Modeling the strong nuclear force with alternating/unequal electromagnetic fields

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ABSTRACT

The strong nuclear force is a fundamental force like the gravitational or electromagnetic forces. Its effects, however, are short-range and undetectable on the human scale. Few, if any, commonplace examples of this quantum-scale phenomenon exist. This paper offers a simple classical method of modeling the quantum behavior of the strong force within both the Coulomb barrier and quark confinement using alternating/unequal sequences of opposite and unequal charges. A recently introduced magnetic "Coulomb" barrier model provides a visual and tactile representation of far-range repulsion and close-range attraction, the latter an important manifestation of the strong force. In light of Maxwell's unification of electricity and magnetism, this paper presents an electrostatic analog of the magnetic "Coulomb" barrier comprising alternating +1 and -2 coulomb electrostatic charges within a pair of opposing electrostatic arrays. Both the magnetic and electrostatic models reproduce the familiar fusion potential curve. The paper also shows how opposite/unequal charges can model the dynamics of quark "confinement," another unusual manifestation of the strong force.

The Coulomb barrier occurs at the quantum interface between the strong and the electromagnetic fundamental forces. Within the barrier, the intense attraction of the strong force confines nucleons and quarks within the atomic nucleus. Beyond the barrier, the electromagnetic force predominates owing to the net positive charge of the nucleus and its tendency to repel other nuclei. Overcoming the Coulomb barrier is the central goal of nuclear fusion, and an effective model of the barrier can only accelerate the achievement of this potential source of clean and abundant energy.

Unfortunately, discussions of the fusion process, including the kinetics of overcoming the Coulomb barrier, are inherently abstract and theoretical to the fledgling student of physics. However, a recently introduced magnetic "Coulomb" barrier model provides a visual and tactile representation of the fusion potential curve, including the counterintuitive combination of far-range repulsion and close-range attraction (https://youtu.be/FzEHs47nylA). The model contains a pair of opposing circular magnet arrays, each array comprising a series of double north-oriented magnets alternating in regular sequence with single south-oriented magnets. This configuration generates complex magnetic fields between the arrays, with the result that the net force between them (attractive or repulsive) depends on the degree of separation. At far range (beyond a few centimeters), the double-N magnets on one array repel the double-N magnets on the other. At close range (inside the potential barrier), the double-N magnets on one array align with the single-S magnets on the opposite array resulting in a strong attraction. The close-range dynamic simulates the behavior of the strong nuclear force within the Coulomb barrier, and the plot of magnetic force versus distance reproduces the familiar fusion potential curve, as shown in Figure 1(a).

Given Maxwell's unification of electricity and magnetism within the electromagnetic fundamental force, the question arises as to whether alternating and unequal *electric* fields might also demonstrate a potential barrier. Opposite poles attract and like poles repel in both electric and magnetic fields, and both fields diminish with the inverse square of the distance. An electrostatic model of the magnetic "Coulomb" barrier apparatus should therefore generate a similar potential barrier force/distance relationship.

In this exercise, the circular alternating and unequal magnet sequences of each magnet array in Fig. 1(a) are replaced by

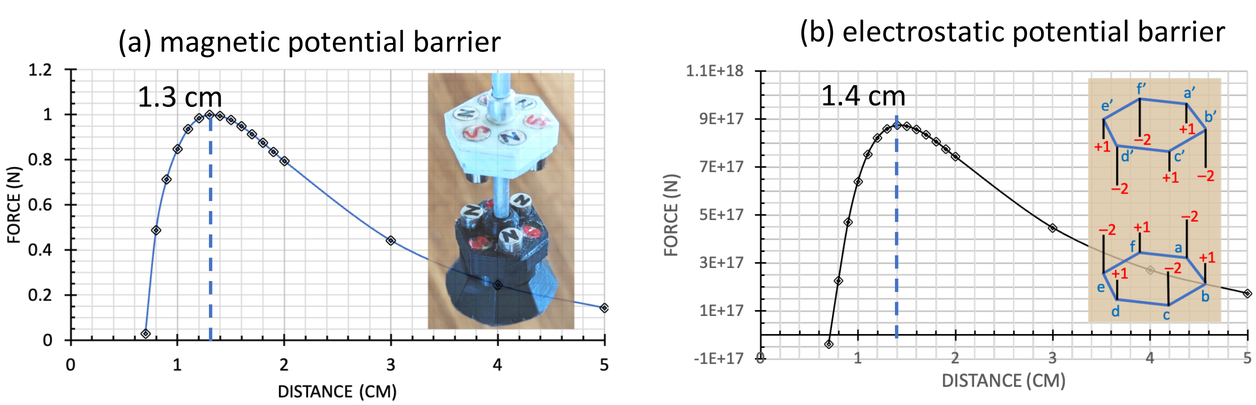

Figure 1- Comparison between an experimental magnetic potential barrier apparatus (a) and a theoretical electrostatic analog (b) configured with the same size and geometry. The force/distance profiles are nearly identical but for the expected difference in force magnitude, and both curves are maximal when the respective arrays are separated by a distance of ≈1.4 cm.

