Anomalous Rutherford Scattering discovered to be Magnetostatic

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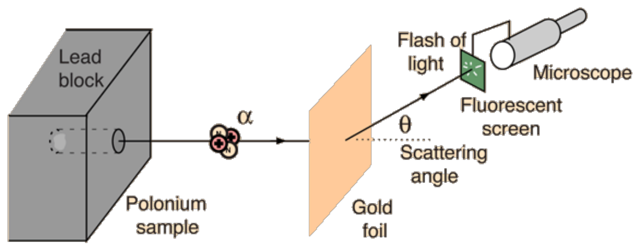

Figure 1: Scattering of α particles projected on nuclei (drawing from [1]). - The α particles are emitted by radioactive polonium, impacting a thin gold foil. The experiment consists to count the number of flashes viewed through the microscope during a given time for a fixed angle. The α particles are scattered all around, even backwards, astonishing Rutherford [2].

Abstract

Rutherford discovered the electrostatic nuclear scattering formula. Unfortunately, there was a discrepancy for kinetic energies above the so-called Rutherford singularity. Even after the discovery of the proton and neutron magnetic moments, the physical nature of the anomalous Rutherford scattering is still assumed to be due to a hypothetical strong force. It has been discovered that the repulsive long range electrostatic Coulomb and the short range magnetostatic Poisson potentials, respectively in 1/r and in $1/r^3$, explain the whole Rutherford scattering. The Rutherford singularity coincides with the transition between electrostatic and magnetostatic potentials and, approximately, in absolute value, with the α particle binding energy. In log-log graphs, the cross-section curves are straight lines with slopes twice the static electric and magnetic potential energy exponents, thus -2 and -6. This is observed experimentally, proving that the Rutherford scattering is electromagnetic.

1. Introduction

Alpha particles from a radioactive source striking a thin gold foil produce a tiny, but visible flash of light when they strike a fluorescent screen (Fig. 1). Surprisingly, alpha particles were found at large deflection angles and some were even found to be back-scattered.

Rutherford explained why some alpha particles projected on an atom were reflected by a small nucleus: "*Assuming classical trajectories for the scattered alpha parti-*

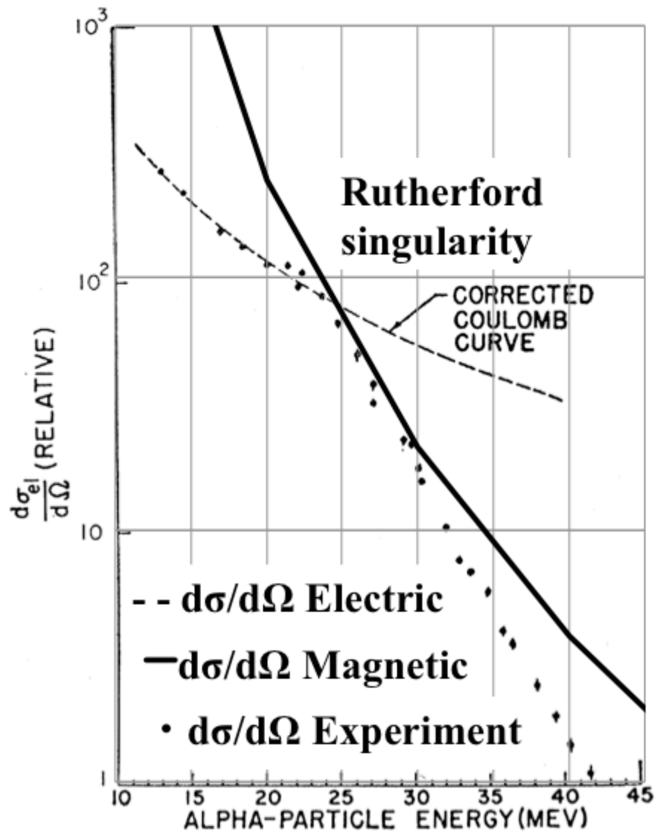

Figure 2: Rutherford type experiment - The concept of relative differential cross section $\frac{d\sigma}{d\Omega}$ is a targeted area per solid angle per a unit time. In practice, it is relative. The α particles are projected on $^{208}_{82}$Pb at a fixed scattering angle $\theta = 60^0$ with initial kinetic energies from 13 to 43 MeV [3]. The α particles are repulsed and deviated by the lead nucleus electrostatic force in the direction of the particle exit trajectory (Fig. 1). The magnetostatically calculated curve is superimposed on the experimental points of the original figure [3]. The "anomalous" Rutherford singularity appears at kinetic energies approaching 28 MeV, the total binding energy, in absolute value, of α particles.

