Nuclear force as purely electromagnetic interaction

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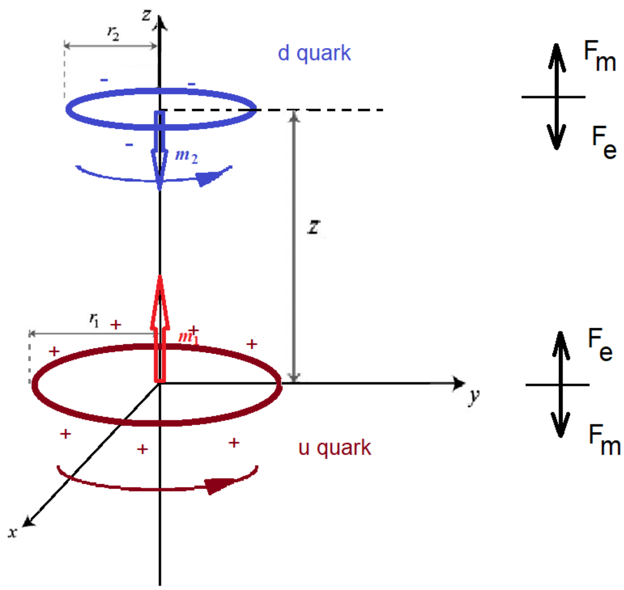
In this paper I will try to demonstrate that nuclear force is electromagnetic in its origin and nature. I will model it solely as an electromagnetic interaction of neighboring quarks. There is a stabile balance point between two near quarks if they magnetically repulse and electrically attract; in connection with that, I will calculate force and bond energy between d and up quark in deuteron (u from proton and d from neutron, and vice versa [1]), similar calculation should hold for any other nucleus.

If we assume coaxial orientation between d and up quark with their "rotation" in same direction, they will electrically attract (opposite charges) and magnetically repel (like two current loops of opposite charges that rotate in same direction).



Then

$$F_N = F_m - F_e$$

Where:

F_N - Nuclear force, F_m- Repulsive magnetic force, F_e- Attractive electric force

Magnitude of magnetic force between two small magnetic dipoles at distance z [2], [3]:

$$F_m = \frac{3\mu_0 m_1 m_2}{2\pi z^4}$$

Where:

$\mu_0 = 4\pi\times10^{-7}$ T·m/A - permeability of space

z-distance between d and u quark

$m_q = \frac{e_q \hbar}{2m_q}$, [4], [5]

$$magnitude\ of\ magnetic\ moment\ of\ any\ quark = \frac{its\ electric\ charge * reduced\ Plank's\ constant}{2 * mass\ of\ the\ quark}$$

For u quark that is:

$$m_1 = \frac{2}{3}\frac{e\hbar}{2m_u} = \frac{2}{3}\frac{1.6x10^{-19}C1.05x10^{-34}Js}{2x3.56x10^{-30}kg} = 1.573x10^{-24}\frac{J}{T}$$

For d quark that is:

$$m_2 = \frac{1}{3}\frac{e\hbar}{2m_d} = \frac{1}{3}\frac{1.6x10^{-19}C1.05x10^{-34}Js}{2x8.90x10^{-30}kg} = 3.146x10^{-25}\frac{J}{T}$$

Therefore, magnetic part of the force is:

$$F_m = \frac{3\text{x}4\pi\text{x}10^{-7}\ \frac{Tm}{A}x1.573x10^{-24}\frac{J}{T}x3.146x10^{-25}\frac{J}{T}}{2\pi}\frac{1}{z^4}$$

$$\boldsymbol{F_m = 2.969x10^{-55}\frac{1}{z^4}}\ Nm^4$$

Magnitude of electric force between two small electric charges at distance z [6]:

$$F_e = k\frac{q_1 q_2}{z^2}$$

$k = 8.99x10^9\ \frac{Nm^2}{C^2}$ - Coulomb's constant

In our case

$q_1 = \frac{2}{3}\ e\ = \frac{2}{3}\ 1.6x10^{-19}C$ and $q_2 = \frac{1}{3}\ e\ = \frac{1}{3}\ 1.6x10^{-19}C$

