The Nuclear Force Computed as the Casimir Effect Between Spheres

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Summary

The purpose of this paper is to investigate the possibility that the Casimir effect, normally very weak, is strong enough to be significant on the scale of nuclear forces around 1 femtometer (fm = 10^{-15}m). Computations were performed for the Casimir effect between two spheres using a proximity force approximation. It was found that at 2.6 fm the computed Casimir force is strong enough to overcome Coulomb repulsion and at 0.8 fm it is 20 times stronger than Coulomb repulsion. These values indicate that this strong Casimir force is important on scales of distance consistent with the nuclear force. With refinement it appears likely that the strong Casimir force can account for the nuclear force in its entirety allowing unification of the nuclear force with quantum electrodynamic theory.

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Background

The Casimir effect was discovered by Casimir and Polder and first introduced in Nature in 1946 and later in more detail in Physical Review in 1948. Both papers were titled "*The Influence of Retardation on the London-van der Waals Forces.*"[1, 2] The theory is based on the idea that vacuum fluctuations can be considered to behave as induced dipoles, producing a London-van der Waals force. What Casimir proposed is if two plates were brought very close together, certain wavelengths would be excluded from the cavity between the plates, thus causing the pressure on the plates due to the van der Waals forces produced by vacuum fluctuations to be reduced. The reduction in force then leads to a pressure differential where the pressure pushing the plates together overcomes the pressure pushing them apart, so that the plates are pushed together unless otherwise constrained. In the late 1990s the effect was measured to a good degree of precision confirming the theory.[3, 4]

Investigation

While the Casimir Effect has a very small magnitude when measured over scales in the 0.1 to 1 micron range, the force generally varies with the inverse of distance to the fourth power. Consequently it becomes much stronger over very small distances, such as the space between nucleons. A search of the Internet revealed a paper by Ardeshir Mehta, which contained a simple computation of the Casimir Effect at 1 fm, using Equation 1 obtaining a value of F = 1.04 x 10^3 Newtons (N). This compared to his computation of Coulomb repulsion of F = 31.64 N. Based on his calculations, the Casimir force was almost 33 times the Coulomb repulsion at 1 fm.

Equation 1 is the standard Casimir force equation for two flat plates of area A and distance L between them to which Mehta added a modifier x. He arbitrarily assigned a value of $x = 5$ in order to correct for the curvature of the nucleons. It has been rewritten here slightly for consistency. The negative sign indicates that the force is attractive. Note that he did use twice the approximate area in the calculation when it was already in the equation as seen by his having 240 in the denominator instead of 480. His result for the Casimir force should have been 16.4 times the Coulomb repulsion, which is nonetheless very important.

1)

$$F = -\frac{\hbar c \pi^2}{240x}\frac{A}{L^4}$$

Given the closeness of this approximation, the author decided to perform the same computation using a Proximity Force Approximation (PFA) equation for two spheres. A PFA equation for two spheres can be found in Appendix A of a paper by Aurel Bulgac et. al.[6] Their energy equation for two spheres with a common radius a and minimum distance between them L is shown in Equation 2.

2)

$$E = -\frac{\hbar c \pi^2}{1440}\frac{\pi a^2}{L^2(2a+L)}$$

We can note that a is the radius of the proton, which is effectively constant. The 2010 CODATA value for the radius of the proton 0.8775(51) x 10^{-15} m was used in all following calculations for radius a.[7] It is similar in magnitude to L, such that we can treat it like a multiple of L and solve for the energy. We can substitute $2a = L = 1.755$ fm such that the minimum distance between the protons equal to the proton diameter giving Equation 3.

3)

$$E = -\frac{\hbar c \pi^2}{1440}\frac{\pi}{8L}$$

To convert from an energy term to a force term Equation 2 must be differentiated and multiply by 2 to account for the force due to each proton. This gives a resulting force Equation 4.

4)

$$F = -\frac{\hbar c \pi^3}{5760}\frac{1}{L^2}$$

That can be compared to the Coulomb repulsion computed by Equation 5.