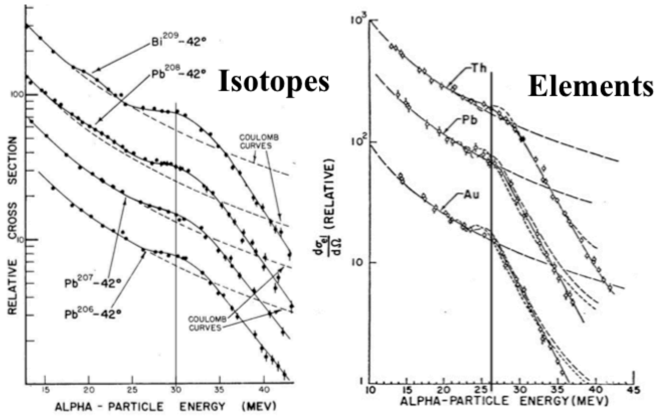

Figure 3: Comparison between isotopes of Pb [4] and elements Au, Pb and Th [3] - No significant difference appears. The curves have different heights to distinguish them easily. Indeed the cross-sections are not absolute values, the number of scattered α particles being undefined. It has been found that, for lighter nuclei, such as Ag, that the singularity appears at 16 MeV.

cles, 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 [5].

The consequence was the abandon of the J. J. Thomson "plum-pudding" model of the atom, replaced by a very small nucleus. Rutherford developed the electrostatic formula explaining the scattering for kinetic energies smaller than that of the total α particle binding energy. Later, the 43 MeV alpha-particle beam of the University of Washington 60-inch cyclotron [3] has been used for the experiments of Farwell and Wegner [5] to measure the energy dependence of the cross section. The elastic scattering over the energy range 13 to 43 MeV of alpha particles from several heavy elements were studied [3, 4, 5].

The discontinuity at 25 MeV, called Rutherford singularity, is somewhat lower than the total α particle binding energy, 25 MeV, in absolute value. The sum of the initial kinetic energy, 25 MeV, positive, and the total binding energy, negative, -28 MeV, is thus near zero at the singularity.

For kinetic energies larger than 25 MeV [3, 4], the relative cross section decreases faster (Fig. 2 and 3) than for smaller kinetic energies. The relative cross-section curve tends to zero, anomalously faster than predicted by the electrostatic Rutherford formula. Magnetic interpretations have been tempted without success [6].

The purpose of this paper is to solve the problem of the not so "anomalous" scattering of α particles.

2. Electromagnetic interactions between nucleons and between nuclei

2.1. The strong force doesn't exist

1 - The nuclear shell model, an ersatz of the Bohr atomic shell model [7], needs a strong attractive central force. This is unphysical: "*In contrast to the situation with atoms, the nucleus contains no massive central body which can act as a force center*" [8]. A theoretician said (personal communication): *"No pb. It is enough to be placed at the center of the two body mass system. The problem is reduced to the study of the relative motion"*. This may be correct mathematically but not physically.

2 - The phenomenological "strong force" of strength 1 is assumed to be 137 times more powerful than the electromagnetic interaction [9, 10] (no proof found).

3 - The electrostatic interaction is considered to be negligible, according to principles of charge-symmetry of nuclear forces [8] and charge-independence "more subtle than a simple invariance" [11], "only approximate" [12]. Protons and not so neutral neutrons contain electric charges contradicting the uncharged assumption [8].

4 - It is incorrect, for binding energy calculations, to use an empirical polarizability α or the approximate electric dipole formula, $\frac{2a}{r^2}$ [11] instead of the exact formula, $\frac{1}{r-a} - \frac{1}{r+a}$ [13].

5 - The magnetic moments of the nucleons, discovered 80 years ago, are still not taken into account for the nuclear interaction [11]. The magnetostatic potential energy, calculated for a 2 fm separation distance, gives 0.03 MeV [8]. With a 0.2 fm separation distance, one obtains 30 MeV, because of the r^{-3} potential. The magnetostatic interaction is thus not negligible.

6 - As the electric Rutherford's theory the magnetic theory doesn't need quantum mechanics and/or relativity.

Many other "modern" unproved concepts have been imagined: magic numbers, centrifugal barrier, unobservable observables, virtual particles ... and hypothetical forces: Yukawa [8], exchange, QCD ... without fundamental laws and constants, thus needing empirical fit.

