A Quantum-Vacuum Thruster

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The London Forces/Van der Waals Interpretation of the Casimir Effect holds that electrically-neutral surfaces in a Casimir experiment are attracted or repelled from one another due to localized charge fluctuations that induce charges in the opposite surface. If the Casimir Cavity surfaces are merely exerting electrical forces on each other, then no Casimir System could ever lift- itself or produce useful work since no self-contained system could ever exert a net force on itself. If this interpretation is physically true, then every Casimir System, like magnets, would require an opposite surface from which the first surface can be attracted or repelled. Furthermore, the effect cannot usually be maintained because the one-moving surface approaches or recedes-from the stationary surface, thus destroying the effect as it destroys the cavity. Since the cavity ceases to exist, no continuous work could be extracted. Furthermore, no self contained system can continuously export energy without depleting itself.

In contrast, the Quantum-Vacuum Radiation-Pressure Interpretation of the Casimir Effect holds that we already use the momentum, and energy of the radiation-pressure of the independently-generated Photons of the Quantum-Vacuum to transfer momentum and energy from the photons of the Quantum-Vacuum System, to a second, separate, Casimir system. This second Interpretation views the Quantum-Vacuum as a much more powerful source of photons than the Sun. It allows for the possibility of continuously obtaining energy from the Photons of the Quantum-Vacuum just as we obtain it from the free-energy of the photons of the Sun..

In this paper, the boundary of this second system will be defined as all of the surfaces of the one moving-object in a Casimir arrangement since it is moved in every direction by collisions with the photons of the Quantum-Flux as they strike every side; however, since the energy-density of the Quantum Flux is altered inside the cavity, one side of the moving object experiences more radiation-pressure than the other side. In other words, this moving object is be moved by the momentum of the photons of the Quantum-Vacuum, but only until the cavity disappears. A new Casimir arrangement is being proposed wherein the cavity is preserved so it will continuously do work.

1. Introduction

On the one hand, this proposed Cavity design will quite likely not work as hoped. On the other hand the proposed concept may be among the most important long-shots in history. The purpose of this paper is not to attempt to prove that any of these assertions are actually true or false. Instead, it argues that the state of our knowledge is uncertain-enough, and that the proposed concept is plausible-enough that the proposed experiment should be performed.

Two Interpretations of the Casimir Effect

The London-Forces/Van der Waals Interpretation of the Casimir Effect holds that the electrically-neutral surfaces in a Casimir experiment are attracted or repelled from one another due to localized charge fluctuations that induce charges in the opposite surface. As with magnets, all Casimir Systems would have to have an unattached, opposite surface for the first surface to be attracted-to or repelled-from, and the Casimir Force would have to reverse its direction so that a pair of Casimir surfaces could reciprocate, as proposed in patents, recently granted to Fabrizio Pinto.

Even so, if the Casimir Cavity surfaces are merely exerting electrical forces on each other, then no Casimir System could ever lift itself, since no self-contained system could ever exert a net force on itself. Why do so many researchers assume that the photons only act perpendicular to surfaces that are situated, across from each other? For one thing, this really will be the case if the Casimir Effect is nothing more than Van der Waals Forces; furthermore, even with a Quantum-Vacuum Radiation-Pressure treatment of a two-surface Casimir System, we often make the useful but fictitious simplifying-assumption that all photons are acting perpendicular to the walls, merely for the sake of reducing the problem down to the relevant Resultant Force Vector acting on each of the two sides. This was fine when we had a two-surface Casimir System, but now, this previously discarded force-vector now acts on the ceiling of the Five-sided Cavity.

In contrast, the Quantum-Vacuum Radiation-Pressure Interpretation of the Casimir Effect, which is well-represented in the literature, says we already use the momentum of the Photons of the Quantum-Vacuum System to transfer momentum and energy from the Quantum Vacuum to move a second independent system - a Casimir System. Accordingly, the independently-generated photons of the Quantum-Vacuum Energy continuously impart momentum, to the surface of a Casimir System - as long as the cavity still exists. In fact, the Quantum-Vacuum Theory was proposed, in the first place, to provide a field with which matter can exchange energy. According to this theory, Casimir Systems have already been used to alter the balance of the ever-present energy exchange between matter and the Quantum Vacuum.

