Electromagnetic Nuclear Physics

Bernard Schaeffer

7, rue de l'Ambroisie, 75012 Paris, France
E-mail: bschaeffer@wanadoo.fr

Abstract

The so-called Coulomb force, repulsive between protons, discovered by Rutherford, is the only electromagnetic interaction recognized in nuclear physics for scattering and energy. A singularity was observed, falsely attributed to an attractive phenomenological strong interaction. In contrast, at high kinetic energy, it needs only to replace, above the singularity, in the Rutherford formula, the electrostatic -2 by -6, magnetic. In log-log coordinates, one obtains two straight lines with slopes -2, and -6, going through the experimental points, crossing at the singularity. At kinetic energies higher than 28 MeV, the -28 MeV binding energy of the alpha particle is annihilated, freeing the magnetic moments of the nucleons. The nuclear binding energy is also electromagnetic. Indeed, the electrostatic attraction between a proton and a not so neutral neutron, as between amber and dust, equilibrates statically the magnetic repulsion. The precision of the calculation is of a few percent for the simplest bound nucleus, the deuteron. In contrast with the electromagnetic theory, the hypothetical strong force cannot be used to calculate nuclear scattering and binding energy. With protons and not so neutral neutrons fundamental constants, it is easy to calculate electromagnetically normal and not so anomalous Rutherford scattering and also binding energy, at least for light nuclei.

1. Introduction

According to conventional nuclear physics, a hypothetical strong force is assumed to hold the nucleons against the **repulsive** "Coulomb force" due to the positive charges of the protons. To publish a paper in nuclear physics journals, the belief that the "strong force" exists is mandatory. In contrast, it will be shown in this paper that the nuclear interaction is entirely and only electromagnetic:

1 - Rutherford scattering is well known to be *electrostatic* at low kinetic energy, with a $-\mathbf{2}$ slope in log-log coordinates. At high kinetic energies, the slope has been discovered to be $-\mathbf{6}$, *magnetic*.

2 - The binding energy of a nucleus has never been calculated successfully, the fundamental laws of the strong force being unknown. In contrast, *electromagnetically*, one is able to calculate the binding energy of at least light nuclei, without fit, with a precision of a few percent for the deuteron. Indeed, there is an *electrostatic* ***attraction*** between a proton and a not so neutral neutron as amber ***attracts*** light bodies, ignored in nuclear physics. The magnetic **repulsion** equilibrates the *electrostatic* ***attraction***.

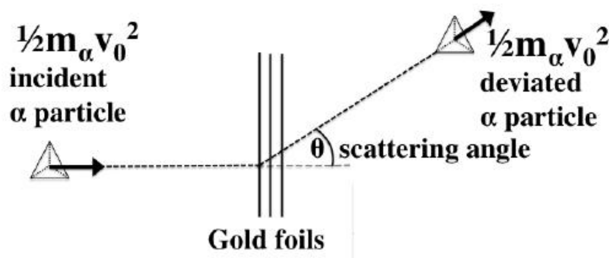

Figure 1: Geiger-Marsden Experiment - The α particles are emitted by radium, impacting thin gold, lead or other metal foils. The number of deflected α particles depends upon the scattering angle and the metal foils determining their velocity. The experiment consists to count the number of flashes viewed through the microscope during a given time and for a fixed solid angle. The α particles are scattered all around, even backwards, astonishing Rutherford [1, 2, 3, 4].

The purpose of this paper is to solve electromagnetically the "anomalous" α particle scattering problem and, in a second part, the nuclear binding energy problem. Up to know these two problems were only described empirically, without fundamental laws.

2. Scattering Theories

2.1. Rutherford Scattering

Rutherford discovered that an impacting *electrostatically* charged α particle is deviated by the **repulsive** *electrostatic* "Coulomb force" of an impacted nucleus. The origin of the concept of strong force comes from the observation of the discrepancy between Rutherford theory and experiment at high kinetic energies.

Alpha particles, from a radioactive source, are deviated by thin gold foils, producing a tiny, but visible flash of light when they strike a fluorescent screen (Fig. 1). Surprisingly, α particles were found at large angles of deflexion and, unexpectedly, some of the particles are scattered back in the direction of the incidence. They back penetrate so close to the central charge, that the field due to the uniform distribution of negative *electricity* may be neglected [1, 2], disproving the J. J. Thomson plum-pudding model.

