# Individual nucleons inside nuclei do not behave according to predictions

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**Abstract**

Individual nucleons do not behave in nuclei as the existing theory predicts. This is a conclusion reached by an international team of scientists. I am not a nuclear physicist but have proposed what I call nuclear string model. Therefore I have good motivations for trying to understand what has been found and what nuclear string model can say about the findings.

## Contents



# 1 Introduction

Individual nucleons do not behave in nuclei as the existing theory predicts (see the popular article). This is a conclusion reached by an international team of scientists which has published their findings as article article in Phys. Rev. Letters).

I am not a nuclear physicist but have proposed what I call nuclear string model [K2]. This gives good motivations for attempts to understand what has been found and what nuclear string model can say about the findings.

There are many models of atomic nuclei and each of them explains some aspects of nucleus. Nucleus can be modelled rigid body or as a kind of quantum liquid. In the prevailing average field approach the presence of other nucleons is described in terms of a potential function and calculates the states of individual nucleons in this potential using Schrödinger equation. It is essential that nucleons are assumed to be independent.

The model taking potential function to be that of harmonic oscillator is surprisingly successful but one must introduce corrections such as spin-orbit coupling in order to understand the energy spectrum. In this approach the notion of nuclear shell emerges. In atomic physics and chemistry the closed shells do not participate to the interaction and the outermost shell characterized by valence dictates to a higher degree the chemical properties of atom. Valence is positive if outer shell contains particles. Valence if negative if some of them are lacking. Something similar is to be expected also now. In this case full shells correspond to magic numbers for protons and neutrons separately (note that protons and neutrons seem to behave rather independently, something highly non-trivial!). The nuclei with valence +1 or -1 would correspond to almost magic nuclei.

One generally accepted correction to the harmonic oscillator model is inspired by the assumption that heavier nuclei can be described as a kind of blob of condensed matter obeying equation of state allowing to introduce notions like acoustic waves and surface waves. The nucleon at the unfilled shell would reside at the surface of this blob. The blob has vibrational excitations characterized by multipolarity (spherical harmonic characterized by angular momentum quantum numbers and the radial part of the oscillation amplitude. These excitations give rise to analogs of surface waves in water. Valence nucleons interact with the oscillations and affect the energy levels of the valence nucleons. The predictions of this model are calculable.

The team has studied almost doubly magic nuclei with valence equal to plus or -1 and calculated the effects on the energy levels of the nucleon and found that the observed effects are significantly smaller than the predicted ones. This finding challenges both the mean field approach or the idea that nucleus can be idealized as a condensed matter like system or both.

# 2 Nuclear string model

In TGD framework ordinary model of nucleus is replaced with what I call nuclear string model [K2].

## 2.1 Core ideas of nuclear string model

The core idea of nuclear string model is that the nucleons are ordered to a string like structure.

1. Nuclei consist of string like objects: protons and neutrons connected by color magnetic flux tubes form string like objects, perhaps separately. The color magnetic flux tubes would would be meson-like objects and could even carry net color. They are either neutral (quark and antiquark at the ends of flux tube have opposite charges) or carry em charge. What "meson-like" does mean

is not completely trivial. Quark anti-quark pair connected by a flux tube is what comes in mind.

Quarks correspond in TGD to closed flux tubes with length of order Compton length of quark traversing through two wormhole contacts and connecting them by monopole flux tubes at parallel space-time sheets. The first wormhole contact has quark quantum numbers and the second one those of a neutrino pair compensating for weak axial isospin of the quark. The compensating weak axial isospin for quark and antiquark would have opposite sign so that they are not necessary in the meson-like state. Does flux tube connect these flux tube structures or is there only single closed flux tube so that quarks would lose half of their identity.

This predicts a large number of exotic states. The exotic states cannot be distinguished chemically from the isotopes of the nucleus. The hypothesis is that the energy scale of the excitations is in keV range and their existence explains the annual variation of nuclear decay rates which seems to be caused by X rays from Sun [C1].

This would be new nuclear physics and perhaps relevant also to the cold fusion. The energy scale would derive from the string tension of the color magnetic flux tube. The lengths of the color magnetic flux tubes corresponding to keV scale (nanometer) would be rather long and correspond color magnetic bodies of the nucleons. If this is the case then the color magnetic energy of the system would depend only weakly on the positions of the nucleons of string inside nuclear volume.

The presence of long flux tubes might allow to understand the anomalous finding that the charge radius of proton is smaller than predicted. u and d quarks are known to be light and have masses in the range 5-20 MeV. The TGD based model for elementary particles [**?**] suggests that quarks correspond to closed flux tubes consisting of two portions at parallel space-time sheets with ends connected by wormhole contacts and with monopole magnetic flux rotating in the tube. Uncertainty principle suggests that the length of the flux tube structure is of the order of Compton length of the quark. The constituents of proton would be larger than proton itself! The paradox disappears if the Compton length is assigned with the magnetic flux tube connecting the two wormhole contacts associated with quark and rather near to each other and much shorter than the flux tube.

