Nuclear Matter and Quark Chain in the Atomic Nucleus

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Abstract
We introduced, two years ago[1], a new model of the atomic nucleus, the DNA nuclear-model, where the neutrons and the protons with their spin up and down seem to be the equivalents of the four bases of the DNA life molecule : Adenine (A), Thymine (T), Cytosine (C) and Guanine (G). The four elements : p↑, p↓, n↑, n↓ are bound in a chain, a close loop. With this model we succeeded to explain nuclear phenomena like : alpha radioactivity, fission or fusion.
Our present work goes further by considering the quark (anti quark) structure of the nucleons : protons, neutrons, or of the quanta (quark antiquark) of the nuclear field interaction : the pion. We suggest that the atomic nucleus is a loop chain of the quarks (real or virtual antiquark).
Keywords: nuclear matter, quark, DNA - nuclear model, quark – nuclear model , alpha – fission - beta – proton radioactivity.

1. Introduction

By explicitly presenting the internal bonds we try to obtain a clear description of our new model **DNAQ** (**D**escription of **N**ucleus of the **A**tom through **Q**uark). The nucleons in the nucleus are formed of three valence quarks. Two of the three valence quarks of the nucleon are busy in the chain and therefore the third quark of the nucleon play a crucial role in the dynamics, stability, hence in the life time of the atomic nucleus.

When the chain of A nucleon splits himself in two rosary loops of : A - 4 and 4 nucleons, we have the alpha radioactivity. The A-1, 1 chain splitting is the proton (neutron) decay or beta radioactivity (if the resulting nucleon from in the beta decay phenomena is recaptured to reform A-chain). Therefore the beta decay interaction takes place **outside of nuclear matter**, it means outside of the nucleons (a quarks) chain.

2. The Binding Energy

One of the first caracteristics of the atomic nucleus, studied from 1920, is the mass defect, the difference between the sum of the mass of the nucleons in the nucleus and the experimental mass of the nucleus.
This mass defect is named **B**inding energy of the nucleus : **B**(A,Z), (B/A is of the order of 0,1% of the energy mass of the nucleon).
The measurements found that **B is proportional with A the number of nucleons in the nucleus.**

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Later, in 1934 **Weizsäcker** [2] suggested the formula :

$$B(A,Z) = a_v A - a_s A^{2/3} - a_c Z(Z-1)/A^{1/3} - a_a (N-Z)^2/A + C \qquad (1)$$

The values of coefficients a_v, a_s, a_c, a_a, C differ between several authors. Three sets of these parameters are given in a data array, as shown below in Table 1:

TABLE 1

	least squares fit	**Wapstra**	**Rohlf**
a_V	15.8	14.1	15.75
a_S	18.3	13	17.8
a_C	0.714	0.595	0.711
a_A	23.2	19	23.7
a_P	12	*n/a*	*n/a*
δ(even-even)	*n/a*	-33.5	+11.18
δ(odd-odd)	*n/a*	+33.5	-11.18
δ(even-odd)	*n/a*	0	0

This is the base of liquid drop model.

All theoretical **nuclear mean field calculations,** (where a nucleon interacts with all the nucleons through **the mean field** - a nuclear negative potential bag – resulted by supperposing all fields of the nucleons) get **reasonable** (1%) values for **B** and for others fundamental properties of the nucleus.

The **B**inding energy proportional with A can be interpreted like appearence of bonds valence interaction of a nucleon with neighbors, and **consequently** the formation of **a chain of nucleons**.

3. Nuclear Force Saturation

The **B**inding energy proportional with A **suggests us** that : one nucleon in the nucleus interact only with two neighbour nucleons, ignoring the others (up to 10 in the CFC crystal model [3]). This is **the so called saturation** of the nuclear forces, unlike **Coulombian** forces where an electrical charge can interact with many others. So, the Yukawa force [19] with the spherical symmetry:

$$U(r) = g \,.\, \exp(-\mu r)/r \qquad (2)$$

$$\mu = m.c/h \qquad (3)$$

will get an assymetrical form when two or more nucleons are in "contact".