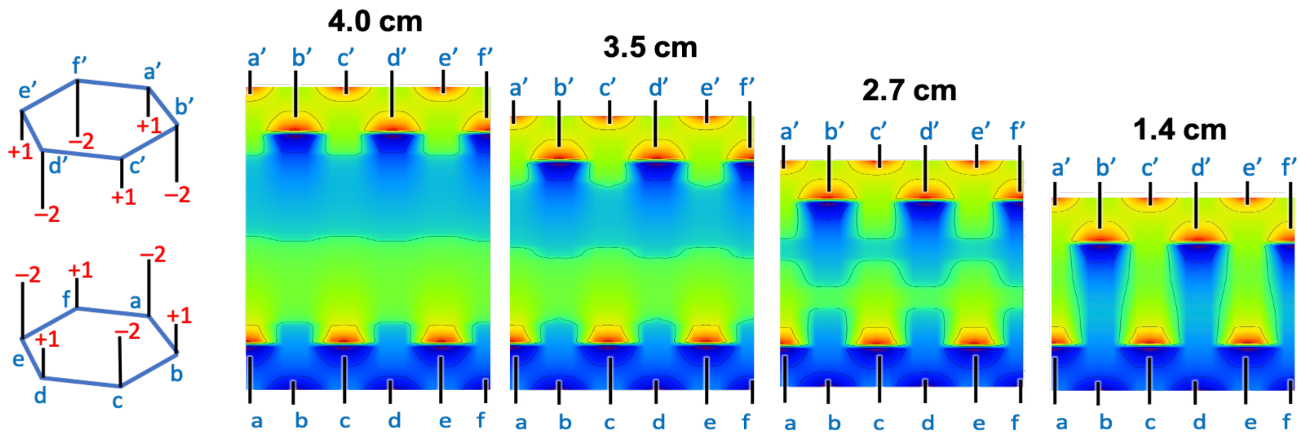

Figure 2 – Heatmaps of the electric fields between a pair of electrostatic arrays as they approach one another. At far-range (4.0 cm), repulsion between -2 charges predominates. At near range (<1.4 cm), attraction predominates between a -2 on one array and the +1 on the other.

theoretical alternating +1 and -2 coulomb electrostatic charges in Fig. 1(b) to produce a pair of opposing electrostatic arrays. The centimeter scale and essential geometry are preserved. Coulomb's law is then used to calculate component forces at incremental distances between the arrays. The theoretical electrostatic analog of the magnetic "Coulomb" barrier apparatus generates a force/distance curve that is nearly identical to the magnetic barrier curve but differing only in magnitude (as expected).

Magnetic forces are generally quite manageable on the human scale. The positions and geometry of the magnets within the magnet arrays shown in Fig. 1(a), for example, are easily fixed within a 3D-printed plastic housing and readily allow classroom demonstration. In fact, the pair of arrays can be held one in each hand, and the increasing repulsive forces are felt as the arrays are pushed together… right up until they slam together as the potential barrier is overcome!

In contrast, the analogous electrostatic array in Fig. 1(b), having the same centimeter scale and geometry as the magnetic "Coulomb" barrier arrays, would produce enormously strong forces…similar in magnitude to the gravitational attraction between Mount Fuji and planet Earth! A classroom demonstration of a potential barrier arising between the electrostatic arrays shown in 1(b) is, therefore, quite problematic. It is possible, however, to visualize the resulting barrier using "heat" map representations of the electrostatic fields.

In Figure 2, the heatmap color indicates the vector component of the electric field in the cartesian "y" direction, with red-yellow-green shades indicating a component in the + y-direction (upward) and blue shades indicating a component in the – y direction (downward). As the pair of arrays approach one another, net repulsion transitions to net attraction. At 4.0 cm, repulsive forces clearly predominate, but through 3.5 cm and 2.7 cm, repulsive and attractive forces begin to interdigitate. Within 1.4 cm (the distance between the pair of electrostatic arrays at the height of the potential

