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The nuclear force in electrostatics

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ABSTRACT

This paper proposes an electrostatic model for the nuclear force. This uses a simple bounded electrostatic field to create the composite attractive and repulsive forces seen when two nucleons are in very close proximity. Rather than attempt to model such a force using the gross behaviour of electrons or positrons, whose electric fields extend to infinity, it works from first principles and applies finite element analysis first to the positron to demonstrate that the seeds of nucleon-nucleon interaction have their roots in the positron-positron interaction, and then truncates the positron field at a fixed radius and shows that nucleonic attraction-repulsion results.

Keywords: Electrostatics, nuclear force.

INTRODUCTION

This discussion letter aims to suggest the simplest possible distributed-field electrostatic field model that will model the attractive/repulsive properties as seen in the nuclear force between neutrons [1].

It seems intuitively wrong to use the behaviour of electrons/positrons as prototypes since their fields extend to infinity and the neutron has no long-distance electric field. The approach taken is therefore to examine the effect of the fields' overlap at each point in space and integrate over all space to get the result, rather than use the Principle of Superposition where one charge is considered as being a point test charge lying in the field of the other charge. This gives a more credible result.

METHODS

The basic electrostatic equations may be found in any good primer on electrostatics [2] but I will summarise the necessary principles of the interaction of distributed electrostatic fields here; although this is elementary, it is essential to understand how the nuclear force model has its roots in the structure of the interaction of like charges. Take a positron as an example - it consists of a distributed electrostatic field whose electric field lines point radially away from the centre and have a vector amplitude at any point of $\mathbf{E} = q/4.\pi.\varepsilon_0.\mathbf{r}^2$, where **r** is the radial vector distance from the centre of the positron. At this point the energy density is $\varepsilon_0.|\mathbf{E}|^2/2$, proportional to the square of the electrical field strength. If two independent electric fields overlap at a single point in space - as when two charges are brought together from infinite separation - then the resultant field strength is the vector sum of the individual field strengths, and the energy density is proportional to the square of this composite value. If the energy density at a point falls when the two electric fields approach each other then attractive forces are produced at that point, while if the energy density rises then repulsive forces are produced. Figure 1 ‘a’ shows two fields overlapping in opposition so that they cancel each other out, reducing the energy density and creating attractive forces (the field vectors in each picture are offset for clarity, but actually refer to the field strengths at a single point in space). In ‘b’ the fields are at right angles – orthogonal to each other – and so there is no change in the energy density and no forces result. In ‘c’ the fields add to increase the energy density and thus create repulsive forces.

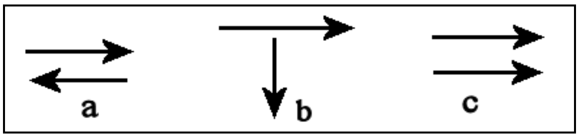

Figure 1

Rather than dealing with the nuclear force straight away, it is easier to first examine the details of the interaction between two positrons. First find the locus of all points that do not interact (i.e. produce no force) when two positrons are brought together (this does not mean we will use positrons as a part of the final model, but it helps as a signpost to the correct construction). In Figure 2 the surface described by the right-angled (orthogonal) intersection of the lines of force from each positron is readily seen to be a sphere whose diameter is the line joining the centres of the two positrons; the centres of the positrons are shown as ‘p+’. This spherical shell is the loci of all points that do not contribute any forces.

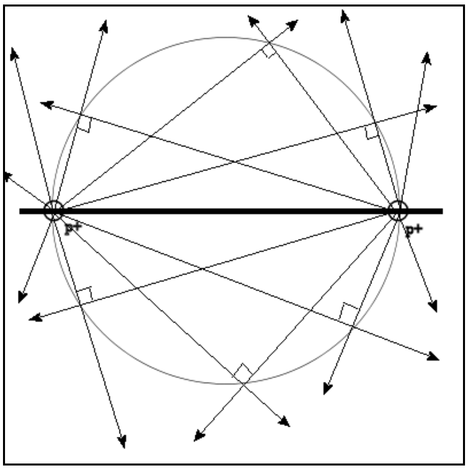

Figure 2

What are the forces inside and outside this sphere of orthogonality? The simplest point to check inside the sphere is at the midpoint of the line joining the centres of the positrons as marked by the letter ‘a’ in Figure 3; the field from the left hand positron is the upper arrow.

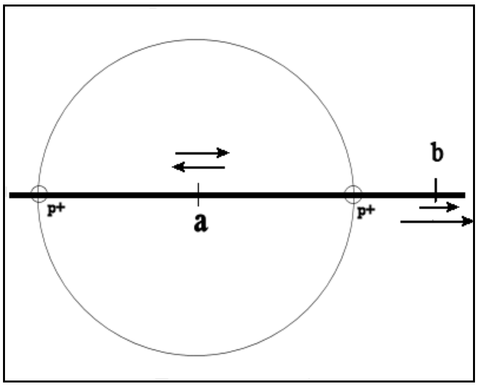

Figure 3

At ‘a’ the strengths of the electrical field lines are equal and opposite, so add to zero, giving a zero energy density. Hence there is a reduction in the energy density when compared with two separated positrons, meaning attractive forces are generated at this point. Examination of the rest of the space inside the sphere will show that energy densities are reduced everywhere inside the sphere, so generate attractive forces. As to what happens outside the sphere, examination of the field strengths at sample point ‘b’ on the right of the Figure 3 show they reinforce each other, raising the energy density and hence creating repulsive forces (again, the field from the left hand positron is the upper arrow). Examination of the rest of the space outside the sphere will confirm that all this external space generates repulsive forces. The clear conclusion is that the interaction between two positrons includes both attractive and repulsive forces, but the repulsive forces always dominate. Finite element analysis shows that the total attractive forces inside the sphere amount in magnitude to about 22% of the total repulsive forces outside the sphere, leading to a net repulsion of 78% of the total repulsive forces. This net repulsion is equal to $q^2/(4.\pi.\varepsilon_0.r^2)$. Note that these ratios apply at every separation since the fields extend to infinity, making the geometry perfectly scalable.

