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Itzhak Orion

Athens Institute for Education and Research
8 Valaoritou Street, Kolonaki, 10683 Athens, Greece

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Itzhak Orion, Head, Department of Nuclear Engineering, Ben-Gurion University of the Negev, Israel

Quark Model versus Shell Model for the Neutron: Electrical Field Simulations

ABSTRACT

The neutron, though an electrically neutral particle, has an internal charge distribution that causes it to have a non-zero magnetic moment. The quark model explains this phenomenon as a consequence of the charged sub-particles content of the neutron as in(+2/3e,-1/3e,-1/3e), which consist of the (u,d,d) quarks, respectively. In contrast, neutral atoms in nature consist of positive charges, protons, with orbital electrons that also sum up to an external zero charge. In this study two electrical field simulation codes were written in order to model and compare the two possible charge arrangements in the neutron. Astrait electron beam was transmitted toward the structure. Electron transport was simulated using the differential special-relativity trajectory equation. Neutron, as a triple-quark structure, was computed using three-point charge fields in the first code, while fields of a positive charge (+2) and two orbital electrons in two radii were formulated in the second code. Each simulation code outputs the electron tracks through the system that were then analyzed using the CGVIEW 3-D viewer program. Differences between the two neutron models were then viewed and analyzed. Based on the findings, a shell-model-like alternative neutron model is suggested.

Keywords: Monte Carlo, computational, track, electron, electromagnetic.

Introduction

The standard elementary particle model describes the nucleon as a system made up of three quarks, which as a rule have fractional electric charge. Gel-Mann first presented a quark model for baryons (Gel-Mann, 1964), demonstrating that baryons in nature are composed of two types of quarks: u(+2/3) and d(-1/3). In addition, it is known that quarks cannot appear as single particle, therefore fractions of the elementary electric charge are not to be observed. Neutron, as a baryon, is made up of the three quarks, (d,d,u), hence its electric charge summing up to zero charge. Two types of fields-bosons carry quark interaction: gluons for attraction field, and weak field bosons ($W\pm$, Z_0) for quark exchange. Both of these fields are short-range limited.

In order to study the full elementary physics picture, quantum chromodynamics (QCD) theory was developed to describe quark-gluon interaction. In general, this theory has predicted many results in the very high-energy range in experiments using accelerators and hadron colliders (Srednicki, 2007). Regardless, there remain some gaps in our understanding of QCD interactions.

Some publications mention the as-yet unrevealed nature of the charge structure of the neutron (Basdevant, 2005; Miller, 2007).

Several researchers have preferred to inspect the internal structure of baryons by considering alternative models. Schaeffer (2014; 2016) introduced theoretical considerations in explaining the repulsion and attraction of nucleons solely as a consequence of Coulomb interactions and magnetic moments. In this paper the ^2H and ^4He binding energies per nucleon are calculated with Coulomb, as well as electric and magnetic fundamental laws, and presented as nuclear potential versus distance. Hence, Schaeffer's model for nuclear force is based on electromagnetic field interaction alone.

Furthermore, Kolikov, Ivanov and Krastev (2012) proposed a theory to describe nucleons as tori, rotating with a constant angular velocity around a straight line passing through their mass centre and perpendicular to their plane of rotation. The binding energies calculated using their method provides evidence for the fact that nuclear forces are exclusively electromagnetic in nature.

In both Schaeffer's and Kolikov's previous research studies, nucleons were arranged by electromagnetic field, thus abandoning the need for QCD involvement. In the current study electromagnetic interaction with electrons is inspected in order to compare two types of charge arrangements inside of a neutron. Neutron shell structure shall repeated such structure for more than one type of scale, therefore shell structure favors quantum theory in that the internal arrangement of a neutron is also resembling a shell.

In a 1956 review paper (Hofstadter, 1956) evidence that a proton is not a point charge particle appeared for the first time. Concerning proton charge form Hofstadter concluded, "Among all the models tested the "hollow" exponential model with $r_e=r_m$ =0.78 Fermi gives the best fit." According to the findings of the current study, the charge distribution inside a nucleon might form the shape of a shell, indicating a similarity to atomic structure.

Methodology

We chose to base our investigation of the internal structure of the nucleon on Monte Carlo computational simulations. It is well known that particles should be provided with stochastic aspects in their transport, thus the rationale for preparing Monte Carlo code. The aim of the study was to produce electron motion from a narrow parallel beam into a neutron structure, there by simulating electrical fields for two different charge structures: multiple-point versus spherical shells.