The nuclear force has a short range of order of 1.4 fm and :

$$\int f(r)\, dv = \text{const} \tag{4}$$

(where f is the density of this nuclear force). A special metric **should be used** for taking into account this effect.

Because a nucleon is "related " with two neighbors, **it does not have forces** to interact with the third neighbours one. But, when the nucleon chain performs strong oscillations, two portions of chain can touch each other and a kind of Heisenberg exchange force appears and the nucleons change their neighbours, a new chain is formed and schematically presented in fig.3.

In our days the theoretical nuclear calculations are using parametrised nuclear potentials. These parameters result from the fit of experimental nucleon scattering data with analytical expressions. This kind of potentials is not adapted in our description of nucleus like a chain of quarks. The chain of quarks forms the nuclear matter with special linear geometry. The ground of our model is the anzatz of the existence of these bounds between the nucleons. An eperimental evidence is the EMC effect [15] where the muon scattering on the Fe is not a simple addition of muon-d scattering cross section. Then a part of the nuclear mouvement is taking place in one dimensional loop chain, like in Toda [11] chain.

4. Nuclear Models

After the discovery of the neutron in 1932 by Chadwick [17], Heisenberg [18] proposed the first model of the nucleus : a bag with Z protons and N neutrons and A nucleons

$$A = Z + N \tag{5}$$

A, Z, N being natural integers. He didn't guess the forces acting between nucleons. In 1935 Yukawa [19] invented the **quantum of nuclear forces**, the pion. The pion was discovered in by Powell [20],

$$m_{\pi}^{\pm} = 139{,}57\text{MeV} \tag{6}$$

The nuclear force is understood like pion exchange between two nucleons and it is easy to feel that a nucleon with around 938MeV of mass should make a big "effort" to communicate with his neighbour through a "letter" of 140MeV of mass. To find the properties of a nucleus (A,Z), **you are supposed to solve a several bodies quantum mechanical problem.** The nuclear potentials are in general obtained by using principles of symmetry and experimental facts.

Many nuclear models tried and sometimes succeeded to mimic the real nucleus. We shall enumerate few of them and we shall give in a few words their fundaments.

In the Liquid Drop Model of 1939, Bohr and Wheeler[4] suggested and succeeded to calculate few of the ground state properties imitating the drop of a liquid : surface tension. They explained the fission phenomena discovered in december 1938 by Hahn and Strassmann and published in January 1939, [21].

The Fermi gaz model [22] is a statistical model which treats the nucleons as if they were particles of a gas restricted by the exclusion principle of Pauli. The probability of occupation of a state with energy E is :

$$F(E) = 1/[1+\exp((E-E_F)/kT)] \qquad (7)$$

$$E_F = p_F^2/2m \qquad (8)$$

The p_F is the momentum of the nucleon at fermi level, the m is the mass of the nucleon and E_F is the energy of the fermi level. The particles will fill the lowest energy levels first, then successively higher ones. There are actually two independent Fermi gases, one of protons and one of neutrons. Some of the important features like density levels are well reproduced.

The Shell model with spin orbit term was introduced by M G Mayer [5] and J H D Jensen [6] tried to explain the magic numbers N, Z = 2, 8, 20, 28, 50, 82, 126 where the properties of the nuclei seem to jump. By using a potential "close" to harmonic oscillator, a Wood-Saxon potential similar to F(E) given in (7),

$$V(r) = V_0/[1+\exp((r-r_0)/a)] \qquad (9)$$

where V_0, r_0, a, are parameters of the model, and by adding the term L*S (coupling spin orbit) Myer[5] and Jensen [6] succeeded to find at the time the magic numbers and spins and magnetic moments of ground state of 60 nuclei known in their time.

The **Order-Desorder** was introduced in [7]. The model is based on the uncertainty principle of Heisenberg [23] and on the Strutinsky [24] suggestion to give a width to the shell model levels. By introducing the new interaction "cumulative interactions" [25], which relate the desorder state of the nuclear matter to ordered nuclear matter. This model helps to explain dynamic properties of the nucleus like decay of superdeformed bands in the fast rotating nuclei.