Flux tubes with Compton lengths corresponding to 10 keV photon energy would be however 3 orders of magnitude longer (10 nm). This could be due to the scaling by $h_{eff}/h \sim 10^3$. These flux tubes could also correspond to the flux tubes connecting neighboring nucleons of nuclear strings. The dark magnetic flux tubes of this length associated with neighboring nuclei could reconnect and bind nuclei to form lattice like structures. This process and thus dark nuclear physics could play a key role in in the formation of condensed matter phases as it is proposed to play also in living matter.

2. These strings of nucleons could topologically condense at larger magnetic flux tubes but could still touch also the nuclear space-time sheet as suggested

by the success of harmonic oscillator model. In biological length scales the assumption that effective Planck constant characterizing dark matter phase equals $h_{eff} = n \times h$ equals to gravitational Planck constant $h_{gr} = GMm/v_0$, where $v_0$ is a parameter with dimensions of velocity, implies that cyclotron frequencies are universal (no dependence on particle mass m) but also implies that particles with different masses correspond to different value of effective Planck constant so that living system would perform spectroscopy putting particles (elementary particles,atoms, ions, molecules,..) neatly at different dark space-time sheets! If the nucleons inside nuclei are dark in this sense protons and neutrons would be at different flux tubes since their masses are slightly different.

3. Nucleus could consist of several - possibly knotted - closed flux tubes containing some number of nucleons each. An attractive hypothesis is that these flux tubes correspond to nuclear shells so that full flux tubes would correspond to full shells and define separate units. In semiclassical approximation this would mean that nuclear string is localized at the surface of sphere.

## 2.2 Could one regard nuclear string at sphere as Hamiltonian cycle?

Nuclear string means the introduction of additional structure to the many-nucleon state. One can consider the addition of even further additional structure, which is purely topological. This addition has not been considered in the earlier variant of the model and might well be un-necessary.

(a) If the vertices of nuclear string at sphere define in a natural manner polyhedron, then nuclear string defines a closed non-intersecting curve going through the with $n$ vertices of this polyhedron known as Hamilton cycle. If color magnetic flux tubes are long, it is convenient to consider a curve defined by line segments connecting the neighboring nucleons of the nuclear string.

The notion of Hamilton cycle is well-defined for any graph so that it makes sense for any polyhedron. It is enough that the cycle is consistent with the underlying graph structure allowing to say which vertices are nearest neighbours (they need not be neighbours in the metric sense but only in the sense of homology that is ends of the same edge).

(b) Graph structure however requires that one assumes graph structure involving not only vertices and edges connecting them but also faces which in homology theory are most naturally triangles (2-simplices). Faces are clearly an additional structure as also nuclear string in the framework of standard nuclear physics. If the state of nucleus is analogous to that of molecule with nucleons having almost fixed positions homology emerges in natural manner but for independent particle model situation is far from clear. Could one identify the 2-simplexes of the homology associated with a non-intersecting curve consisting of segments uniquely from the condition that the additional edges do not intersect at sphere? Already the example of square in plane shows that the additional edge can be either diagonal.

(c) In the case of Platonic solids the rotational symmetries preserving Platonic solid generate finite number of Hamilton cycles of same shape from a given one and it is natural to define Hamilton cycles as equivalence classes of cycles with same shape. For instance, for icosahedron one has 17 Hamilton cycles and for 11 cycles one has symmetry group $Z_n$, $n \in 6, 4, 2$ and the cycles obtained from them by rotations. In this case one can however say that independent particle approximation is given up and one considers equilibrium configurations analogous to those of molecules. Nuclear string however orders the nucleons and brings in additional information. Hamilton cycles make sense also for the deformations of icosahedron since it is only the homological nearness that matters. Note however that the allowed deformations of metric Hamilton cycle must be such that the edges do not intersect: in other words the deformation of nuclear string is not self intersecting.

(d) If the nucleons can perform only small oscillations around the vertices of a polyhedron, independent particle assumption fails badly. One would however have collective wave function for orientations of the polyhedron. In this case Platonic solids or their homological generalization define good candidates for full shells.

# 3 How does nuclear string model relate to the shell model?

In the mean field approximation particles move independently in a potential describing the effects of the other nucleons. The basis for N-nucleon wave functions can be constructed as products of those associated with individual nucleons. The natural question is under what conditions nuclear string model is consistent with independent particle model.

## 3.1 What does the consistency of nuclear string model with independent particle model imply?

Quite generally, the consistency with independent particle approach requires that the nuclear string property does not contribute much to the energy of the states.

