density is about 10 ^ +113 years, much greater than the minimum allowed by quantum calculations, about 10 ^ +33 years,

compatible but with the above in the case of electron capture and the upper limit allowed dala quantum mechanics.
intervene or artificially from the outside to modify this type of rate frequency, is very difficult.

--- Ratings General-
In summary:

1-Tr attiamo decay β -, + β in nuclei with many nucleons, forming the nucleus, and we assume a neutron or proton
can swing on the core itself, and illuminate a space of 10-19mt, resulting in the production of Higgs bosons, which decad ono in Z ° bosons and subsequent interaction with the final processing of the neutron into a proton and vice versa.

2-treat the decay ,α where small chains of two protons and two neutrons can vibrate on the core, locating the space for the production of pairs of Z ° it virtual.

3-treat decay β - in individual neutrons, which have special conditions, where the quarks can be detached from each other and find a space that produces virtual Z °, and then decay in about 15 minutes in proton + e-+ antineutrino,

4-treat the phase strange induced in a single proton from vortices of electrons and in individual deuterons.

5 - treat proton decay "stable

6-treat transmutation-induced fission in complex nuclei

We have shown how, with the same mechanism based lighting of spaces with "light heavy
Or bundles of bosons Z ° the decay of Higgs bosons, we can explain all types of decays, and also the strange reactions of fusion or fission in cold fusion.
It said one of the major differences between the mechanisms of nuclear decay weak and strong, the different energy response of the particles involved in the phenomena.

CONCLUSIONS ---

With the introduction of the concept of nuclear energy density probability frequency of capture and decay, we can treat statistically beta-and beta + decays in a simplified way,
also we can bring everything to a single parameter, the amount of space or distance illuminated by the behavior of electrons and quarks with the production of Z °, and interactions with magnetic fields.
And then also the possibility of identifying techniques that can artificially affect the "normal natural characteristics of these decays.
This seems easier in the case of oscillations of electrons, neutrons than forming the nucleus, but points out that unify the two types of decay could open many avenues for new kinds of technologies.

In addition, we have a large contribution from the analysis of behavior "deep pairs of W ∓ And possible interactions with real quarks, to treat a simplified model of protons and neutrons, which allows us a simplified analysis of the electro-weak force and the strong nuclear

The decay behavior of artificial fusion reactions can explain the "weak and release of energy that we observe in the so-called cold fusion.
We could open a new nuclear chemistry with a huge amount of possibilities and permutations of the mergers, to high energies, the old dream that could come true alchemy.
In addition, certain behaviors may open interesting perspectives also for uses of energy production.

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Mr. Heffner, Mr Abd Lomax, and many others that are mentioned in the references.

Table of sinboli

α = alpha decay in nuclei

β = beta decay in nuclei

γ = photon

Δ = delta phase in the nucleus

Σ = sigma hyperon

Λ = lambda hyperon

Ξ = Xi hyperon

Ω = omega hyperon

References

Neutrons from Piezonuclear Reactions
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Piezonuclear reactions

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On the possible physical mechanism of Chernobyl catastrophe and the unsoundness of official conclusion

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Adamenko S and mr Vysotskii V (2005) Observation and modeling of the ordered motion of hypothetical magnetically charged particles on the multilayer surface and the problem of low-energy fusion. Condensed Matter Nuclear Science, ICCF-12, Yokohama, Japan, World Scientific

Piezonuclear neutrons from fracturing of inert solids

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Resource Letter QCD-1: Quantum Chromodynamics

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\Asymptotic freedom and quantum chromodynamics: the key to the understanding of the strong nuclear forces," Advanced Information on the Nobel Prize in Physics, http://nobelprize.org/nobel_prizes/physics/laureates/2004/phyadv04.pdf. (E{I)

Some encyclopedia articles on QCD are

4. \Quantum chromodynamics," A. S. Kronfeld in Macmillan Encyclopedia of Physics, vol. 3, edited by J. S. Rigden, pp. 1260{1264 (Macmillan, New York, 1996). [doi: 10.1223/0028973593]. (E{I)
5. \Quantum chromodynamics," G. Sterman in Encyclopedia of Mathematical Physics, edited by J.-P. Fran_coise, G. L. Naber, and Tsou Sheung Tsun, pp. 144{153 (Elsevier, Amsterdam, 2006). [hep-ph/0512344]. (I{A)
6. \Quantum chromodynamics," C. Quigg in McGraw-Hill Encyclopedia of Science & Technology, vol. 14, pp. 670{676 (McGraw-Hill, New York, 2007), 10th ed. [doi: 10.1036/1097-8542.562500]. (E{I)

For a book-length exposition of the wonders of QCD, see

7. The Lightness of Being: Mass, Ether, and the Uni_cation of Forces, F. Wilczek (Basic Books, New York, 2008). (E)

The rest of this Resource Letter is organized as follows. We begin in Sec. II by reviewing the basics of the theory of QCD, giving its Lagrangian, some essential aspects of its dynamics, and providing a connection to earlier ideas. In Sec. III we cover literature on theoretical tools for deriving physical consquences of the QCD Lagrangian. Section IV covers the most salient aspects of the confrontation of QCD with experimental observations and measurements. Section V situates QCD within the broader framework of the standard model of particle physics. We conclude in Sec. VI with a brief essay on frontier problems in QCD. Appendix A gives links to basic online resources.