Rutherford developed the *electrostatic* scattering formula relating the cross-section and the kinetic energy of the α particles. He explained why some alpha particles projected on an atom were reflected by a small nucleus: "*As-*

suming classical trajectories for the scattered alpha particles, Coulomb's law was found to hold for encounters between alpha particles and nuclei" [2]. The first evidence of departures from Coulomb's law other than those in alpha scattering by H and He was observed by Bieler [4].

The discontinuity appearing near to the total absolute value of the α particle binding energy, 28 MeV, is called Rutherford singularity. For kinetic energies larger than 23 MeV [3, 5], the relative cross section decreases anomalously faster than predicted by the *electrostatic* Rutherford formula (Fig. 2). *Magnetic* interpretations have been tempted without success [4, 6], due to the wrong assumption of an ***attractive***, negative *magnetic* moment.

2.2. Strong Force Potential (Chadwick)

Geiger [1] observed that, at high kinetic energies,"the deviation was larger than predicted by the *electrostatic* force". Chadwick and Bieler [3, 7] determined that forces of very great intensity hold the nucleus together, a force distinct from the *electromagnetism* [3, 8, 9]. The *electrostatic* potential is **repulsive** as discovered by Rutherford. The hypothetical "strong force", was assumed to be negative, thus ***attractive*** [3, 10]:

$$V(r) = +\frac{2Ze^2}{4\pi\epsilon_0 r} - \frac{B}{r^{\mathbf{n}}}\ (\mathbf{n} > \mathbf{1}) \qquad (1)$$

The first term of equation (1) corresponds to the "normal"*electrostatic* Rutherford scattering and the second term to the "anomalous"scattering, *magnetic* if **n = 3**. The sign of B, not specified, seems to be *positive* [10]. Many empirical theories have been developed. The first one is Yukawa's with two empirical parameters [11]. Up to now, the fundamental laws of the "strong force"remained unknown.

2.3. Electromagnetic Potential (Bieler)

Using formula (1) Bieler hypothesized the existence of ***attractive*** *magnetic* moments combined with the *electrostatic* **repulsion**, thus with **n = 3** for the potential [3, 4]:

$$V(r) = +\frac{2Ze^2}{4\pi\epsilon_0 r} - \frac{2Z|\mu_0\mu_n\mu_p|}{4\pi r^3} \qquad (2)$$

Nuclear scattering became entirely and only electromagnetic. Unfortunately, with the ***attractive*** negative sign of the *magnetic* potential and a combined electromagnetic formula, Bieler was unable to solve the problem.

2.4. Electrostatic and Magnetic Potentials Separated

At low kinetic energies, r being large, the interaction is governed by the Rutherford *electrostatic* formula with a $1/r$ potential. In log-log coordinates, the experimental points are aligned on straight lines with slopes -2 and -6 (fig. 2). The intersection of these two straight lines, at 23 MeV, coincides approximately with the binding energy of the α particles -28 MeV, except for the sign. At kinetic energies higher than 28 MeV, the α particles are thus broken into protons and neutrons.