So

$$F_e = 8.99x10^9 \frac{Nm^2}{C^2} \frac{\frac{2}{3}\,1.6x10^{-19}C \; x \; \frac{1}{3}\,1.6x10^{-19}C}{z^2}$$

$$\boldsymbol{F_e = 5.114x10^{-29} \frac{1}{z^2}} \, Nm^2$$

Therefore, magnitude of the nuclear force as purely electromagnetic interaction of neighboring quarks is:

$$F_n = F_m - F_e$$

$$\boldsymbol{F_n = 2.969x10^{-55} \frac{1}{z^4}} \, Nm^4 - \boldsymbol{5.114x10^{-29} \frac{1}{z^2}} \, Nm^2$$

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In[1]:= Plot[2.969*10^-55 *1/z^4 - 5.114*10^-29 *1/z^2, {z, 7.3*10^-14, 100*10^-14}, AxesLabel → {z [m], F[N]}, AxesOrigin → {0, 0}]
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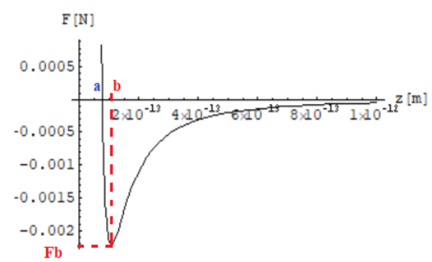


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Out[1]= - Graphics -
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In[2]:= NSolve[2.969*10^-55 *1/z^4 - 5.114*10^-29 *1/z^2 == 0, z]

Out[2]= {{z → 7.61947×10^-14}, {z → -7.61947×10^-14}}   (a)

In[3]:= ∂z (2.969*10^-55 *1/z^4 - 5.114*10^-29 *1/z^2)
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$$\text{Out[3]=} \; -\frac{1.1876\times10^{-54}}{z^5} + \frac{1.0228\times10^{-28}}{z^3}$$

$$\text{In[4]:=} \; \text{NSolve}\left[-\frac{1.1876*10\text{^}-54}{z^5} + \frac{1.0228*10\text{^}-28}{z^3}, z\right]$$

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Out[4]= {{z → 1.07756×10^-13}, {z → -1.07756×10^-13}}   (b)

In[5]:= Fmin == 2.969*10^-55 *1/ (1.07756*10^-13)^4 - 5.114*10^-29 *1/ (1.07756*10^-13)^2

Out[5]= Fmin == -0.00220217   (Fb)
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$$\text{In[6]:=} \; -\int_{1.07756*10\text{^}-13}^{1} (2.969*10\text{^}-55 *1/z\text{^}4 - 5.114*10\text{^}-29 *1/z\text{^}2)\, dz$$

Out[6]= 3.95493×10^{-16} J **work against nuclear force (bond energy)**

The profile of the function looks proper, but the distance between neighboring quarks seems too large [7], [8], min function (i.e. max attractive force) and binding energy appears to be small [9].

Now I will calculate the same things but with a change that magnetic, repulsive part of a net force is not at its maximum but is in fact 100 000 times smaller, and I will assume 3 of these interactions. Logic behind these changes is in my opinion physically acceptable because even if its parts are forced to be in magnetically repulsive configuration by some other internal structural relations it is difficult to believe that balance will be in form of a maximum magnetic repulsion. If we define maximum magnetic repulsion angle, between m_1 and m_2, to be 0^0 (see picture above), "100 000 times smaller" magnetic repulsion corresponds to the 89.999 427^0 angle between m_1 and m_2.