The semi-empirical formula developed by Bohr and others remains the most resilient of nuclear models.

2.2. Rutherford scattering

The Rutherford scattering curve has 3 parts: electric, intermediate and anomalous:

- The classical Rutherford scattering between nuclei, acting at low kinetic energies, uses Coulomb's electrostatic potential, in r^{-1}, repulsive between protons [8, 11, 14, 15]. The theory is perfect, with electrostatic fundamental laws.
- At the Rutherford singularity, the kinetic energy is equal to both equal electrostatic and magnetostatic potential energies and, approximately, to the α particle binding energy, in absolute value.
- At high kinetic energies, the impacting α particles approach very near to the impacted nucleus. The separation

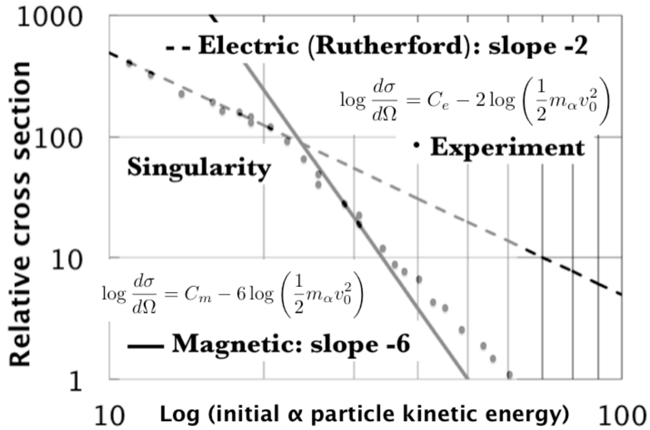

Figure 4: Thanks to the Rutherford formula and the log-log presentation, calculated electrostatic and magnetostatic scattering curves are straight lines with slopes -2 and -6, crossing at the Rutherford singularity. The difference with Fig. 2 is the abscissa, logarithmic instead of proportional.

distance is no more between nuclei, but between nucleons, almost upon contact, needing stronger forces, such as r^{-n} with $n > 1$ or exponential $\frac{e^{-r}}{r}$, as in Yukawa's theory [8] where "nuclear forces massive mesons are assumed to provide the necessary glue between nucleons by jumping to and fro" [12].

2.3. Application of Coulomb $1/r$ and Poisson $1/r^3$ laws

We shall separate the electrostatic and magnetostatic interactions, justified by the Rutherford singularity at the angle between two straight lines as shown in log-log coordinates (Fig. 4). Indeed, the electrostatic potential energy is in r^{-1}, thus linear in log-log coordinates with slope -2 for the cross-section. For smaller r, the short range Poisson magnetostatic repulsive potential energy [16], in r^{-3}, decreases faster than the Coulomb repulsive potential energy, in r^{-1} [15]. In log-log coordinates, the cross-section being surfaces, the slopes are respectively twice the exponents, thus -2 for the electrostatic interaction and -6 for the magnetostatic interaction, as observed on Fig. 4. More details below.

2.3.1. Conservation of energy

The scattering angle θ (Fig. 1), being here a constant coefficient, we may provisionally simplify the calculations by considering only head-on collisions. The law of conservation energy with electrostatic repulsion is [12, 17]:

$$\frac{1}{2}m_\alpha v_0^2 = \frac{1}{2}m_\alpha v^2 + \frac{zZe^2}{4\pi\epsilon_0 a_e} \tag{1}$$

where m_α is the mass of the α particle, v_0 and v its initial and current velocities. a_e is the separation distance between α particles and gold nuclei, only in head-on collisions. At the collision, diameter a_e [8], the α particle is at rest: $v = 0$. Thus, the initial kinetic energy $\frac{1}{2}m_\alpha v_0^2$ is equal to the positive, repulsive, potential energy $\frac{zZe^2}{4\pi\epsilon_0 a_e}$. The α particle is at rest. The electrostatic potential is thus:

$$\frac{1}{2}m_\alpha v_0^2 = \frac{zZe^2}{4\pi\epsilon_0 a_e} \tag{2}$$

Same thing magnetically, also repulsive, equal to the same kinetic energy:

$$\frac{1}{2}m_\alpha v_0^2 = \frac{zZ\mu_0}{4\pi}\frac{|\mu_n\mu_p|}{a_m^3} \tag{3}$$