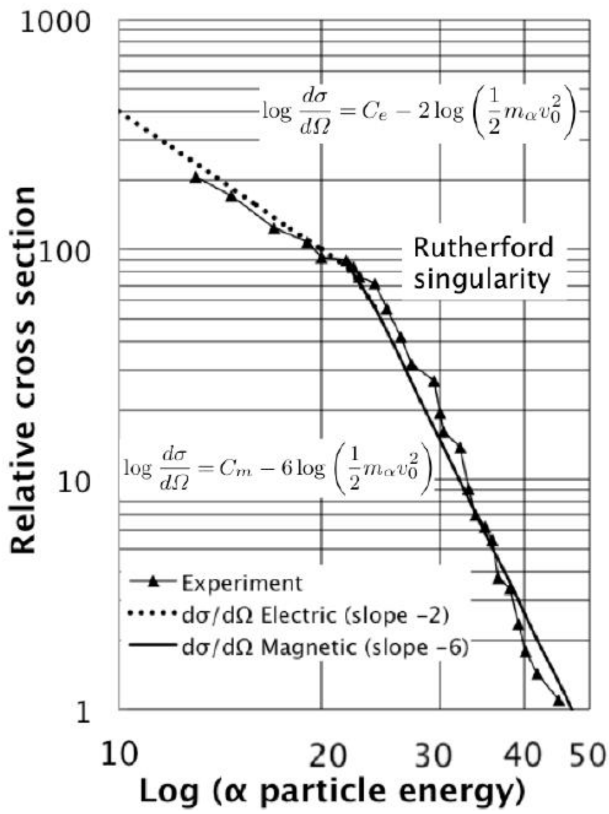

Figure 2: Applying Coulomb [12] and Poisson [13] potentials - The relative differential cross section $\frac{d\sigma}{d\Omega}$ is a targeted area per solid angle per unit time. In other words, it is the differential ratio between the geometrical area divided by the corresponding solid angle, multiplied by the ratio between potential and kinetic energies. The α particles are projected on Ta foils at a fixed scattering angle $\theta = 60^0$ with initial kinetic energies varying between 13 and 42 MeV [6]. The α particles are **repulsed** and deviated by the Ta nucleus *electrostatic* force in the direction of the particle exit trajectory (Fig. 1). The Rutherford singularity appears for a kinetic energy near 23 MeV. At higher kinetic energies, the curve deviates, wrongly assumed to be due to an attractive strong force [3]. Bieler assumed, also wrongly, an attractive magnetic force [4]. In contrast, with a **repulsive** *magnetic* force one obtains a straight line with a $-\mathbf{6}$ slope going through the experimental points. The Rutherford formula works fine, even for the so called anomalous scattering, provided that the *electric* $-\mathbf{2}$ shall be replaced by the *magnetic* $-\mathbf{6}$ at kinetic energy able to annihilate the α particle around its total binding energy -28 MeV.

The separation distance r between impacting α particles and impacted heavy nuclei decreases with increasing kinetic energy. The *electrostatic* interaction between the protons of the impacting α particles and of the impacted Z nuclei is given by the Coulomb potential formula:

$$V(r_e) = +\frac{2Ze^2}{4\pi\epsilon_0 r} \tag{3}$$

At high kinetic energy, e.g. near or above 28 MeV, the total nuclear binding energy of the α particles, -28 MeV, is annihilated, freeing the *magnetic* moments of the nucleons. The Poisson potential in $1/r^3$ [13] replaces the Coulomb potential in $1/r$ [12], due to the small separation distance r between nucleons. Thus, the *magnetic* moments of the nucleons interact with those of the impacted nuclei. The $-\mathbf{3}$ *magnetic* potential replaces the $-\mathbf{1}$ *electrostatic* potential:

$$V(r_m) = +\frac{2Z|\mu_0\mu_n\mu_p|}{4\pi r^3} \tag{4}$$

2.5. Differential cross-section

The differential cross-section $\frac{d\sigma}{d\Omega}$ is defined as the ratio of the number of particles scattered into a constant direction θ, per unit time and per unit solid angle $d\Omega$. Squaring the initial kinetic energy of the α particle, $\frac{1}{2}m_\alpha v_0^2$, gives the so-called differential cross-section $\frac{d\sigma}{d\Omega}$, only relatively known. The complete Rutherford formula [2],

$$\frac{d\sigma}{d\Omega} = \left(\frac{1}{4\sin^2\frac{\theta}{2}} \times \frac{zZe^2}{4\pi\epsilon_0} \times \frac{1}{\frac{1}{2}m_\alpha v_0^2}\right)^2 \tag{5}$$

may be simplified for constant m_α, θ, z and Z:

$$\frac{d\sigma}{d\Omega} \propto \left(\frac{1}{2}m_\alpha v_0^2\right)^{-2} \tag{6}$$

The exponent $-\mathbf{2}$, due to the *electrostatic* interaction cross-section, becomes, logarithmically, the coefficient $-\mathbf{2}$:

$$\log\frac{d\sigma}{d\Omega} = C_e - 2\log\left(\frac{1}{2}m_\alpha v_0^2\right) \tag{7}$$

where C_e, only relatively known, is adjusted to the singularity. The log-log graph shows two straight lines on Fig. 2, Coulomb *electrostatic*, slope $-\mathbf{2}$, and Poisson *magnetic*, with slope $-\mathbf{6}$ [13, 14].