II. QCD

As a theory of the strong interactions, QCD describes the properties of hadrons. In QCD, the familiar mesons (the pion, kaon, etc.) are bound states of quarks and antiquarks; the familiar baryons (the proton, neutron, _(1232) resonance, etc.) are bound states of three quarks. Just as the photon binds electric charges into atoms, the binding agent is the quantum of a gauge field, called the gluon. Hadrons made of exclusively of gluons, with no need for valence quarks, may also exist and are called glueballs. Properties of hadrons are tabulated in

8. \Review of particle physics," C. Amsler et al., Particle Data Group, Phys. Lett. B667, 1{1340 (2008) [doi: 10.1016/j.physletb.2008.07.018] [http://pdg.lbl.gov]. (E{I{A)

10. \Ultraviolet behavior of non-Abelian gauge theories," D. J. Gross and F. Wilczek, Phys. Rev. Lett. 30, 1343{1346 (1973) [doi: 10.1103/PhysRevLett.30.1343]. (A)

11. \Reliable perturbative results for strong interactions," H. D. Politzer, Phys. Rev. Lett. 30, 1346{1349 (1973) [doi: 10.1103/PhysRevLett.30.1346]. (A)

Asymptotic freedom points to the existence of a domain in which the strong interactions become sufficiently weak that scattering processes can be treated reliably in perturbation theory using techniques based on the evaluation of Feynman diagrams. The path to asymptotic freedom is described in the Nobel Lectures,

12. \The discovery of asymptotic freedom and the emergence of QCD," D. J. Gross, Rev. Mod. Phys. 77, 837{849 (2005) [doi: 10.1073/pnas.0503831102]. (I)

13. \The dilemma of attribution," H. D. Politzer, Rev. Mod. Phys. 77, 851{856 (2005) [doi: 10.1073/pnas.0501644102]. (I)

14. \Asymptotic freedom: from paradox to paradigm," F. Wilczek, Rev. Mod. Phys. 77, 857{870 (2005) [hep-ph/0502113]. (I)

For another view of the historical setting, see

15. \When was asymptotic freedom discovered? Or the rehabilitation of quantum field theory," G. 't Hooft, Nucl. Phys. Proc. Suppl. 74, 413{425 (1999) [hep-th/9808154]. (A)

\Mass without mass I: most of matter," F. Wilczek, Phys. Today 52, 11{13 (November, 1999) [doi: 10.1063/1.882879]. (E)

19. \Mass without mass II: the medium is the mass-age," F. Wilczek, Phys. Today 53, 13{14 (January, 2000) [doi: 10.1063/1.882927]. (E)

20. \The origin of mass," F. Wilczek, Mod. Phys. Lett. A21, 701{712 (2006) [doi: 10.1142/S0217732306020135]. (I)

21. \Spontaneous symmetry breaking as a basis of particle mass," C. Quigg, Rept. Prog. Phys. 70, 1019{1054 (2007) [arXiv:0704.2232 [hep-ph]]. (I{A)

The development of lattice gauge theory has made possible a quantitative understanding of how these phenomena emerge at the low-energy scale associated with con-

_nement.

22. \Con_nement of quarks," K. G. Wilson, Phys. Rev. D10, 2445{2459 (1974) [doi: 10.1103/PhysRevD.10.2445]. (A)

The essential ideas are described in

23. \The lattice theory of quark con_nement," C. Rebbi, Sci. Am. 248, 54{65 (February, 1983). (E)

24. \Quarks by computer," D. H. Weingarten, Sci. Am. 274, 116{120 (February, 1996). (E)

and how it all began is recalled in

25. \The origins of lattice gauge theory," K. G. Wilson, Nucl. Phys. Proc. Suppl. 140, 3{19 (2005) [hep-lat/0412043]. (I)

Visualizations of the QCD vacuum, the structure of the proton, and other insights from lattice QCD are presented and explained at

26. \Visualizations of QCD," D. B. Leinweber, http://www.physics.adelaide.edu.au/~dleinweb/VisualQCD/Nobel/. (E{I{A)

An example is shown in Fig. 1, depicting the process p $ _K+ on a background of the gluonic ground state.