(a) At classical level the independent motion of nucleons (along elliptic orbits in harmonic oscillator approximation) of the nuclear string would give rise to a rather complex motion of nuclear string leading to self intersections unless the flux tubes have much longer length scale than the nucleus. In this case nucleus would be like seed from which flux tubes would emerge like a plant and self intersections could be avoided but the motion of nucleons could induce local braiding of the strands emanating from nucleons. This is indeed what has been assumed. Note that the U shaped flux tubes connecting neighboring nucleons could reconnect with the similar tubes associated with other nuclei so that the motions of nucleons would give rise to genuine global braiding.

(b) Harmonic oscillator states would induce wave function in the space of string configurations having interpretation as Hamilton cycles associated with polyhedron with $N$ vertices whose positions can vary, also in the radial direction although semiclassical shell model would force particles at the same radius. TGD allows to consider a collective localization at spherical shells: this would be rather long range correlation but consistent with the spirit of shell model. A more general approximation would be the localization to a union of spherical shells associated with the maxima of modulus of the radial wave function.

(c) In independent particle model basis wave functions are products. This is not consistent with the assumption that nucleons arrange to form a string unless the nearest neighbour nucleons at string can have arbitrary angular distance along the sphere: this would hold true exactly at the limit of vanishing string tension.

The longer the angular distance, the higher the color magnetic energy of the string. This energy would give rise to correlations inducing the mixing of harmonic oscillator wave functions. This would be the minimal breaking of independent particle approximation and would describe possibly new kind of nuclear forces between neighboring nucleons of the nuclear string as color magnetic forces.

If the color magnetic interaction corresponds to MeV scale, the length scale of the flux tubes is electron's Compton length and even in this case considerably longer than nuclear radius and independent particle approximation would not be badly broken. In this case the interpretation in terms of strong force might make sense. Even for the flux tubes which length of order Compton length for u and d quarks the flux tubes are much longer than the distance between nucleons.

If the energy scale of exotic nuclei is 1-10 keV as the variation of the nuclear decay rates seemingly induced by the variations of X ray flux from Sun suggests, the color magnetic energy would be rather small and independent particle approximation would even better than in previous case. This is expected to be the case if the color magnetic flux tubes correspond to the length scale assignable to 1-10 keV scale and thus long so that the positions of nucleons inside nucleus do not matter. 10 keV scale would in fact correspond to photon wavelength about 1 Angstrom - size of atom - so that a new interaction between nuclear and atomic physics is predicted. Note that classical and quantal pictures are consistent with each other.

(d) Independent particle model allows the nucleons with same quantum numbers to be in same position. This means self-intersection for nuclear string. Two-nucleon configuration space is $S^2 \times S^2$ and self-intersections occur in diagonal $S^2$ so that they are very rare and one could perhaps allow them when quantum numbers are different. Fermi statistics takes care that self-intersections do not take for nucleons with identical quantum numbers and also that the probability density for almost self-intersections is small. What is nice that Fermi statistics have geometric correlate int hat it would guarantee the absence of self-intersections in this strong sense if nucleons of given kind with given spin arrange on nuclear string so that one would have the analog of spontaneous magnetization. One would have four-kinds of strings corresponding to different directions of spin and strong isospin.

## 3.2 Semiclassical considerations

One can consider the situation also semi-classically.

(a) Nuclear shells correspond in the Bohr model based on harmonic oscillator potential to spheres with radii fixed by Bohr's quantization rules. Wave functions are indeed concentrated also around the classical radius but for principal quantum number $n$ one obtains $n+1$ local maxima (see this). The wave function at given shell would be localized at $n+1$ surfaces rather than single surface, which is definitely a non-classical aspect. The probability density however concentrates mostly to the shell with the largest radius so that for large values of $n$ the semiclassical approximation becomes better.

One can of course ask, whether this picture contains deeper seed of truth expressible in terms of space-time topology. This would conform with the TGD based idea that matter resides on geometric shells: this idea is suggested already by the model for a final state of star [K1] predicting that mass is concentrated on shell. In many-sheeted space-time one expects an onion-like structure made of these shells.

The TGD based proposal is that in solar system planets would be accompanied by this kind of dark matter shells with radii predicted approximately by Bohr rules. TGD based explanation for Pioneer and Flyby anomalies [K4] predicts the same surface density of dark matter at these shells as deduced for the effective surface density of dark matter in the case of galactic nucleus. Of course, nucleons inside nuclei cannot correspond to dark matter unless the value of $h_{eff}/n = n$ is small. Otherwise the size of nucleus would be too large.

(b) In the semiclassical approximation the radii of the sphere at which the vertices of polyhedron are located would correspond to the radii of nuclear shells. An approximation in which one treats the angular degrees of freedom quantally using independent particle model and radial degree of freedom collectively looks reasonable and would allow to keep the rotational symmetries but would mean giving up the additional symmetries making if possible to solve harmonic oscillator model exactly. With this assumption nuclear strings would reside at spheres.