Closed & Open Box-Shaped Cavities

If the Quantum-Vacuum equilibrium radiation-pressure inside a closed, box-shaped cavity is greater than the ambient flux

pressure, outside of the cavity, each pair of the six cavity sides will experience equal and opposite forces, so there is no net force; however, if we remove the box-floor while maintaining the Quantum-Vacuum radiation-pressure near the ceiling, then there is no equal and opposite force to cancel-out the force on the ceiling, so the pressure acting on the ceiling is now unopposed. The ceiling perpetually feels a net Casimir Force, but not because the missing Floor forms an opposite Surface, but rather, this is because the ceiling perpetually inhabits a permanent Casimir Cavity. The cavity does not move itself; rather, the Quantum-Vacuum can move the entire five-sided cavity as long as the cavity still exists.

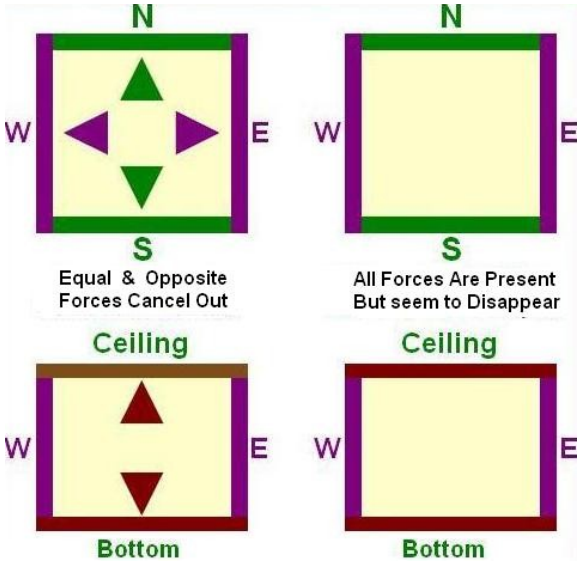

Fig. 1. A Six-Sided Pressurized Box

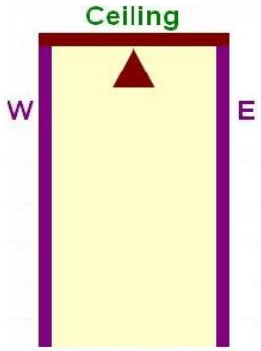

Fig. 2. No Bottom to Push Against

We must recall that the photons travel within the cavity in every possible direction. Random directionality plus the three-dimensionality of photons, the characteristics of wave-heights and wave-widths, as well as their wave-lengths cause the walls to affect all photons inside the cavity. In other words, the walls will affect each photon that is inside the cavity in exactly the same way, regardless of its direction of travel, even those photons that strike the ceiling. Furthermore, these photons only exist long-enough to travel about half a wavelength; in other words, the photons of the Quantum-Vacuum do not exist long enough to travel between the ceiling and the opening; therefore, the ceiling and opening simply cannot affect one-another.

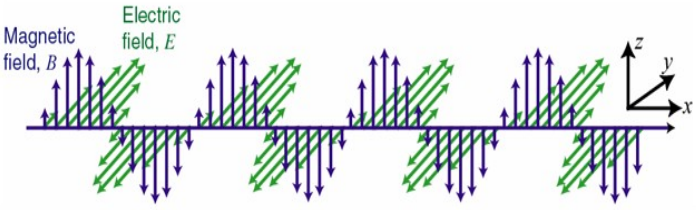

Fig. 3. The Three-Dimensionality of Photons [1]

Why do so many researchers assume that the photons only act perpendicular to surfaces that are situated across from one another? For one thing, this really will be the case if the Casimir Effect is mere London-Style Van der Waals Forces.

Even with a Quantum-Vacuum Radiation-Pressure treatment of a two-surface Casimir System, we often make the useful but fictitious simplifying-assumption that all photons are acting perpendicular to the walls, merely for the sake of reducing the problem down to the relevant Resultant Force Vector acting on each of the two sides. This is fine for a two-surface Casimir System, but now the reverse is true. That is, the forces on the now-stationary sides cancel out and no longer matter, but the previously-discarded force-vector now acts on the ceiling of the Five-Sided Cavity.