5. Mean Field Calculations

The success of the shell model (introduced phenomenologically) in calculation of basic properties of the nucleus imposes and justifies the assumption that in the nucleus the nucleons move independently in an average potential produced by all the nucleons. Basically, we "know" the two body interactions, and the problem is to calculate a single-particle potential (a mean field) :

$$V(r) = \sum^{A}_{i<j} V(i,j,r) \qquad (10)$$

This mean field was calculated through by using a variational principle on a space of

Slater determinants [26] as trial wave functions. The Hartree [8] Fock [9] methods are the principal ingredients of the calculation. Many potentials have been used like Reid [10]

$$V = V_C(\mu r) + V_T(\mu r) . S_{12}+V_{LS}(\mu r) + \mathbf{LS} \qquad (11)$$

where : V_C, V_T, V_{LS}, have simple Yukawa forms, like in Eq. (9).
Today potentials like Gogny [27] or Skyrme [28] give more accurate evaluations.

The important point is that all the calculations are supposing the bag form of the nucleus. All the symmetries are respected in this central potential, even when adjusted with the deformed part, to explain experimental data in nuclear spectroscopy or nuclear reactions. Generally, this mean field calculations, explain the experimental data in few cases, less than few percent of the enormous amount of experiments in nuclear physics.

In the DNA [1] model the potential can be avereged over the length of the loop (tore) and the total surface and, the "classical" mean field can be restored; in this model we have a loop chain where the nucleons are moving like solitons. The Toda [11] chain technique helps the nucleons wave functions calculations.
Finally, when the lattice have Yukawa exponential interaction the Korteweg-de Vries (KDV) [12] equation for nonlinear oscillator :

$$u_t + u .u_x + \delta^2 .u_{xxx} = 0 \qquad (12)$$

is obtained. This is the KDV equation for the amplitude u(x,t); u_t is **the t derivative of u** and u_{xxx} is the third x derive of u. This can **easly** be related to Schrödinger equation with eigen values.

6. DNA Model (Chain of Nucleons)

In a nucleus there are nucleons of two families : protons and neutrons. They are **fermions** and each nucleon has a spin up or down.
This, only four kind of particles : p↑, p↓, n↑, n↓ remind us of the four bases A, C, G and T of DNA-biology (**D**esoxyribo**N**ucleic**A**cid):

DNA chain with the four bases Adenine, Thymine, Guanine, Cytosine,
DNA chain with nucleosoms (the fibers).

Taking into account nuclear force saturation and experimental data on the binding energy we proposed in [1] new model of the nucleus :
"a chain of nucleons p↑, p↓, n↑, n↓".
In a "live" molecule **DNA**, the four bases are fixed in their positions, in their order in the chain, so, the DNA molecule codify information for cells evolution. More than 30 billions of the quadruplets ACTG describe our life from the birth to the death, linearely. In the atomic nucleus it seems that this is not the case; there is no beginning and no end of the chain of nucleons, is a real loop.

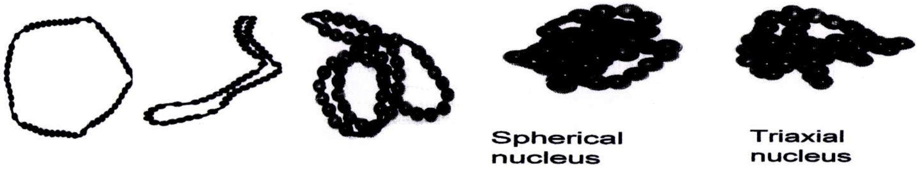


Fig. 1. Artist presentation of the chain of the nucleons in a nucleus.

