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An Electromagnetic Model for Proton-Neutron Binding in Deuterium Based on a Modified Lockyer Framework

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An Electromagnetic Model for Proton-Neutron Binding in Deuterium Based on a Modified Lockyer Framework

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Abstract

This study investigates a modified version of Thomas Lockyer's model, which calculates the proton-to-electron and neutron-to-electron mass ratios with high precision (relative errors of -0.00000026 for the proton and $+0.00000335$ for the neutron). In Lockyer's framework, the proton is conceptualized as a positron with increasing energy layers nested inside it like Russian dolls, and the neutron as a proton with an additional electron and a doubled first energy layer. We modify this by modeling the neutron as a proton with an electron orbiting at a radius of approximately 0.935 fm, calculated to reproduce the neutron's mass. The proton-neutron binding in the deuterium nucleus is hypothesized to result from the sharing of this electron between the proton and the neutron's internal proton, mimicking a covalent-like electromagnetic interaction. This hypothesis tests Lockyer's model, which excludes quarks and gluons central to quantum chromodynamics (QCD), proposing instead that the strong force could arise from electron sharing, analogous to molecular bonding. Using CODATA 2022 values, we calculate a binding energy of 2.097461571 MeV, remarkably close to the experimental deuterium binding energy of 2.224589 MeV (94.29% of the true value). This suggests that Lockyer's framework, despite its departure from QCD, captures significant aspects of nuclear binding.

Keywords: proton-neutron binding; deuterium; electromagnetic model; neutron structure; Lockyer's mass ratio; strong force

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1. Introduction

The proton-to-electron and neutron-to-electron mass ratios, approximately 1836.15267343 and 1838.68366173 per CODATA 2022 [1], are critical constants in physics. Thomas Lockyer's theoretical model achieves remarkable precision in calculating these ratios, with relative errors of -0.00000026 for the proton and $+0.00000335$ for the neutron [2,3]. In Lockyer's model, the proton is described as a positron containing nested energy layers, akin to Russian dolls, while the neutron includes an additional electron with the first energy layer doubled.

This study modifies Lockyer's model by treating the neutron as a proton with an electron orbiting at a radius calculated to match the neutron's mass ($\approx$ 0.935 fm). We hypothesize that the proton-neutron binding in the deuterium nucleus (^{2}H) results from the sharing of this electron, resembling a covalent bond in molecular systems. This approach tests Lockyer's framework, which excludes quarks, gluons, and fractional charges central to quantum chromodynamics (QCD). Instead, we explore whether the strong force could arise from an electromagnetic interaction via electron sharing, analogous to how atoms form molecules. Using CODATA 2022 values, we compute the binding energy and compare it to the experimental value of 2.224589 MeV, finding surprising agreement.

2. Theoretical Model

2.1. Neutron as a Proton-Electron System

We model the neutron as a proton ($m_p = 1.67262192369 \times 10^{-27}$ kg, charge $+e = 1.602176634 \times 10^{-19}$ C) with an electron ($m_e = 9.1093837015 \times 10^{-31}$ kg, charge $-e$) orbiting at a radius r. The radius is chosen to reproduce the neutron's mass ($m_n = 1.67492749804 \times 10^{-27}$ kg):

$$m_n \approx m_p + m_e - \frac{E_{\text{bind}}}{c^2} \tag{1}$$

$$m_p + m_e \approx 1.67353286206 \times 10^{-27}\,\text{kg} \tag{2}$$

$$m_n - (m_p + m_e) \approx 1.39463598 \times 10^{-30}\,\text{kg} \tag{3}$$

Using $c^2 = 8.985551858 \times 10^{16}\,\text{m}^2\text{s}^{-2}$, the binding energy is:

$$E_{\text{bind}} \approx 1.39463598 \times 10^{-30} \cdot 8.985551858 \times 10^{16} \approx 1.253086285 \times 10^{-13}\,\text{J} \tag{4}$$

$$E_{\text{bind}} \approx \frac{1.253086285 \times 10^{-13}}{1.602176634 \times 10^{-19}} \approx 0.782111879\,\text{MeV} \tag{5}$$

To find the orbital radius, we use the electrostatic potential energy:

$$E_{\text{bind}} = -\frac{1}{2}\frac{e^2}{4\pi\epsilon_0 r} \tag{6}$$

$$\frac{e^2}{4\pi\epsilon_0} \approx 2.306943583 \times 10^{-28}\,\text{J·m}, \quad \epsilon_0 = 8.8541878128 \times 10^{-12}\,\text{F/m} \tag{7}$$

$$1.253086285 \times 10^{-13} = \frac{2.306943583 \times 10^{-28}}{2r} \tag{8}$$

$$r \approx 9.206 \times 10^{-16}\,\text{m} \approx 0.9206\,\text{fm} \tag{9}$$

This radius, slightly larger than the proton's charge radius (0.84 to 0.88 fm) [1], is consistent with nuclear scales (~ 1 fm).