Only Positive-Pressure Cavities Will Work

Five-sided cavities will not experience a net thrust if the Quantum-Flux Pressure inside them is less than the ambient Quantum-Flux Pressure, outside of the cavities. This is because the wavelengths that do not fit inside the cavity still act across the opening as though it was a solid surface; therefore, wavelengths of the same magnitude and distribution act equally in all directions, thus negating each other, leaving no net force.

Below, the red lines show that the wavelengths that are excluded from the cavity, bridge across the opening as though it was solid. The size of the arrows indicates the relative magnitudes of the Quantum-Vacuum Electromagnetic Flux that is inside each cavity versus the ambient Flux, outside of the Cavities, which in every case is the same.

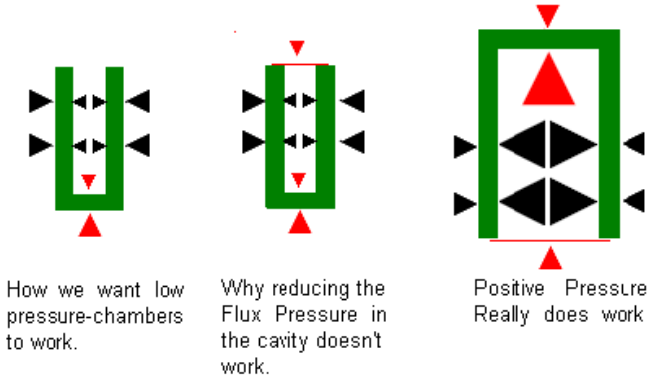

Fig. 4. How Pressure Chambers Work

The two downward-facing arrows, in the middle figure, perfectly counteract the larger, upward-directed arrow.

Fortunately, **some** researchers assert that nanoscopic cavities can be constructed, cavities wherein the Radiation Pressure of the Quantum-Flux has a higher, spontaneous equilibrium pressure inside the cavities than exists in the ambient Quantum-Flux, outside of the cavities [For example, see items **1, 3, 6, 8, 10, 11 and 12 in**

the Appendix below with their respective references.] In positive pressure cavities, the walls actually enhance the flux-density for photons that are traveling in every direction. **It should be noted that positive pressure cavities are NOT the norm but rather the exception with the Casimir effect. It is only under special conditions that there is a greater radiation pressure inside the cavity than outside. It is these positive pressure cavities that claim our attention here.**

Quantum-Vacuum Photons Are Always Moving in Every Direction

Why do so many researchers assume that the photons only act perpendicular to surfaces that are situated across from one another? This really will be the case if the Casimir Effect is nothing more than London-Style Van der Waals Forces. Even with a Quantum-Vacuum Radiation-Pressure treatment of a two-surface Casimir System, we often make the useful but fictitious simplifying-assumption that all photons are acting perpendicular to the walls, merely for the sake of reducing the problem down to the relevant Resultant Force Vector acting on each of the two sides.

This is fine for a two-surface Casimir System, but with a Casimir five-sided box-cavity, the previously-discarded resultant-vector that was parallel to the two surfaces is still parallel and irrelevant to the sides of the cavity, but now it acts on perpendicular to the cavity ceiling; therefore that term must be reintroduced. In fact, since none of the surfaces move in relationship to them the resultant forces on all of the sides cancel out, the unopposed force that is acting on the ceiling is all that remains as a net force.

Assuming we can achieve a conspicuously-large effect, a large array of nanoscopic holes would feel strange in exactly the same way as a magnet. That is, a mysterious, invisible force would seem to pull or push on it; however, in this case, it is not attracted or repelled by another magnetized object. Instead, it is pushed by an induced difference in the Radiation-Pressure of the Quantum-Vacuum Electromagnetic Flux. This Radiation-Pressure pushes harder on the one cavity-covered surface of an array than on the other side, which has no cavities.