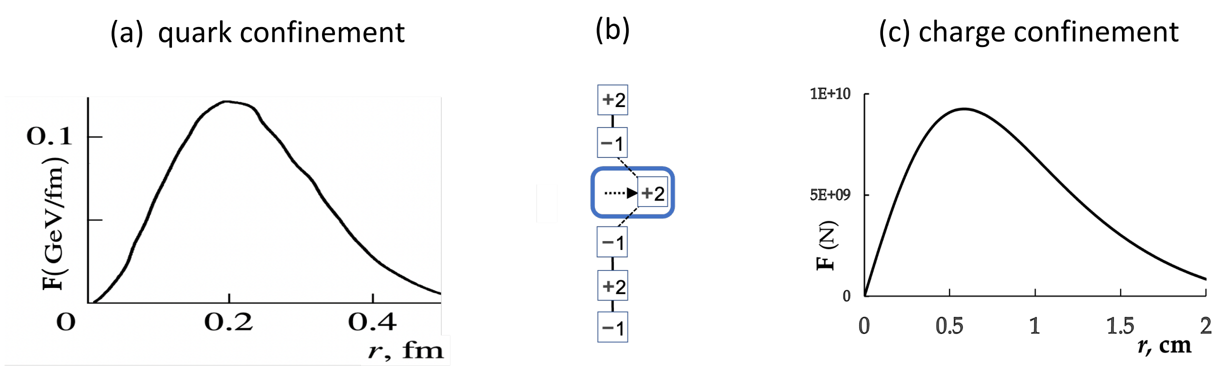

Figure 3 – Confinement force dynamics. The force acting on a point charge within a regular sequence of alternating unequal charge (b) confines the charge within the sequence. The resulting charge confinement force (c) resembles the theoretical quark "confinement" force (a) published by Musulmanbekov. *[1]* Although force/distance units differ, the curve morphologies indicate a similar dynamic.

barrier), strong attraction from the proximity and alignment of opposite charges finally penetrates the potential barrier.

The results illustrated in Fig. 1(b) and Fig. 2 parallel the magnetic “Coulomb” barrier findings. The potential curves are nearly identical, and the observable behavior of the magnet arrays is illustrated analogously in the electrostatic heat maps. Both reveal that the force between the respective arrays (attractive or repulsive) depends on the degree of separation. And both demonstrate strong attraction within the potential barrier that emulates the behavior of the strong nuclear force within the Coulomb barrier.

The exercise gives a new perspective on the electromagnetic fundamental force as an inverse square law. While it is certainly true that the force between individual electrostatic charges falls off with the inverse square of the distance, the same is not true of groups of opposite and unequal charges arranged alternately within a regular array. Such arrays produce complex force/distance relationships sufficient to model the Coulomb barrier and fusion potential curve, as demonstrated here. But combinations of opposite and unequal charges also have the capacity to emulate or model quark “confinement,” another unusual behavior of the strong nuclear force.

The unique force/distance profile of the strong force has no classical equivalent and is difficult to model outside the realm of quantum mechanics. Its range is limited, on the order of the diameter of a proton, so its effects are undetectable at the human scale. Nevertheless, while the electromagnetic force and gravity *decrease* with the inverse square of the distance, the strong force actually *increases* with distance in a near-linear fashion, as shown in the initial 0.2 fm of Figure 3(a). Quarks cannot escape the nucleus because the farther the displacement the more tightly the strong force pulls them back. This phenomenon is called quark confinement, and Musulmanbekov’s conception of the force/distance relationship is shown in Figure 3(a). [1]

Like the Coulomb barrier, confinement is a quantum mechanical phenomenon. Nothing like it exists in the classical domain. And like the Coulomb barrier, confinement forces may be modeled with an appropriately configured sequence of alternating and unequal charges, as shown in Figure 3(c).

Here, the six alternating +1 and -2 coulomb charges are assumed to occupy fixed positions 1 cm apart. A displacement force is applied to an internal -2 charge in a direction orthogonal to the linear sequence. The orthogonal force component between the internal -2 charge and each of the other charges in the sequence is then determined using Coulomb's law. The sum of these forces is plotted versus the distance between the displaced charge and its original in-line position (see Figure 3(c)). The plot is undeniably electrostatic and yet bears no resemblance to the inverse square plot normally associated with the force between a pair of charged particles. In fact, this electrostatic force/distance curve more closely resembles Musulmanbekov’s quark “confinement" force. The unusual force units of GeV/fm refer to the energy scale, a more meaningful expression of force at the quantum level. The length units in 3(a) and 3(c) do not correspond (cm versus fm), but regardless of length or force units, the salient point is that the general *morphology* of both force/distance curves indicates a confinement force. This force is least at small separations and (initially) increases in a roughly linear fashion with increasing separation. In the Musulmanbekov graph, the increasing strong force between a displaced quark with increasing distance results in its confinement within the nucleus. (It is important to point out that individual quarks have never been isolated, and the work required to displace a quark beyond a certain distance from the nucleus results in the formation of a quark/antiquark pair). [2]

In the case of the magnetic “Coulomb” barrier, the force/distance behavior of a pair of approaching magnetic arrays parallels the behavior of a pair of identically configured theoretical electrostatic arrays. The student may elect to confirm that the force/distance curve resulting from the displacement of a single charge from a regular sequence of alternating/unequal charges, as shown in Figure 3(a), may be emulated experimentally by the application of an orthogonal force to a linear sequence of equally-spaced, coupled magnets.

The strong nuclear force is on par with gravity and electromagnetism as a fundamental force. And yet, while the human experience is full of reminders of the consequences of gravity and electromagnetism, the same cannot be said of the strong nuclear force. Its unique behavior can only be understood through modeling and representation. Alternating and unequal electromagnetic fields offer a simple way to model the abstract behavior of the strong force within both the Coulomb barrier and quark confinement. Given the unrealized dream of sustained nuclear fusion (despite decades of earnest effort), a greater understanding of the nature of the strong force may prove indispensable.

Bibliography

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