Like in the DNA-biology, the first 3 pictures are not likely, the chain is not compact. The fourth one is supposed to mimic a spherical nucleus, and the fifth one the deformed nucleus. Information on the shape of the nucleus was obtained through the elastic and inelastic scattering, gamma spectroscopy or fission.
The forces like Van der Waals one can explain this tendency to get packed nucleons.
In [1] we explain that these forces have not electrical caracter like in the Van der Waals liquids. Nevertheless this force exchange the configuration of the original chain.
In fig. 2 we see a schematic presentation of the ^{10}B chain, the exchange forces, the alpha and fission. It explains directly the alpha,fission radioactivity,transfer or other nuclear reactions

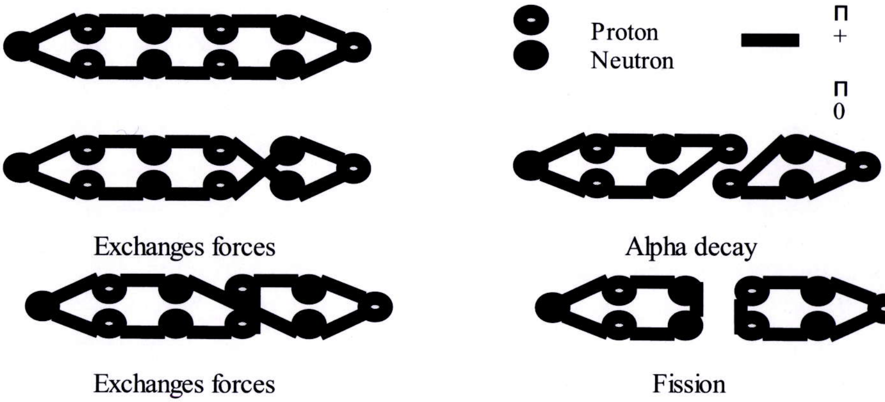
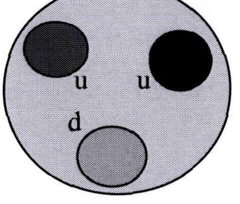


Fig. 2. Example of ^{10}B chain, the exchanges forces, the alpha and fission phenomena.

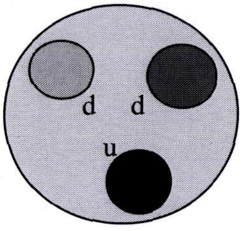
7. DNAQ Model. Chain of Quarks (Antiquarks or Virtual Quarks)

Before discussing about quark structure of the nucleons, a small flash, I remember hearing the famous James Rayford Nix, in 1990 at Los Alamos, telling me about his dream: to explain the fission phenomena (he was at the time the most erudite person in fission) through the quarks movements.

May be our ideas in the DNAQ (**D**escription of **N**ucleus of the **A**tom through **Q**uarks) which come directly from DNA-biology (**D**esoxyribo**N**ucleic**A**cid chain) **will inspire scientists in theoretical nuclear physics for hard calculations and fulfill** his dream, may be in ten years.
In the end of fifties many physicists thought that "the elementary particles" had a structure. Nambu [13] gives some hints, and Gell Man [14] suggested later, the SU3 symmetry and named **quarks** the particles of this substructure of the nucleons (hadrons). The proton and neutron are formed **of three valence quarks** (with electrical charge of 1/3 or 2/3 of electron charge, positive or negative and three differents flowers), which interact between them through the gluons all having different colors red, green or blue. The proton, neutron are colorless. The proton is built of two up (**u**) quarks (2/3+) and one down (**d**) quark (1/3-), so the proton charge is 1+, the neutron is formed from one **d** and two **u** then the electrical charge is 0
More, in the proton, neutron and other hadrons there are infinite numbers of **nonvalent quarks and antiquarks.** Recently, the proton radius was remeasured at 0,844fm, and one supposes that the quarks move in this bag with infinite high walls. The theory which describe the movement of the quarks in the hadrons is the QCD (quantum chromo dynamic).



proton (u, u, d)



neutron (d, d, u)

Fig. 3. The nucleons (proton and neutron) bags with the valance quarks.

8. Virtual Quarks and Antiquarks, the Pion

The "classical picture" of the nucleon is a bag surrounded by pions in a sea of Goldston bosons in the nucleus. Up to now, no evidence appears for the pion like nuclear matter constituent of the nuclear matter. In high resolution experiments, deep inelastic scattering of leptons at $Q^2 >> GeV^2/c^2$, one sees just quarks in nuclei. The significant dependence of the quark momentum distribution on the nuclear binding, demonstrates clearly that the nuclear properties cannot be considered in isolation from the underlying quark structure of the nucleons and of the virtual pion. It is very unlikely that the consistent nuclear theory could be built of a less fundamental level than that of the quark-gluon interaction. This is rather a trivial statement and does not mean that understanding of the nucleus could necessarily be achieved on the quark level only.