With new assumptions, magnitude of the nuclear force as purely electromagnetic interaction of neighboring quarks is:

$$\boldsymbol{F_n} = \mathbf{3(2.969x10^{-60}\frac{1}{z^4}}\ Nm^4 - \mathbf{5.114x10^{-29}\frac{1}{z^2}}\ Nm^2)$$

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In[5]:= Plot[3* (2.969*10^-60 *1/z^4 - 5.114*10^-29 *1/z^2), {z, 2*10^-16, 4*10^-15}, AxesLabel → {z [m], F[N]}, AxesOrigin → {0, 0}]
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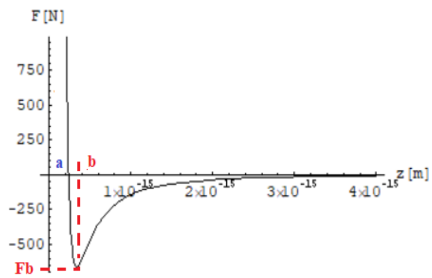


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Out[5]= - Graphics -

In[6]:= NSolve[3* (2.969*10^-60 *1/z^4 - 5.114*10^-29 *1/z^2) == 0, z]

Out[6]= {{z → -2.40949×10^-16}, {z → 2.40949×10^-16}}   a

In[7]:= ∂z (3* (2.969*10^-60 *1/z^4 - 5.114*10^-29 *1/z^2))

Out[7]= 3 (- 1.1876×10^-59 / z^5 + 1.0228×10^-28 / z^3)

In[12]:= NSolve[3 (- 1.1876`*^-59 / z^5 + 1.0228000000000002`*^-28 / z^3), z]

Out[12]= {{z → 3.40753×10^-16}}   b

In[14]:= Fmin == 3* (2.969*10^-60 *1/ (3.4075*10^-16)^4 - 5.114*10^-29 *1/ (3.4075*10^-16)^2)

Out[14]= Fmin == -660.652   Fb

In[13]:= - ∫_{3.4075*10^-16}^{1} 3* (2.969*10^-60 *1/z^4 - 5.114*10^-29 *1/z^2) dz

Out[13]= 3.752×10^-13   J   work against nuclear force (bond energy)
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As you can see from the data these corrections yield much better results [7],[8], [9]. Using only this approach further improvements are possible, but that would go outside of this demonstrative work.

On the other hand, inside nucleus there are numerous processes and changes, everything reacts with every other thing, nonetheless I hope that this calculations are enough to convince and inspire others to pursuit solution for the nuclear interactions in this particular direction.

References

[1] https://profmattstrassler.com/articles-and-posts/particle-physics-basics/the-structure-of-matter/protons-and-neutrons/

https://i0.wp.com/profmattstrassler.com/wp-content/uploads/2013/04/nucleons1.png

[2] Kar W. Yung, Peter B. Landecker, Daniel D. Villani, "An Analytic Solution for the Force Between Two Magnetic Dipoles", *Physical Separation in Science and Engineering*, vol. 9, Article ID 079537, 14 pages, 1998. https://doi.org/10.1155/1998/79537

[3] https://player.slideplayer.com/39/10911280/#

[4] Perkins, Donald H. (1982). Introduction to High Energy Physics. Reading, Massachusetts: Addison Wesley. pp. 201–202. ISBN 978-0-201-05757-7.

[5] http://www.ep.ph.bham.ac.uk/general/seminars/slides/Themis-Bowcock-2018.pdf

[6] Halliday, David; Resnick, Robert; Walker, Jearl (2013). Fundamentals of Physics. John Wiley & Sons. pp. 609, 611. ISBN 9781118230718.

[7] deuteron rms charge radius, $r_d = 2.128 \times 10^{-15}$ m

https://physics.nist.gov/cgi-bin/cuu/Value?rd

[8] proton rms charge radius, $r_p = 8.414 \times 10^{-16}$ m

https://physics.nist.gov/cgi-bin/cuu/Value?rp|search_for=proton+

[9] “The measured binding energy of the deuteron is 2.2 MeV” (2.2 MeV≈3.52×10^{-13} J)

http://hyperphysics.phy-astr.gsu.edu/hbase/Particles/deuteron.html#:~:text=The%20deuteron%2C%20composed%20of%20a,to%200.99985%20for%20ordinary%20hydrogen.