The Four Great Laws

Does this violate the laws of thermodynamics? Even though we have every expectation that the Four Great Laws are inviolable and unchanging, we must nonetheless assume that our understanding of them is imperfect; already, there are many diverse descriptions of them; it is probably impossible to state any general principle so perfectly that it does not need to be restated to accommodate widely diverse circumstances, so we should not be shocked if we may need to add a few more new descriptions to this already-long list. As we shall soon see, the Quantum-Flux is uniquely prone to misinterpretation by descriptions of the Four Great Laws that are incomplete or inappropriate for non-thermodynamic systems.

It is the Quantum Vacuum Flux itself that seems to violate the laws of motion as we currently formulate them. For example, a photon that is emitted by an atom must experience a recoil; in contrast a photon of Vacuum Energy is "emitted" (for lack of a better term!) by space-itself, which seemingly does not experience any recoil. In other words, the Vacuum Energy Process acts as an unmoved mover every time one of its photons imparts momentum to an atom. With such an unorthodox fundamental mechanism, we should not be surprised if the Cavity Thruster behaves in a manner that strikes us as peculiar.

If we believe that the Quantum-Vacuum Energy exists then we are forced to accept the proposition that matter exchanges energy with it all of the time, since this is why the Quantum-Vacuum Concept was originally invented: It provides a field with which matter can exchange energy. For example, the Quantum-Vacuum Photons are thought to impart energy to matter in order to compensate for the energy that is continuously emitted by atoms in the form of Larmor Radiation.

A Hot Corona from A Cold Sun & Other Anomalies: Why Not This?

Transferring energy from one independent system such as the Quantum-Vacuum, to another independent system, such as these Casimir Thrusters, violates no Laws of Motion or of Thermodynamics. As with Atomic Energy, Energy-Conservation is satisfied even if it turns out that Energy of the Quantum Vacuum is being depleted as it dissipates into the ordinary thermodynamic World or vice versa. As for Entropy: In principle, Casimir Systems, could very well use extra energy from the Photons of the Quantum-Vacuum, globally increasing entropy while reducing it locally, just as plants also do with the photons of the Sun, everyday.

Fortunately, modern Science has matured to where it has atleast begun to embrace seemingly-aberrant experimental evidence, such as Expansion, Galaxies that don't spin themselves apart, the Pioneer Anomaly and the Flyby Anomaly. Radioactivity once appeared to be a self-generating source of energy. Later, we discovered that it was a kind of stored energy that was being depleted as its energy was released into the environment. In many ways, the Zero-Point Energy that fills space is just as mysterious to us as radioactivity was, prior to Einstein.

Here is another example: For quite some time, we have been accepting the fact that the comparatively Cold Sun somehow heats the hot Corona, while maintaining Faith that some sort of satisfactory explanation would eventually be forthcoming. The fact that there are so many theories about the Corona strongly suggests that none of us really knows for sure.---In other words, we don't refuse to perform--nor do we discredit perfectly good experimental measurements. Nothing proposed in this paper is even remotely as peculiar as any of these examples. Therefore we should not engage in a premature rush-to-judgment when conventional thermodynamic analyses in systems that interact with the seemingly anomalous Quantum Vacuum don't immediately conform to our expectations. All of these things may be perfectly clear to us someday, including the secret-life of Casimir Cavities.

The Electromagnetic Flux of the Quantum Vacuum In Contrast to Heat

The "Zero-Point, part" when referring to the Energy of the Quantum-Vacuum, merely refers to Absolute Zero Degrees; we really should call it Zero-Temp Energy (ZTE) since its actual

definition is: "That Energy which remains, even in Space that is devoid of matter and even at absolute-zero degrees." In other words, it is non-thermodynamic energy. Of course it is present, in addition to thermal energy, at all temperatures.

We must recall that "heat" is not a real phenomenon; it is a model of a real phenomenon. It is an aggregate-treatment of countless individual events. We do not usually consider the action of individual molecules in modeling the behavior of a fluid; likewise, the Heat-Model treats heat-transfer as though it was a kind of homogenous fluid. Temperature is viewed as a kind of pressure that drives this imaginary fluid. In other words, the "Zero-Temp" part of the Quantum-Vacuum Terminology does indeed imply that it is unavailable from the standpoint of a conventional Thermodynamic Analysis since heat cannot flow out of it, since it has no actual temperature of its own.