$$\log\frac{d\sigma}{d\Omega} = C_m - 6\log\left(\frac{1}{2}m_\alpha v_0^2\right) \tag{8}$$

The variables are the differential cross section $\frac{d\sigma}{d\Omega}$ and the initial α particle velocity v_0. C_e and C_m are adjusted to make coincide the intersection between the *electrostatic* and *magnetic* straight lines (in log-log coordinates) with the Rutherford singularity. At the singularity, experimentally, the initial kinetic energy, $|-23|$ MeV, coincides nearly with the absolute value of the α particle total binding energy, $|-28|$ MeV (Fig. 2). We have now one formula for *electrostatic* scattering (eq. 7) and another one for *magnetic* scattering (eq. 8). The difference between "normal"and "anomalous"scattering is the potential exponent, $-\mathbf{3}$, *magnetic*, instead of $-\mathbf{1}$, *electrostatic*. The slopes are $-\mathbf{6}$, *magnetic*, and $-\mathbf{2}$, *electrostatic*, due to the cross sections in a log-log graph. The constant is defined at the Rutherford singularity, 23 MeV on Fig. 2, experimentally smaller than the ^4He binding energy, 28 MeV, taken positive, probably not significant.

The kinetic energy at the Rutherford singularity is somewhat less than the experimental value of the total binding energy of the α particle, in absolute value, $|-28|$ MeV (Fig. 2).

2.6. Conclusion on Nuclear scattering

Rutherford discovered the electrostatic part of the nuclear interaction. The **repulsion** between protons was improperly called "Coulomb force".

Indeed, the Coulomb force may be ***attractive*** or **repulsive**. Chadwick [3] choose an ***attractive*** strong force interacting indistinctly between nucleons (NN). Instead of being **repulsive** (equation 3), as for Rutherford's *electric* scattering, Bieler assumed the interaction to be *electromagnetic* with a *magnetic* part (equation 2) , falsely ***attractive***[4]:

$$V(r) = -\frac{2Z|\mu_0\mu_n\mu_p|}{4\pi r^3} \tag{9}$$

Bieler was thus unable to solve the problem of the high energy scattering. As far as I know, nobody tried a *magnetic* **repulsive** force.

At short r, at high kinetic energy, the **repulsive** *magnetic* potential in r^{-3} replaces the Rutherford also **repulsive** *electrostatic* potential in r^{-1}. As the Rutherford model overturned Thomson's model, the *magnetic* interaction overturns Chadwick's ***attractive*** strong force hypothesis [3, 7]. Bieler had almost solved the problem *magnetically*: unfortunately, the sign was wrong, falsely assumed to be negative, ***attractive***. In log-log coordinates, it suffices to replace the $-\mathbf{2}$ of the Rutherford *electrostatic* formula by the $-\mathbf{6}$, *magnetic*, to obtain two straight lines coinciding respectively with the *electrostatic* and *magnetic* scattering curves (figure 2) crossing at the singularity. Except for the position of the singularity, slightly adjusted near to the total α particle binding energy, there is no adjustment, only fundamental laws and constants.

No need of relativity and/or quantum mechanics, both unable to explain the not so anomalous scattering. *Electric* and *magnetic* interactions explain nuclear scattering, both original Rutherford, *electric* and so anomalous anomalous scattering, *magnetic*. We may say that there is an extended Rutherford scattering theory, *electric* at low kinetic energy and not so anomalous *magnetic* scattering at high kinetic energy, both **repulsive**.

3. Nuclear Binding Energy

The neutron, discovered in 1931 by Chadwick, seeming to be uncharged, the *electromagnetic* hypothesis for the nuclear interaction was unfortunately abandoned. The *magnetic* moments of the proton and of the deuteron were discovered in 1932 by Stern and the *magnetic* moment of the neutron in 1938 by Bloch. Except for the proton-proton repulsion, in spite of the discovery of the neutron *magnetic* moment and its *electrostatic* charges with no net charge, *electrostatic* and *magnetic* interactions between nucleons are generally ignored in nuclear physics.

Thales discovered, two millenaries ago that amber ($\eta\lambda\epsilon\kappa\tau\rho\omega\nu$) ***attracts*** light objects. Similarly, a proton ***attracts*** a not so neutral neutron. In other words, an electric dipole is induced into a not so neutral neutron by a nearby proton. The principle can be found in the book by Feynman [15].