The quark motif (pion-nucleon-pion-nucleon-pion) is presented in the figure fig.4 (artist view).

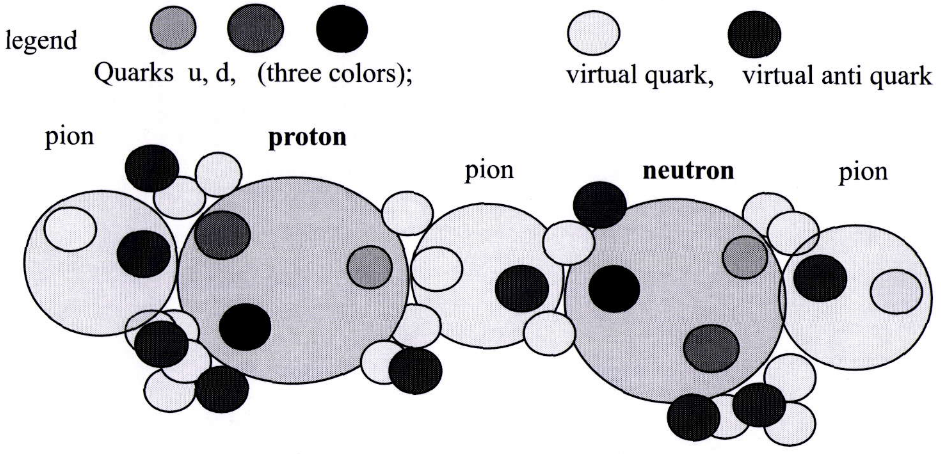


Fig. 4. The detailed part of the nuclear quarks chain.

9. Nuclear Matter Chain of Quarks and Dynamics

We postulate that nuclear matter is formed from that chain of quarks, antiquarks and virtual quarks which for sure is not a spherical bag. It has a segmented likes hape. The quark chain (string) is formed from standard motif Fig. 4 : (the virtual quark and virtual anti quark which form the pion, one quark of **a nucleon** and one quark **an another nucleon)** structure of four virtual elements.
In our model, DNAQ nucleus, the potential is "one dimensional" on a fragmented line. The quarks are moving like **a wave** . The dynamics come from exchange forces induced by the third quark of the nucleon (in fig. 6 the blue quark in the proton and red in neutron) which are not involved in the chain (string). This quark, **the third quark**, of the nucleon tries and succeeds many times to reshape the chain. This description is a kind of "classical" view of the "quantum nuclear field", of DNAQ.

The well known effect EMC (European Muon Collaboration [15]) in the collision of the muons with Fe nucleus indicate that the quark structure of the nucleons in Fe is different from that of "free nucleons" in deuteron. That means the quarks from different nucleons are in "interaction" like in DNAQ chain. Recently the NuTeV anomaly effect [16] in Femilab experiment of nutrinos on the quarks of the nucleons in He, was explained in the same manner. So, there are at least two experimental evidences of the quark chain (string) in the nucleus from our point of wiev.

More recently P. E. Koehler et al. [30] published data on anomalous fluctuations of s-wave reduced neutron widths of $^{192,194}Pt$ resonances and concluded that the nucleons in the nucleus are not chaotic at **relatively high excitations** near the neutron threshold. From DNAQ model point of view this is a manifestation of the chain of the nucleons.

10. Conclusion

The quark structure of the nucleons in nucleus is well recognized. But the confinement of the quarks in the hadrons and mesons, forbids free quarks outside of the nucleons. The quark structure of the nucleon is very complex. The three "visible" quarks are the "valence quarks". Like in the black hole theory of Hawking where there is a weak evaporation of black hole, for the "nucleon" we postulate the existence of few virtual quarks, anti quarks in his vicinity. They come in collision and form the virtual pion. Through this mechanism the chain (string) of quarks is formed and destroyed. The chaos comes back to order in a continuously dynamic way, the nuclear "life".

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