Lattice gauge theory is yielding a growing range of nonperturbative computations of hadron properties that are needed to interpret experiments and observations in particle physics, nuclear physics, and astrophysics:

27. \Quantum chromodynamics with advanced computing," A. S. Kronfeld, USQCD Collaboration, J. Phys. Conf. Ser. 125, 012067 (2008) [arXiv:0807.2220 [physics.comp-ph]]. (E{I)

[http://cdsweb.cern.ch/search.py?recid=570209]. (E{I)

Zweig used the term \aces" for quarks. An early review of the quark model is in

51. \Quarks," M. Gell-Mann, Acta Phys. Austriaca Suppl. 9, 733{761 (1972). (I{A)

and helpful compilations of references on the quark model appear in

. \Resource letter Q-1: quarks," O. W. Greenberg, Am. J. Phys. 50, 1074{1089 (1982) [doi: 10.1119/1.12922]. (E{I{A)

. \Hadron spectra and quarks," S. Gasiorowicz and J. L. Rosner, Am. J. Phys. 49, 954{984 (1981) [doi: 10.1119/1.12597]. (I{A)

A challenge to these ideas came from the nonobservation of free, fractionally-charged particles. The current limits are collected in Ref. 8, and descriptions of the techniques may be found in

54. \Quark search experiments at accelerators and in cosmic rays," L. Lyons, Phys. Rept. 129, 225{284 (1985) [doi: 10.1016/0370-1573(85)90011-0]. (I)

55. \Searches for fractional electric charge in terrestrial materials," P. F. Smith, Ann. Rev. Nucl. Part. Sci. 39, 73{111 (1989) [doi: 10.1146/annurev.ns.39.120189.000445]. (I)

56. \Searches for fractionally charged particles," M. L. Perl, E. R. Lee, and D. Loomba, Ann. Rev. Nucl. Part. Sci. 59, 47{65 (2009) [doi: 10.1146/annurev-nucl-121908-122035]. (I)

With con_nement in QCD, however, the search for isolatable fractional charges is a somewhat more subtle subject, perhaps explaining why searches for fractionallycharged particles have been to no avail.

3. Quarks with color

A second challenge to the quark model lay in the spinand-statistics puzzle for the baryons. If the baryon J = 1
2
octet and J = 3
2 decuplet are taken to be composites of three quarks, all in relative s-waves, then the wave functions of the decuplet states appear to be symmetric in space_spin_isospin, in conict with the Pauli exclusion principle. As explicit examples, consider the □, formed of three (presumably) identical strange quarks, sss, or the _++, an isospin- 3
2 state made of three up quarks, uuu. To reconcile the successes of the quark model with the requirement that fermion wave functions be antisymmetric, it is necessary to hypothesize that each quark avor comes in three distinguishable species, which we label by the primary colors red, green, and blue. Baryon wave functions may then be antisymmetrized in color. For a review of the role of color in models of hadrons, see

57. \Color models of hadrons," O. W. Greenberg and C. A. Nelson, Phys. Rept. 32, 69{121 (1977) [doi: 10.1016/0370-1573(77)90035-7]. (I{A)

Further observational evidence in favor of the colortriplet quark model is marshaled in

58. \Light-cone current algebra, _0 decay, and e+e□ annihilation," W. A. Bardeen, H. Fritzsch, and M. Gell-Mann in Scale and Conformal Symmetry in Hadron Physics, edited by R. Gatto (Wiley, New York, 1973), pp. 139{151, [hep-ph/0211388]. (A)

For a critical look at circumstances under which the number of colors can be determined in _0 ! decay, see

59. \Can one see the number of colors?," O. B□ar and U. J. Wiese, Nucl. Phys. B609, 225{246 (2001) [hep-ph/0105258]. (A)

Then the appropriate e_ective _eld theory is potential NRQCD (PNRQCD):

185. \Potential NRQCD: an e_ective theory for heavy quarkonium," N. Brambilla, A. Pineda, J. Soto, and A. Vairo, Nucl. Phys. B566, 275{310 (2000) [hep-ph/9907240]. (A)

PNRQCD provides a _eld-theoretic basis for understanding the success of the potential models of Sec. III B. For a review, consult

\E_ective _eld theories for heavy quarkonium," N. Brambilla, A. Pineda, J. Soto, and A. Vairo, Rev. Mod. Phys. 77, 1423{1496 (2005) [hep-ph/0410047]. (I{A)

NRQCD and PNRQCD have also been used to understand top-quark pair production at threshold. Top quarks decay before toponium forms:

187. \Production and decay properties of ultraheavy quarks," I. I. Y. Bigi, Y. L. Dokshitzer, V. A. Khoze, J. H. K□uhn, and P. M. Zerwas, Phys. Lett. B181, 157{163 (1986) [doi: 10.1016/0370-2693(86)91275-X]. (I{A)

188. \Threshold behavior of heavy top production in e+e□ collisions," V. S. Fadin and V. A. Khoze, JETP Lett. 46, 525{529 (1987). (I{A)

189. \Production of a pair of heavy quarks in e+e□ annihilation in the threshold region," V. S. Fadin and V. A.