Greeks also discovered the *magnetic* properties of *magnetite* from mount *Magnetos* that may be ***attractive*** or **repulsive**. Coulomb [12] and Poisson [13] discovered the formulas of the *electrostatic* and *magnetic* fundamental laws, ignored in nuclear physics except the so-called "Coulomb force", between protons, only **repulsive**.

In the deuteron, the Coulomb *electrostatic* ***attraction*** between a proton and a not so neutral neutron can be equilibrated statically by the **repulsive** Poisson *magnetic* moments of the proton and of the neutron. First results have been obtained for hydrogen and helium isotopes [16, 17, 18].

3.1. Calculation of Electromagnetic Potential Energies

In contrast with scattering, the *electrostatic* Coulomb [12] and *magnetic* Poisson [13] potential energies between nucleons may be united into a single formula [19, 20, 21]:

$$U_{em} = \sum_i \sum_{i \neq j} \frac{q_i q_j}{4\pi\epsilon_0 r_{ij}}$$

$$+\sum_i \sum_{i \neq j} \frac{\mu_0}{4\pi r_{ij}^3}\left[\vec{\mu}_i \bullet \vec{\mu}_j - \frac{3\left(\vec{\mu}_i \bullet \vec{r}_{ij}\right)\left(\vec{\mu}_j \bullet \vec{r}_{ij}\right)}{r_{ij}^2}\right] \quad (10)$$

The first term is the sum of Coulomb's *electrostatic* interaction energy potential between *electrostatic* charges q_i and q_j separated by r_{ij} (no need of hypothetical quarks). The second term is Poisson's *magnetic* interaction energy potential between nucleons with *magnetic* moments $\vec{\mu_i}$ and $\vec{\mu_j}$, separated by $\vec{r_{ij}}$.

3.1.1. Total Deuteron Electrostatic Energy Potential (Coulomb)

The *electrostatic* potential energy U_e of this system of three point charges is, from formula (10):

$$U_e = \frac{1}{4\pi\epsilon_0}\left(\frac{q_1 q_2}{r_{12}} + \frac{q_2 q_3}{r_{23}} + \frac{q_3 q_1}{r_{31}}\right) \quad (11)$$

where q_1, q_2, and q_3 are the three electrostatic charges. r_{12}, r_{23}, and r_{31} are their separation distances along their com-

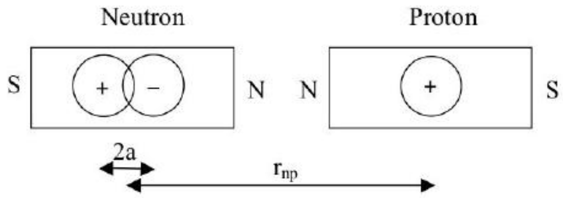

Figure 3: Schematic deuteron structure. - The elementary charges are assumed to be punctual. The proton contains an elementary charge $+e$ in the proton. The neutron contains *electrostatic* charges with no net charge, assumed to be $+e$ and $-e$. The *electrostatic* field of the proton produces a separation distance of $2a$ between the *electrostatic* charges of the neutron, distant by r_{np} from the proton. The proton attracts *electrically* the neutron as a rubbed plastic pen attracts small pieces of paper. The *magnetic* moments of the proton and the neutron are collinear and opposite, North against North (or South against South). Their *magnetic* interaction equilibrates the *electrostatic* attraction.