5)

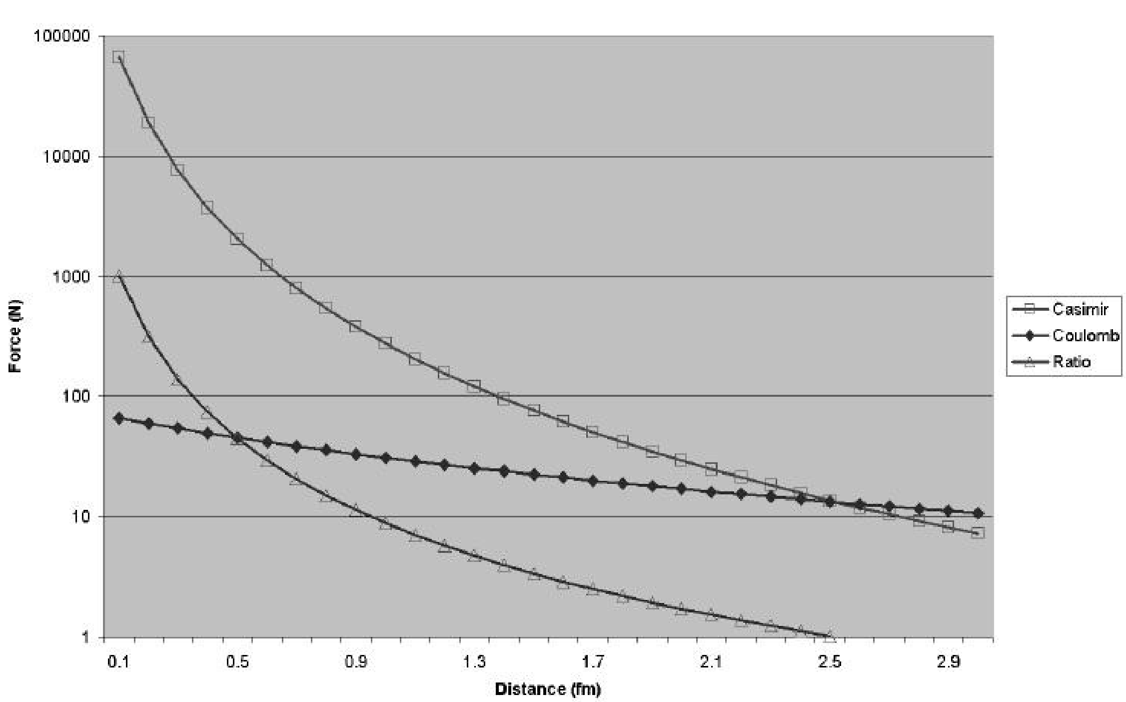
$$F = \frac{1}{4\pi\varepsilon_0}\frac{q^2}{r^2}$$

Note that in this special case r = 2L. The Casimir force pushing the two protons together is 55.3 N while the Coulomb force pushing the two protons apart is 20.6 N. Based on the PFA equation the Casimir force is 2.69 times stronger than the Coulomb repulsion at a distance of 1.755 fm.

Computation

By continuing to substitute for *a* in terms of *L* the Casimir force was calculated for minimum approach distances *L* between spheres in 0.1 fm increments from 0.2 fm to 3 fm. The Coulomb repulsion was also computed using the proton charge and a distance between the centers of the spheres based on the same distance *L*. Lastly the ratio of the Casimir force over the Coulomb force was determined. The data was plotted with a logarithmic Y scale given the rapid change in the Casimir force for distances less than 1 fm. The results are in Figure 1.