## 3.3 Could magic numbers be understood in terms of Platonic solids?

Harmonic oscillator model predicts the numbers of nucleons for magic nuclei as sums of numbers of nucleons for the full shells involved but the predictions are not quite correct. One can however modify the model to get the observed magic numbers. This explanation is based on dynamics and slightly broken symmetries and arguably more convincing than explanations relying on elementary geometry.

Still one can ask whether these numbers could be consistent with the idea that a full shell corresponds to a Platonic solid such that closed nuclear string, which can connect only neighboring vertices goes through its vertices without intersecting itself?

(a) Icosahedral and tetrahedral Platonic cycles are in a key role in TGD inspired vision about bio-harmony predicting that DNA sequences have interpretation as sequences of 3-chords of what I call bio-harmony realizing genetic code [K3].

One can also consider replacing metric Platonic solid with combinatorial objects in which neighboring vertices are defined to be ends of the same edge which can be rather long. This option is consistent with independent particle model in angular degrees of freedom. In this case however the addition of 2-simplexes (triangles) is not unique so that it seems that the Platonic cycles are expected to be natural only for molecule like states.

(b) If the polyhedron defined by the positions of nucleons can be interpreted as Platonic solid (cube, octahedron, tetrahedron,icosahedron, dodecahedron) the number of nucleons at given shell would be equal the number of vertices of the Platonic solid. One can of course consider more complex scenarios. One could consider adding nucleons also to the centers of edges and faces and even superpose different Platonic solids associated with the same sphere. Same Platonic solid could also appear as scaled variants.

(c) One could consider building the nuclei by adding new spherical layers gradually and assuming that the nucleons are at the vertices (one could consider also putting them in the centers of the faces). The lowest magic numbers are 2,8,20,28,50,82,126,184 and are reproduced if shells have $n = 2, 6, 12, 8, 22, 32, 44, 58$. In the standard approach one can say that each oscillator wave function corresponds to two spin directions so that the proper number to consider would be $m = n/2$. The values of $m$ would be be $m = 1, 3, 6, 4, 11, 16, 22, 29$.

If nuclear string contains only nucleons with given spin direction, the integers $m$ are the numbers that one should explain: this option is strictly speaking the more convincing one. If nuclear string contains nucleons with both spin directions, one must explain the integers $n = 2 \times m$.

Note that protons and neutrons can be assumed to belong to different nuclear strings.

Could one understand the integers $m$ or $n$ in terms of Platonic solids?

(a) $m = 1$ would correspond to the nucleon at origin, where modulus of wave function has maximum. $m = 3$ would correspond to triangle. $m = 6$ could be interpreted in terms of octahedron, and $m = 4$ in terms of tetrahedron. The larger values of $m$ would require constructions which look artificial.

(b) $n = 2$ would correspond to line segment with 2-vertices. n=6 would correspond to octahedron. n=12 would correspond to icosahedron. $n = 8$ would correspond to cube. Note that tetrahedron, the only self-dual Platonic solid, predicting $n = 4$ is missing fron the list. Also dodecahedron with $n = 20$ is missing. $n = 22$ would require articial looking constructions.

These findings would suggest that the independent particle model is not a good approximation for light nuclei for which a model as a molecule like entity with rather rigid position of nucleons might be considered if Platonic solids are taken as metric objects. If one is not willing to give up so easily, one could argue that the exotic states in which some color bonds between nucleons are charged change the apparent numbers of neutrons and protons: one would have only apparently $n = 22$ rather than $n = 20$. For double magic nuclei the sum of the anomalous looking magic numbers would be however 20+20: say 22 protons and 18 neutrons.

# 4 The experimental findings from TGD point of view?

On basis of the experimental findings it is far from clear whether one can model nuclei as objects characterized by continuous nucleon densities and obeying some thermodynamical equation of state from which the dynamics describing the oscillations of nucleon densities can be deduced.

(a) Suppose that nuclear shells make in TGD framework sense also as geometric objects, that is as (say) spherical space-time sheets containing the nuclear string for which the nucleons at vertices behave independently in angular degrees of freedom. In this kind of model the approximation as condensed matter blob is not the thing that comes first into mind. It would be like modelling of solar system by replacing planets by introducing planet density and oscillations of this density.

(b) If the shell contains only single particle, the collective wave function for the radius of the sphere associated with shell co-incides with single particle wave function. In this case one cannot say that the particle is at the surface of nucleus.

(c) There is no direct interaction with the oscillations of the full shell in the lowest order since the shells correspond to different space-time sheets. The interaction is only in terms of potential functions assignable to the large space-time sheet.

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