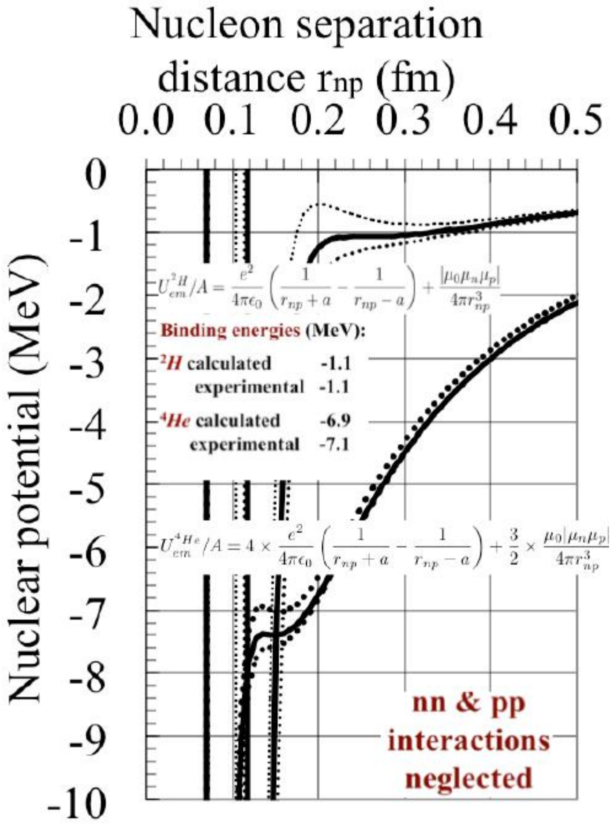

Figure 4: Calculated deuteron (^2H or heavy hydrogen, with one proton-neutron bond) and helium (^4He or α particles). - The *electrostatic* interaction between a proton and a not so neutral neutron is not negligible. Calculated helium (^4He or α particles) On helium, one has 6 bonds, 4 neutron-proton bonds, one neutron-neutron bond and one proton-proton bond. The proton-proton and neutron-neutron bonds may be neglected in a first approximation.

mon axis. The electrostatic energy potential between the 3 electrostatic charges of the deuteron (equation 11) becomes (r_{np} and a are defined on figure 3):

$$U_e = \frac{e^2}{4\pi\epsilon_0}\left(\frac{1}{r_{np}+a} - \frac{1}{r_{np}-a} - \frac{1}{2a}\right) \tag{12}$$

The usual dipole formula, $\frac{2a}{r_{np}^2}$ for $a << r_{np}$ doesn't work because a and r_{np} are of similar size. This can be solved by changing $\frac{1}{2a}$ by $\frac{1}{r_{np}+a} - \frac{1}{r_{np}-a}$. Although hypothesized, this gives the most precise result for the *electrostatic* dipole formula [15, 16], used instead of the usual approximate formula, $\frac{2a}{r_{np}^2}$. With this change one obtains a formula giving a zero dipole for both $r_{np} = 0$ and $r_{np} = \infty$:

$$U_e = \frac{e^2}{4\pi\epsilon_0}\left(\frac{2}{r_{np}+a} - \frac{2}{r_{np}-a}\right) < 0 \tag{13}$$

Although it is not rigorous, this ***attractive*** approximation gives a good result for ^2H and ^4He (Fig. 4).

3.1.2. Total Deuteron Magnetic Energy Potential (Poisson)

According to formula (10), the *magnetic* potential energy of the deuteron is:

$$U_m = \frac{\mu_0}{4\pi r_{np}^3}\left[\vec{\mu}_n \bullet \vec{\mu}_p - \frac{3\,(\vec{\mu}_n \bullet \vec{r}_{np})\,(\vec{\mu}_p \bullet \vec{r}_{np})}{r_{np}^2}\right] \tag{14}$$

The *magnetic* potential is positive, **repulsive**, assuming that the *magnetic* moments of the proton and of the neutron in the deuteron are collinear and opposite ($\vec{\mu}_n \bullet \vec{\mu}_p < 0$) as shown on figure 3. The coefficient in the brackets is thus equal to $2|\mu_n\mu_p|$. The *magnetic* potential is thus:

$$U_m = \frac{\mu_0}{4\pi}\frac{2|\mu_n\mu_p|}{r_{np}^3} > 0 \tag{15}$$

3.1.3. Total Deuteron Electrostatic and Magnetic Energy Potentials Added

Adding the total ***attractive*** *electrostatic* (equation 13) and **repulsive** *magnetic* (equation 15) components of the *electromagnetic* potential formula (10) becomes:

$$U_{em} = \frac{e^2}{4\pi\epsilon_0}\left(\frac{2}{r_{np}+a} - \frac{2}{r_{np}-a}\right) + \frac{\mu_0}{4\pi}\left(\frac{2|\mu_n\mu_p|}{r_{np}^3}\right) \tag{16}$$

or, numerically:

$$U_{em} = 1.442\left(\frac{2}{r_{np}+a} - \frac{2}{r_{np}-a}\right) + \frac{0.170}{r_{np}^3}\ MeV \tag{17}$$