Strong Casimir Force (Figure 1)



At 3 fm the Casimir force is 8.2 N while the Coulomb force is 11.2 N. At 2.6 fm the Casimir force has strengthened to 13.7 N overtaking the Coulomb repulsion at 13.4 N. As the nucleons approach 2 fm the Casimir force reaches 35 N while the Coulomb repulsion is only 18 N and at 1 fm they are at 381 N and 33 N respectively with the Casimir Force now 11.5 times stronger. This is slightly less than Mehta's corrected result, however, the factor of 5 he chose was a good first approximation. By the time the nucleons are within 0.5 fm, the Casimir force is 3720 N while the Coulomb repulsion is 50 N giving a 75x ratio. The values for this strong Casimir force are consistent with he known strengths and distances of the nuclear force.

The strong Casimir force calculations do however show an exponential increase as the two nucleons continue to approach, reaching 67,000 N at 0.2 fm, which would be similar to the gravitational attraction of a proton sized Black Hole if it were be true. Since there is no force known that is strong enough to oppose such a strong Casimir force, there must be something else that takes place to minimize the Casimir effect at distance below 0.5 fm, such that the net force becomes repulsive matching observation. That will be speculated on later in the discussion.

Discussion

The Nuclear force has long been considered to be due to particle exchange since Yukawa first described it that way in 1935.[8] After pions where discovered this exchange was said to be due to the exchange of neutral pions. A single pion exchange event was not, however, adequate to describe the interaction in its entirety, especially not the repulsive force at small distances, so additional exchanges where theorized such as two pion and omega particle exchanges. With the advent of quark theory these exchanges were now thought to be meson exchanges where the mesons where composed of quarks. Some have proposed that gluons may also play a role. A neutral pion is composed of the quark arrangement specified in Equation 6. It is not clear how a fundamental particle could be subtracted from another fundamental particle or how a fundamental particle could be divisible by the square root of two.

6)

$$\pi^0 = \frac{u\bar{u} - d\bar{d}}{\sqrt{2}}$$

With the strong Casimir force having approximately the same range and strength as the nuclear force between 0.5 fm and 3 fm, that puts us in a bit of a quandary, as it is highly unlikely that there are two separate forces with the same range and strength that are responsible for the same force interaction. The strong Casimir force has several advantages. First of all it is based on London-van der Waals forces, which are well known. Secondly, the Casimir effect has been proven experimentally at the micron range, so its existence cannot be readily dismissed. There is no known mechanism by which the Casimir Effect could be thought not to act at the fm distance range. Probably the most important point in favor of the strong Casimir force model is that the Casimir effect is part of quantum electrodynamic theory, so the nuclear force no longer needs to be thought of as a separate force, and can be unified with electromagnetic force theory.

There is, however, still a problem with the strong Casimir force model, as there must be a mechanism that makes the strong Casimir force ineffective at distances below 0.5-0.7 fm. The trouble likely goes back to an assumption used in the Casmir force equation, namely that the spherical shell surface is infinitely smooth. In any realistic model for a proton shell that acts as the charge radius, it must become porous at some physical dimension rather than have an infinitely fine structure. If the proton is porous to ~0.7 fm wavelengths, that would explain both endpoints of the range of the Casimir-van der Waals forces between protons. The Casimir force would cease at distances below 0.7 fm in that case. Additionally, since van der Waals forces propagate more or less linearly they would also cease at distances around 2 fm as illustrated in Figure 2.