This is a lot of work when the Principal of Superposition can be so easily applied with much less effort. However, it gives an insight into a potential model for the neutron where the electric field is truncated to zero suddenly beyond a radius ‘r’; inside this radius the electric field follows the normal $1/r^2$ pattern, while outside this radius it is zero.

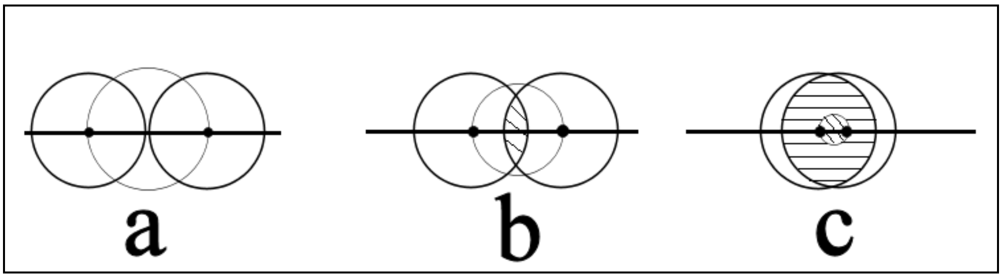

Figure 4

Figure 4 shows the interaction of two such truncated fields for three different separations; the radial limit of the truncated charge is show as a bold circle of radius r, and the sphere of orthogonality (as it would be for a positron) is a light circle; attractive regions are shown with diagonal hashing, and repulsive regions with horizontal hashing. In Figure 4a there is no interaction at separations greater that 2r because the electric fields do not overlap. As the separation drops below 2r in Figure 4b the fields start to overlap and therefore interact, but the first point of overlap is entirely within the sphere of orthogonality, so the first forces felt are attractive. When the separation is much smaller than r (as shown in Figure 4c) the sphere of orthogonality and its included attractive force becomes very small; the region of repulsion is much larger by comparison so the net forces are now repulsive. Hence a sharply bounded charge distribution exhibits both attractive and repulsive properties. Figure 5 shows the results of a finite element analysis for the force/distance plot for two such bounded positive electrostatic fields.

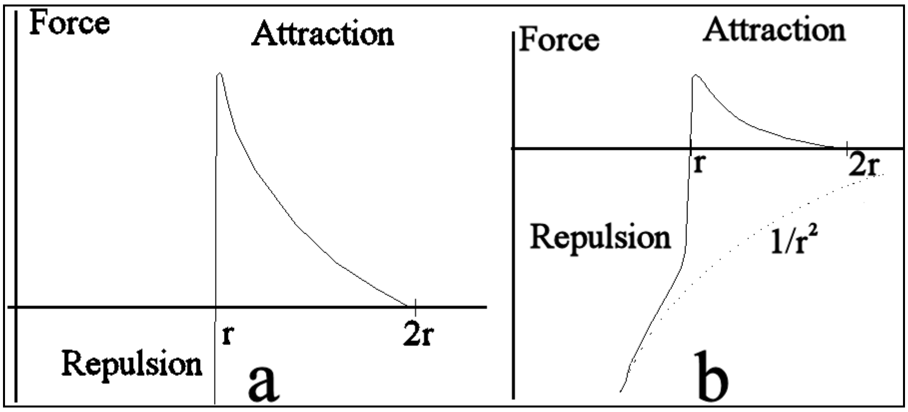

Figure 5

Figure 5a shows the attractive/repulsive force graph for a truncated field in detail, with 5b showing how it relates to the regular positron/positron interaction. Figure 5a shows no forces at separations greater than 2r, then attractive forces building up as the separation drops from 2r down to nearly ‘r’ after which the attractive forces collapse suddenly to zero at ‘r’, below which repulsive forces build up dramatically. Figure 5a is qualitatively similar to the nuclear force’s force/distance relationship; to make it quantatively similar to the nuclear force one would need to assign the electric field radius limit ‘r’ to perhaps about 10^{-15} metres, and make the electric field strength or ‘unit charge’ of the neutron perhaps ten or more times that of the positron, the forces involved being proportional to the square of this field strength. A similar approach may be taken with the proton, using the same truncated-radius model embedded the heart of its regular positron-like electrostatic field.

CONCLUSION

The composite attractive/repulsive nature of the nuclear force is readily modelled in electrostatics by a radial electrostatic field falling off at the standard rate of $1/r^2$, but made much stronger than the positron field and truncated beyond a radius of about 10^{-15} m. Its behaviour cannot be accurately derived from the behaviour of positrons and electrons, as with these particles the electric field extends to infinity and thus cannot evoke this complex behaviour, so the analysis must be made from first principles.

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