There is one variable r_{np} and one parameter a in formula (17). In order to find the binding energy it is necessary to adjust the parameter a of the curve to obtain a potential minimum for both r_{np} and a. This is not to be confused with fitting to adjust the binding energy. Due to the Coulomb singularity, the potential has only one local minimum, a horizontal inflection point due to the point-like assumption of the *electric* charges. A real minimum [22] would be better, of course, but, needing an empirical parameter, would break the fundamental nature of the theory. The curve of the *electromagnetic* potential is shown on figure 4, continuous dark line, calculated with formula (17). The horizontal inflection part of the curve corresponds to the deuteron binding energy. The result, obtained by applying *electrostatic* Coulomb's law and *magnetic* Poisson's law with the corresponding fundamental constants, is in accord with the experimental value of the deuteron binding energy $-2.225\ MeV$ for $-2.13\ MeV$ calculated (4% weaker).

3.2. Conclusion on Nuclear Energy

The binding energy of the deuteron has been calculated by applying the *electrostatic* and *magnetic* laws, knowing that the deuteron contains the electrostatic charge $+e$ of the proton, plus the neutron electrostatic charges with no net charge, assumed to be $+e$ and $-e$ (no need of hypothetical quarks). The magnetic moments of the proton and of the neutron being opposite in the deuteron (figure 3), the *electrostatic* ***attraction*** (equation 13) between a proton and a neutron is equilibrated statically by their *magnetic* **repulsion** (equation 15). On the graph (figure 4), the continuous dark curve shows the calculated nuclear potential of the deuteron where the horizontal inflection point matches with the binding energy of ^2H and ^4He with less than 5 % error. Although less precise, similar results have been obtained for H and He isotopes and N = Z nuclei [16, 17, 18, 23, 24, 26, 27]. Agreement between theory and experiment proves the *electromagnetic* nature of the nuclear binding energy, contradicting the conventional theory, based on a hypothetical strong force whose fundamental laws and constants remain unknown even after one century of nuclear physics.

4. Conclusion on Nuclear Interaction

Chadwick et Bieler have recognised in 1921: "The present experiments do not seem to throw any light on the nature of the law of variation of the forces at the seat of an electrostatic charge, but merely show that the forces are of very great intensity"[7]. Indeed, the radius of a nucleus being one million times smaller than for an atom, according to Coulomb's potential energy, the nuclear binding energy is, inversely, one million times stronger.

Bieler, assuming that the *magnetic* force is ***attractive***, missed the discovery [4]. To solve the not so anomalous scattering problem, it needs only to reuse Rutherford formula where the **repulsive** *electrostatic* $\mathbf{-2}$ exponent is replaced, at high kinetic energies, by the also **repulsive** *magnetic* $\mathbf{-6}$ exponent as shown on figure 2.

For the binding energy, the problem is different. Inside the nucleus, at zero kinetic energy, the ***attractive*** *electrostatic* force between a not so neutral neutron and a proton equilibrates statically the **repulsive** *magnetic* force, allowing the calculation of the binding energy of nuclei, never obtained before with fundamental laws and constants only.

Strong Force, Strong Interaction and QCD are obsolete as Plum pudding model, Aether, Hollow Earth, Phlogiston theory, Flat Earth, Geocentric model…

In a few words, the main nuclear physics interactions are:

- Nuclear scattering: dynamic **repulsion** between nucleons, *electrostatic* at low kinetic energy and *magnetic* at high kinetic energy.

- Nuclear binding energy: *electrostatic* ***attraction*** between protons and neutrons equilibrated statically by their *magnetic* **repulsion**.

Acknowledgement

Thanks to persons at Dubna for their interest to my electromagnetic theory of the nuclear energy. The first question was about scattering. I said I don't know. Now I know: the anomalous Rutherford scattering is magnetic. The second question was: *"The strong force doesn't exist?"* and a third one about orbiting nucleons.

References

[1] H. Geiger and E. Marsden, "On a Diffuse Reflection of the $\alpha-$Particles ", *Proc. Roy. Soc. 82, 495, 1909.*

[2] E. Rutherford, "The scattering of alpha and beta particles by matter and the structure of the atom ", *Phil. Mag.*, **21**, 669 vol. A83, pp.492-504, 1911.