The Monte Carlo method provides approximate solutions to a variety of mathematical problems by performing statistical sampling that rely on repeated random sampling. A computer code calculates the results of simulated experiments. Particularly useful for complex problems that cannot be modeled by computer codes that use deterministic methods, itis used to resolve problems with no probabilistic content as well as those with inherent probabilistic structure, such as the interaction of nuclear particles with various materials.

The electrical field of a neutron made up of three quarks with three points symmetrically surrounding its center is:

$$E(r) = \left(\frac{e}{3}\right)[-\frac{1}{\left(x-\frac{a}{2}\right)^2+y^2}-\frac{1}{\left(x-\frac{a}{2}sin\frac{\pi}{6}\right)^2+\left(y+\frac{a}{2}cos\frac{\pi}{6}\right)^2} + \frac{2}{\left(x+\frac{a}{2}sin\frac{\pi}{6}\right)^2+\left(y-\frac{a}{2}cos\frac{\pi}{6}\right)^2}]\hat{r}$$

Where,
a – the radius inside the neutron from the center to each charge point (quark).
x,y – coordinates set by the plan of the three quarks.

It is easy to see from a far distance (a << r), that the filed is E = 0.

Another case was simulated involved charge arrangement constructed in a fashion similar to that of atomic orbitals around a positive charge central point. In this structure we have a +2e point charge at the center, while a spherical hollow charge distribution at the first orbit, R, with a total charge equaling –e, and the next spherical hollow charge distribution at the second orbit, 2R, with total charge equaling –e. This arrangement corresponds to non-fractional charges, atomic-like construction and total zero electrical charge as is proposed for a neutron. The electrical field is:

$$E(r) = \frac{-2e}{r^2} + [\frac{e}{R^3}r]_{for\ 0<r\leq R} + [\frac{e}{(2R)^3}r]_{for\ R<r\leq 2R} + [\frac{2e}{r^2}]_{for\ r>2R}$$

R –the first orbital radius;
2R – the second orbital radius.
R was set at 0.1 fm, which is also the size of a; these radii can be changed in the code.

The electron beam was set as a parallel broad beam moving vertically up toward the neutron, all electrons with the same initial kinetic beam energy of 550

MeV. The beam width was set to at least cover neutron diameter, and a random variable was used to scan the target. Initial speed β was calculated from electron energy at the start of the simulation.

Electron motion is continuously influenced by the field, therefore for each progressive step velocity is changed accordingly:

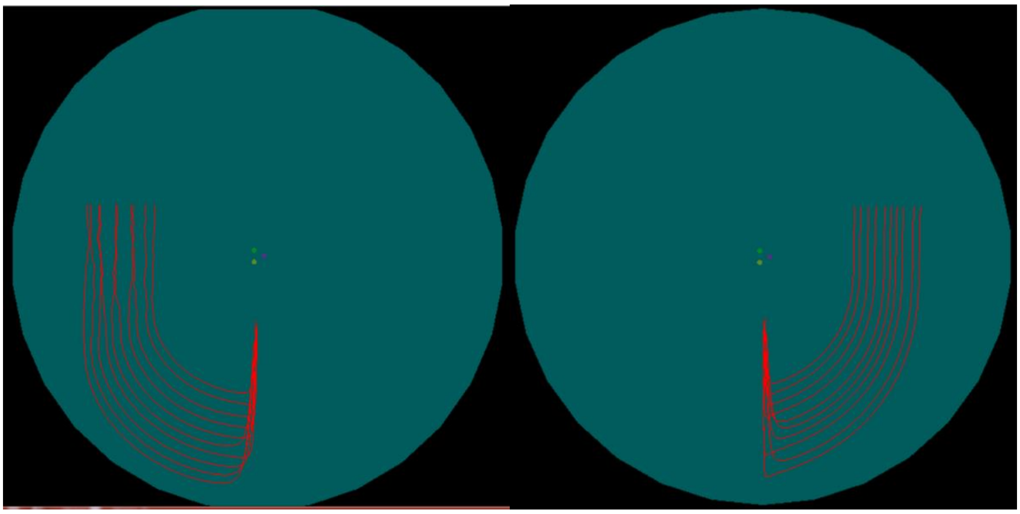
$$\frac{1}{c}\frac{d\vec{v}}{ds} = \left(\frac{e}{m_0 c^2 \beta\gamma}\right)\left[\vec{E} - \frac{\vec{v}}{c^2}\left(\vec{E}\cdot\vec{v}\right)\right]$$

Where,
ds – Trajectory element
β, γ – Special relativistic parameters.

While a new step-size and direction is dictated by the field, step-size acquires a lateral change by random sampling, and velocity is modified after each step. After a change in speed was obtained, a new step was repeatedly calculated and limited to not exceed more than 5% of the radius. Moreover, each history was terminated when the electron passed the external radius of the neutron five times.