Khoze, Sov. J. Nucl. Phys. 48, 309{313 (1988). (I{A)

but top and antitop still orbit each other during their fleeting existence. A useful review is

190. \Top-antitop pair production close to threshold: synopsis of recent NNLO results," A. H. Hoang et al., Eur. Phys. J. direct C2, 1{22 (2000) [hep-ph/0001286].

3. Soft collinear effective theory

In high-energy amplitudes, one often considers a jet of particles, the details of which are not detected. The semiinclusive nature of jets circumvents issues of infrared and collinear divergences, much like the Bloch-Nordsieck mechanism in QED:

191. \Note on the radiation field of the electron," F. Bloch and A. Nordsieck, Phys. Rev. 52, 54{59 (1937) [doi: 10.1103/PhysRev.52.54]. (I{A)
192. \Mass singularities of Feynman amplitudes," T. Kinoshita, J. Math. Phys. 3, 650{677 (1962) [doi: 10.1063/1.1724268]. (I{A)
193. \Degenerate systems and mass singularities," T. D. Lee and M. Nauenberg, Phys. Rev. 133, B1549{B1562 (1964) [doi: 10.1103/PhysRev.133.B1549]. (I{A)

The infrared and collinear degrees of freedom can be isolated in the soft collinear effective theory (SCET), first established for decays of B mesons:

194. \Summing Sudakov logarithms in B ! X_s in effective field theory," C. W. Bauer, S. Fleming, and M. E. Luke, Phys. Rev. D63, 014006 (2000) [hep-ph/0005275]. (A)
195. \An effective field theory for collinear and soft gluons: heavy to light decays," C. W. Bauer, S. Fleming, D. Pirjol, and I. W. Stewart, Phys. Rev. D63, 114020 (2001) [hep-ph/0011336]. (A)
196. \Soft-collinear factorization in effective field theory," C. W. Bauer, D. Pirjol, and I. W. Stewart, Phys. Rev. D65, 054022 (2002) [hep-ph/0109045]. (A)
197. \Soft-collinear effective theory and heavy-to-light currents beyond leading power," M. Beneke, A. P. Chapovsky, M. Diehl, and T. Feldmann, Nucl. Phys. B643, 431{476 (2002) [hep-ph/0206152]. (A)

Meanwhile, SCET has been applied to many high-energy scattering processes, starting with

198. \Hard scattering factorization from effective field theory," C. W. Bauer, S. Fleming, D. Pirjol, I. Z. Rothstein, and I. W. Stewart, Phys. Rev. D66, 014017 (2002) [hep-ph/0202088]. (A)

and more recently to many aspects of jets:

199. \On the structure of infrared singularities of gaugetheory amplitudes," T. Becher and M. Neubert, JHEP 06, 081 (2009) [arXiv:0903.1126 [hep-ph]]. (A)
200. \Soft radiation in heavy-particle pair production: all-order colour structure and two-loop anomalous dimension," M. Beneke, P. Falgari, and C. Schwinn, Nucl. Phys. B828, 69{101 (2010) [arXiv:0907.1443 [hep-ph]]. (A)
201. \Factorization structure of gauge theory amplitudes and application to hard scattering processes at the LHC," J.-y. Chiu, A. Fuhrer, R. Kelley, and A. V. Manohar, Phys. Rev. D80, 094013 (2009) [arXiv:0909.0012 [hep-ph]]. (A)
202. \Factorization at the LHC: from PDFs to initial state jets," I. W. Stewart, F. J. Tackmann, and W. J. Waalewijn, Phys. Rev. D81, 094035 (2010)

[arXiv:0910.0467 [hep-ph]]. (A)
203. \Factorization and resummation of Higgs boson differential
distributions in soft-collinear e_ective theory,"
S. Mantry and F. Petriello, Phys. Rev. D81, 093007
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204. \Consistent factorization of jet observables in exclusive
multijet cross-sections," S. D. Ellis, A. Hornig, C.
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82{89 (2010) [arXiv:0912.0262 [hep-ph]]. (

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K.-H. Schmidt, B. Jurado, arXiv:1007.0741v1 [nucl-th].
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J. Adams et al. Nucl. Phys. A 757 (2005)102; PHENIX Collaboration, K. Adcox et
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