[3] E. Rutherford, J. Chadwick, C. D. Ellis, *Radiations from Radioactive Substances, Cambridge University Press*, 1951, 2010.

[4] E. S. Bieler, "Large-Angle Scattering of Alpha-Particles by Light Nuclei", *Proc. R. Soc. Lond.* A 105, pp.434-450, 1924.

[5] H. Paetz, *Nuclear Reactions: An Introduction*, Springer, 2014.

[6] R. M. Eisberg, C. E. Porter, "Scattering of Alpha Particles", *Rev. Mod. Phys.*", vol. 33, Issue 2, pp.190-230, 1961.

[7] J. Chadwick and E. S. Bieler, "The Collisions of Alpha Particles with Hydrogen Nuclei", *Phil. Mag.*, 42: 923, 1921.

[8] G. Farwell, H. E. Wegner, "Elastic scattering of Intermediate Energy Alpha Particles by Heavy Nuclei", *Phys. Rev.*, **95**, Nb 5, 1954.

[9] C. E. Burkhardt, J. J. Leventhal, *Foundations of Quantum Physics*, Springer Science, 2008.

[10] G. Gamow, C. L. Critchfield, *Theory of Atomic Nucleus and Nuclear Energy-Sources*, Oxford at the Clarendon Press, p. 9, 1949.

[11] H. Yukawa, "On the Interaction of Elementary Particles", *Proc. Phy. Math. Soc. Japan* 17, pp. 48-57, 1935.

[12] Coulomb, Second Mémoire sur l'Electricité et le Magnétisme, *Mémoires de l'Académie Royale des Sciences de Paris*, 1785.

[13] Poisson, Théorie du magnétisme, *Mémoires de l'Académie Royale des Sciences de Paris*, 1824.

[14] B. Schaeffer, "Anomalous Rutherford Scattering Solved Magnetically, *World Journal of Nuclear Science and Technology*, 2016, 6, 96-102.

[15] R. Feynman, R. B. Leighton, M. Sands, *The Feynman Lectures on Physics 2*, Pearson/Addison-Wesley, Reading, Mass, 2006.

[16] B. Schaeffer, "Electric and Magnetic Coulomb Potentials in the Deuteron", *Advanced Electromagnetics*, Vol. 2, No. 1, 2013.

[17] B. Schaeffer, "Electromagnetic theory of the nuclear interaction. Application to the deuteron ^2H", *Frontiers of Fundamental Physics*, 6-9 July 2010, Paris, France, AIP Conf. Proc. 1446, 123-131, 2012.

[18] B. Schaeffer, " Electromagnetic Theory of the Binding Energy of the Hydrogen Isotopes", *Journal of Fusion Energy*, 30:377-381, 2011.

[19] J.C. Maxwell, *A treatise on electricity and magnetism*, Vol.2, Oxford University Press, 1998.

[20] G.E. Owen, *Introduction to Electromagnetic Theory*, Courier Dover Publications, Oxford, 2003.

[21] K. Yosida, *Theory of magnetism*, Springer-Verlag, Berlin, 1996.

[22] A. Bobeszko, "Electromagnetic Interaction In Deuteron, Potential energy of electric and magnetic dipoles", January 2015 *http://www.tetrahedralsymmetry.talktalk.net/eid.pdf.*

[23] B. Schaeffer, "Ab Initio Calculation of ^2H and ^4He Binding Energies", *Journal of Modern Physics*, 3, pp.1709-1715, 2012.

[24] B. Schaeffer, "Electromagnetic Nature of Nuclear Energy: Application to H and He Isotopes", *World J. Nucl. Sci. Techn.,* 3, pp.1-8, 2013.

[25] B. Schaeffer, "Proton-neutron electromagnetic interaction", *ISINN-22*, Dubna, pp.27-30, 2014.

[26] B. Schaeffer "Binding Energy Curve of N = Z Atomic Nuclei", *25th Int. Nuclear Physics Conf., INPC 2013*, Firenze (Italy), 2-7 June 2013.

[27] B. Schaeffer, "Pairing Effect on the Binding Energy Curve of N = Z Atomic Nuclei", *World Journal of Nuclear Science and Technology*, 3, pp.19-22, 2013.