Tailor-made Monte Carlo code was written in FORTRAN, with a random generator function type RANLUX (James, 1994), each for a model. The geometry and code output were formed according to the requirements of the CG-View 3-D viewer program (Namito, 2016), a tool for drawing particle track output in a solicited geometrical space.

Figure 1. *Two Images of Electron Tracks from the 3-Points Model: Left-Leaning Tracks Resulted in a Slightly Left Initial Beam Position and Right-Leaning Tracks Resulted in a Slightly Right Initial Beam Position. The Quarks can be seen at the Center*

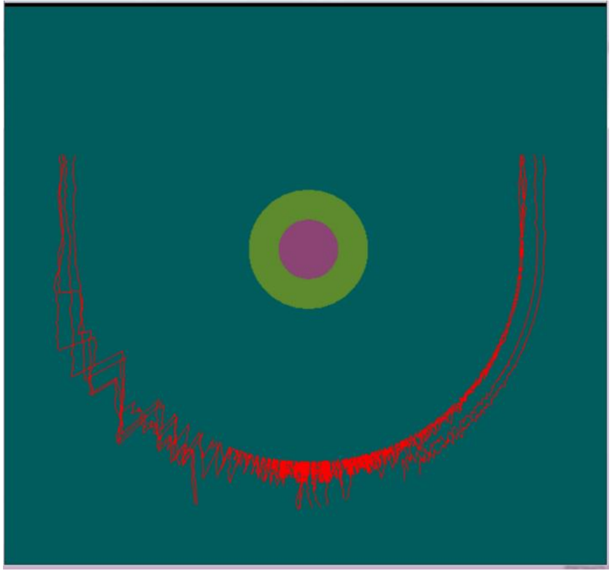


Results

Simulation results were output in a format that allowed us to visualize electron tracks along the neutron models, close in proximity to the nucleon center. In order to illuminate the electron path, only ten tracks were chosen for presentation in each image. Figure 1 exhibits the tracks from the 3-Points Model, while Figure 2 shows the track image from the Shell Model.

A comparison between left tracks and right tracks revealed a minor difference: while the left tracks end by crossing one other, the right ones are almost parallel. This difference is due to the point arrangement, in which the positive point is toward the right of the system and thus has less influence on the left tracks. Ultimately, however, this asymmetry has minor influence on electron trajectory.

Figure 2. *Electron Tracks from the Shell Model: A Wide Symmetrical Beam from below Attracts the Shells' Electrical Field. Two Shells are shown*



Discussion

Comparing the two electron track models, it can be observed that in the 3-Points Model electrons were reflected into an angle of about π, and backscattered before traveling around the neutron. In the Shell Model electrons were not reflected, although visible fluctuations can be seen in part of their trajectory. In both models, the endings of the shifted trajectories were found to be parallel to the initial beam direction. Electron track ending points were obtained with differences due to the simulated model. In Table 1 an analysis of the track endpoints is summarized, and left tracks are compared to right tracks. The average endpoints (s.d. values for each) were compared between models, and up to an 18.8% distance difference was shown.

Table 1. *Average of Final Position of Each Track Bypassing Neutron versus the Neutron Model (Standard Deviation Values Listed). Differences between Model Results in Percentage for Left Tracks and for Right Tracks*

Model:	**3 Points**	**Shell**	**Difference**
Left Tracks mean distance [fm] (σ)	-5.36 (0.89)	-3.66 (0.16)	18.8%
Right Tracks mean distance [fm] (σ)	4.71 (0.86)	4.06 (0.11)	7.4%

Conclusions

Two Monte Carlo codes were written for this study in order to show differences in electron tracks conducting electrical charges inside a neutron. The tracks obtained from simulations were compared in order to identify the differences between models as evinced by electron interactions.

The images in Figure 1 and Figure 2 show different pictures, each one of which is dependent upon the particular charge arrangement inside the neutron. Electromagnetic interactions inside a totally neutral system showed similarity in both cases, i.e. the quark arrangement and the shell Parton structure.

Scattering experiments aim to reveal electron endpoint direction and position, yet the findings of this study indicate the difficulty in differing between the two models, as explicated in Table 1. However, it may be possible to arrange appropriate future experiments in order to seek further evidence for which one of the track shapes is fulfilled.

The three quark model can be explained by QCD physics, however, its shell structure is very similar to atomic structure which likewise results in neutral atoms having internal charges. In atomic shells, for a neutral atom, inside the atom the total electrical charge, the Z-effective, shows non-integer values, however it does not indicate fractional charges.

Quantum theory shows that shell structure repeats itself for more than one type of field or scale, thus it can be concluded that a neutron's internal arrangement is also spherical in shape.

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