2.2. Relativistic Correction to Orbital Radius

To assess relativistic effects, we calculate the electron's orbital velocity at $r \approx 0.9206$ fm, balancing the Coulomb force with the centripetal force:

$$\frac{e^2}{4\pi\epsilon_0 r^2} = \frac{m_e v^2}{r} \tag{10}$$

$$v = \sqrt{\frac{e^2}{4\pi\epsilon_0 m_e r}} \approx \sqrt{\frac{2.306943583 \times 10^{-28}}{9.1093837015 \times 10^{-31} \cdot 0.9206 \times 10^{-15}}} \approx 5.249258 \times 10^7\,\text{m/s} \tag{11}$$

$$\frac{v}{c} \approx \frac{5.249258 \times 10^7}{2.99792458 \times 10^8} \approx 0.175070 \tag{12}$$

The Lorentz factor is:

$$\gamma = \frac{1}{\sqrt{1 - (0.175070)^2}} \approx 1.015791 \tag{13}$$

The effective mass is:

$$m_{\text{eff}} = \gamma m_e \approx 1.015791 \cdot 9.1093837015 \times 10^{-31} \approx 9.252676 \times 10^{-31}\,\text{kg} \tag{14}$$

This represents a $\approx 1.5791\%$ increase in mass. Adjusting the radius to maintain the binding energy ($E_{\text{bind}} \approx 0.782111879$ MeV):

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$$E_{\text{bind}} = -\frac{1}{2}\frac{e^2}{4\pi\epsilon_0 r_{\text{rel}}} \tag{15}$$

Using the effective mass in the centripetal force does not directly alter E_{bind}, as it is fixed by the mass defect. Instead, we approximate the relativistic radius by scaling:

$$r_{\text{rel}} \approx \gamma \cdot r \approx 1.015791 \cdot 0.9206 \approx 0.935126\,\text{fm} \tag{16}$$

2.3. Proton-Neutron Binding via Electron Sharing

In the deuterium nucleus, the neutron is a proton (p_1) with an electron orbiting at 0.935 fm, and a second proton (p_2) shares this electron. We model the binding as an electromagnetic interaction, assuming the electron is midway between the protons, separated by $d \approx 2$ fm (typical deuteron size). The potential energy is:

$$V = -\frac{e^2}{4\pi\epsilon_0}\left(\frac{1}{r_1} + \frac{1}{r_2}\right), \quad r_1 = r_2 = \frac{d}{2} = 0.935\,\text{fm} = 0.935 \times 10^{-15}\,\text{m} \tag{17}$$

$$V \approx -2 \cdot \frac{2.306943583 \times 10^{-28}}{0.935 \times 10^{-15}} \approx -4.934638680 \times 10^{-13}\,\text{J} \tag{18}$$

$$V \approx \frac{-4.934638680 \times 10^{-13}}{1.602176634 \times 10^{-19}} \approx -3.079959210\,\text{MeV} \tag{19}$$

The binding energy is:

$$E_{\text{liaison}} \approx V - E_{\text{bind (neutron)}} \approx -3.079959210 - (-0.782111879) \approx -2.2978473\,\text{MeV} \tag{20}$$

$$|E_{\text{liaison}}| \approx 2.2978473\,\text{MeV} \tag{21}$$

2.4. Comparison with Experimental Deuterium Binding Energy

The experimental binding energy of deuterium is:

$$E_b \approx 2.2978473\,\text{MeV} \tag{22}$$

$$\frac{E_{\text{liaison}}}{E_b} \approx \frac{2.2978473}{2.224589} \approx 1.03293 \tag{23}$$

The calculated binding energy differs by **3.3%** from the experimental value.

3. Discussion

The calculated binding energy (2.2978473 MeV) is remarkably close to the experimental value (2.224589 MeV), suggesting that Lockyer's framework, with the neutron as a proton-electron system and the strong force modeled as electron sharing, captures a significant portion of the nuclear interaction. This study tests Lockyer's model, which excludes quarks, gluons, and fractional charges, proposing an electromagnetic analogy for the strong force similar to molecular bonding. Limitations include:

1. **Non-Relativistic Approximation**: The model uses a classical electrostatic potential, with relativistic corrections (e.g., $r_{\text{rel}} \approx 0.9351$ fm) having minimal impact.
2. **Simplified Geometry**: The choice of $d \approx 2$ fm and symmetric electron positioning is an approximation. The deuteron's wave function is more complex.

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3. **Absence of QCD**: Lockyer's model avoids quarks and gluons, unlike QCD, where the strong force arises from meson exchange. The 3.3% discrepancy may reflect missing nuclear effects.

The close agreement supports exploring alternative models, though Lockyer's framework is not intended to replace QCD but to offer a phenomenological perspective.

4. Conclusion

This study modifies Lockyer's model, where the proton is a positron with nested energy layers and the neutron includes an electron orbiting at $\approx 0.9206\,\text{fm}$, adjusted to $\approx 0.9351\,\text{fm}$ with relativistic corrections. By hypothesizing that the proton-neutron binding in deuterium results from electron sharing, we calculate a binding energy of $2.2978473\,\text{MeV}$, wich differs by 3.3% from the experimental value ($2.224589\,\text{MeV}$). This remarkable agreement suggests that an electromagnetic analogy can approximate nuclear binding within Lockyer's framework, which operates without quarks or gluons. Future work could incorporate quantum effects or test the model against other nuclear systems.

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Conflicts of Interest: The author declares no competing interests.

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