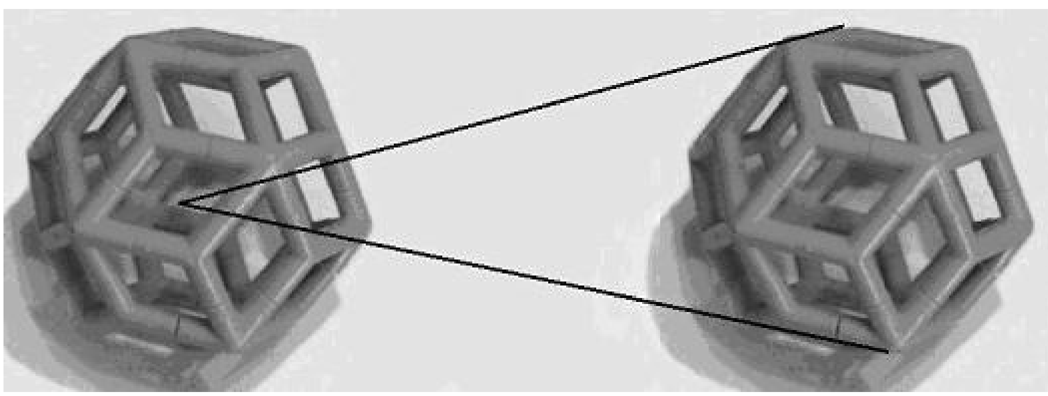


Figure 2 Two lines show the van der Waals force shadow cast by one particle on another depicted as rhombic triacontahedrons. It is clear that if the van der Waals force propagates linearly that it will decline once the distance across the opposite particle's structure within a cone drawn between them is smaller than the openings in the structure. [Pictured with permission, Roger von Oech's Star-Ball® www.CreativeWhack.com]

If the openings in the particle structure are smaller than the dimensions of a cone drawn from the center of one particle to the outside of the opposite particle, then the van der Waals force will cease to act. The rhombic triacontahedron is used to illustrate the point since it has the proper dimensional structure of outer diameter versus openings to explain the nuclear force interaction distances. It also is also the only structure the author has identified that is electrodynamically stable while possessing an unequal number of opposite charges located at the vertices. This makes the rhombic triacontahedron an excellent candidate for a semi-classical particle model.

Conclusion

While the Casimir effect is usually thought of as a very weak force, computations show that it becomes very strong at distances of a few fm or less. This strong Casimir force is consistent with the known magnitude and distances associated with the nuclear force between nucleons within the atomic nucleus. While the computations here show a strength somewhat below the known values, it is expected that more precise computations including the van der Waals attraction over the entire particle volume will yield a better result. The addition of a realistic degree of porosity to the particle structure can be used to explain the distance range of the nuclear force more precisely.

The question is then, that given we have both a particle exchange model and a strong Casimir force model to explain the nuclear force, whether we should discard one in favor of the other or somehow combine the two. It seems unlikely, however, that there are redundant force mechanisms in nature doing the same thing, so the combination solution should be rejected unless there is no other solution. The particle model certainly has time in its favor, as most physicists of today were indoctrinated into that idea. The Casimir effect, as a London-van der Waals force has a strong fundamental basis, both theoretical and experimental, so it cannot be dismissed. The Casimir effect is also the simpler and more elegant of the two solutions, and ultimate allows us to unify the nuclear force with electromagnetic theory, thus reducing the number of the so-called fundamental forces. I can only conclude that the nuclear force is the strong Casimir force.

[1] Casimir, H.B.G., Polder D., "The Influence of Retardation on the London-van der Waals Forces", Nature 158, 787-788 (30 November 1946) doi:10.1038/158787a0
[2] Casimir, H.B.G., Polder D., "The Influence of Retardation on the London-van der Waals Forces", Phys. Rev. 73, 360-372 (1948).
[3] Lamoreaux, S. K. (1997). "Demonstration of the Casimir Force in the 0.6 to 6 μm Range". Physical Review Letters 78: 5. doi:10.1103/PhysRevLett.78.5.
[4] Mohideen, U.; Roy, Anushree (1998). "Precision Measurement of the Casimir Force from 0.1 to 0.9 µm". Physical Review Letters 81 (21): 4549. doi:10.1103/PhysRevLett.81.4549.
[5] Mehta, A., "Modification of the strong force nuclear force by the zero-point field," April 7 1999. http://homepage.mac.com/ardeshir/ModificationOfTheStrong....pdf
[6] Bulgac, A., Magierski, P., Wirzba, A., " Scalar Casimir effect between Dirichlet spheres or a plate and a sphere," Phys. Rev. D 73, 025007 (2006). doi:10.1103/PhysRevD.73.025007
[7] http://physics.nist.gov/cgi-bin/cuu/Value?rp
[8] Yukawa, H., "On the Interaction of Elementary Particles," PTP, 17, 48, 1935