In a first approximation, the total binding energy of the α particle coincides, in absolute value, with the kinetic energy and both electrostatic and magnetostatic interactions:

$$\frac{1}{2}m_\alpha v_0^2 = \frac{zZe^2}{4\pi\epsilon_0 a_e} = \frac{zZ\mu_0}{4\pi}\frac{|\mu_n\mu_p|}{a_m^3} \lesssim |B_\alpha| \tag{4}$$

In practice, we shall slightly adjust the Rutherford singularity to the total α binding energy, $|B_\alpha|$, taken positive. Numerically, at the singularity, for the α particle, $z = 2$ and for lead, $Z = 82$, we may write:

$$\frac{1}{2}m_\alpha v_0^2 = 1.438\frac{164}{a_e} = 0.0847\frac{164}{a_m^3} = 28\ MeV = -B_\alpha \tag{5}$$

This separation distance between the nuclei decreases from $a_e = 8.7 \approx 8.4$ fm, above the singularity, equal to the lead radius, to $a_m = 1.7 > 0.88$ fm, twice the proton radius.

2.3.2. 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 a_e and the initial kinetic energy of the α particle, $\frac{1}{2}m_\alpha v_0^2$, one obtains the so-called differential cross-section $\frac{d\sigma}{d\Omega}$, only relatively known, given by the simplified Rutherford formula:

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

The complete Rutherford formula is [12, 17] where one may see the singularity for $\theta = 0$ or $\theta = 180^0$:

$$\frac{d\sigma}{d\Omega} = \frac{a_e^2}{16\sin^4\frac{\theta}{2}} = \left(\frac{1}{4\sin^2\frac{\theta}{2}} \times \frac{zZe^2}{4\pi\epsilon_0} \times \frac{1}{\frac{1}{2}m_\alpha v_0^2}\right)^2 \tag{7}$$

The exponent 2, due to the electrostatic interaction cross-section, becomes, logarithmically, the coefficient 2:

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

The log-log graph shows straight lines on Fig. 4. Same thing for the Poisson magnetostatic formula [16], except that the exponent of a_m is -3 (eq. 3) instead of -1 for a_e (eq. 2). Due to the cross sections, the magnetostatic exponents are also multiplied by 2, thus 6:

$$\log\frac{d\sigma}{d\Omega} = C_m - 6\log\left(\frac{1}{2}m_\alpha v_0^2\right) \tag{9}$$

The only parameters 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 electric and magnetic straight lines with the Rutherford singularity. At the singularity, the initial kinetic energy is approximately equal and opposite to the α particle total binding energy (Fig. 4).

We have now a formula for electrostatic (eq. 8) and for magnetostatic (eq. 9) scattering. The difference between normal and "anomalous" scattering is the potential exponent, -3 for the magnetostatic interaction instead of -1 for the electrostatic interaction. The slopes are -6 and -2 due to the cross sections in a log-log graph where the constant is defined at the Rutherford singularity, 25 MeV on Fig. 4, generally somewhat smaller than the ^4He binding energy.

The Rutherford singularity energy is slightly less than the experimental value of the total binding energy of the α particle, 28 MeV (Fig. 2, 3, 4).

3. Discussion

The constants C_e and C_m vary slightly with the nuclides for a still unknown reason, probably due to the use of the laboratory frame of reference. They are adjusted manually in such a way that the electric and magnetic straight curves cross at the experimental Rutherford singularity (Fig. 4). It is the only empirical parameter of this theory.

In the range of the nuclei tested, the energy of the singularity increases with Z, from light to heavy nuclei: 16 MeV for Ag, 25 MeV for Pb, 26 MeV for Au, 26 MeV for Pb, 27 MeV for Th. The maximum value observed is almost equal to the absolute value of the ^4He binding energy. It may be seen on Fig. 2 and 3, that the Rutherford singularity appears at an energy more or less smaller than 28 MeV.

Although the precision is not as good as for the Rutherford electrostatic scattering, the magnetostatic results for the so-called anomalous scattering concords broadly but significantly with experiment.

4. Conclusion

It is well known that the Rutherford scattering can be calculated by applying Coulomb's law only. However, for energies larger than the binding energy of the α particle, in absolute value, the electrostatic scattering formula doesn't work, falsely called anomalous Rutherford scattering. The bare application of the short range magnetostatic Poisson's law, shown on Fig. 4, proves successfully that the "anomalous" scattering is magnetostatic.

As the nuclear binding energy [14], the Rutherford scattering (normal and anomalous) has been discovered to be entirely and only electromagnetic, slightly adjusted.

5. Acknowledgements

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 [18].

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