Nonetheless, the Quantum-Vacuum Electromagnetic-Flux has its own mechanisms for exchanging energy with matter. Some of these interactions with matter result in the newly energized or de-energized matter having altered thermodynamic effects. In fact, this is sometimes cited as the reason for the energetic superfluidity of helium at thermally-trivial energy levels.

Again, we must bear in mind the fact that the whole Quantum-Vacuum concept was invented in the first place, to provide an energy-field for matter to exchange energy with; as already mentioned, the Quantum-Vacuum Energy Field is said to restore the energy that is lost by "orbital" electrons to Larmor Radiation. Clearly, matter exchanges energy with the Quantum-Vacuum in a way that can only be understood by considering and summing the individual reactions between a single individual Quantum-Vacuum photon and a single, individual atom or subatomic particle; this kind of analysis is very untypical of fluid-like Heat-Model of what, after all, really is a collection of individual events.

Here is another non-thermodynamic characteristic: It is impossible for two thermodynamic reservoirs at different temperatures, that is, different energy-levels to be in direct contact with each other without having heat flow from the higher temperature to the lower temperature; In contrast, the adjacent regions of differing Quantum Vacuum Energy density do not flow from high to low energy, again, because there is no thermal gradient. Remarkably, the Vacuum Energy is not subject to the same thermodynamic rules, because the high photon-density Quantum-Vacuum EM Flux outside of a typical two-metal-plate Casimir Cavity does not flood-in to equalize the lower Quantum-Vacuum-density inside its Cavity. In other words, unlike thermodynamic systems, the Quantum-Flux can give-rise to energy reservoirs that are in direct contact with each other, reservoirs that have different energy densities yet, aside from edge-effects, they have minimal impact on each other.

The reason the usual thermodynamic behavior does not occur is because these photons vanish almost as soon as they appear and are immediately replaced before they have time to travel more than about half a wavelength. In other words, there is very little exchange of photons between the two regions except right along the edges. Even though the Quantum-Vacuum Electromagnetic-Flux is assumed to not alter the total energy of the Universe, there is no ignoring the fact that energy is being created and destroyed - or at the very least, it is constantly removed from and reintroduced to or moved between random points in space, perhaps through the Planck-Length size wormholes of John Wheeler's Seething Quantum Foam.

This is also why the ambient flux does not affect the ceiling of our elongated floorless, pressurized box-shaped cavity; no photons live long enough to traverse the length of the cavity, and the walls still enhance the flux-density of photons that are directed toward the ceiling due to the photons' wave-widths and wave-heights. In other words, a high pressure region arises because of nearby boundary conditions that are imposed by the walls of the cavity, not because the higher-than-ambient pressure is held inside some sort of leak-proof vessel.

It is fruitless to dance around these facts and play terminology word-games, the point is simple: Of course, the Cavity Thruster Array seems odd when compared to systems where all the underlying principles conform to our normal expectations. The Cavity-Thruster is not thermodynamically unreasonable, rather, the Quantum-Vacuum itself, is non-thermodynamic---at least in the conventional formulations of these still-vital principles; it is far too early to consider sending these four Venerable Guardians to a Retirement Community for tired, old ideas; nonetheless, we clearly need to attempt to see these same Laws in a broader context. Relativity does not invalidate Newton's Laws; instead, it reveals more about their inner workings; most importantly, Newton's Laws are put in a broader, more detailed, more useful context. Likewise, we must purge these Laws of excess baggage, not to weaken them, but rather to strengthen them and to see them in a clearer, larger, more-detailed, more useful context.

To maintain some sense of Mass-Energy Conservation, we must surmise either that the Vacuum Energy, like atomic energy is a finite resource that is continually being depleted Or we must conclude, that some mechanism restores this energy, which is lost from the Vacuum Energy, back to the Vacuum. As already stated, the notion of a feedback mechanism, the idea that matter continually exchanges energy with the Quantum-Flux, is the original reason that the Quantum-Vacuum Energy Theory was devised in the first place. Again, it is widely accepted that electron "orbits" would decay from constantly emitting Larmor Radiation if they were not continually replenished by the Quantum Vacuum Energy Field which may very well be replenished by the Larmor Radiation. After all, the Quantum Vacuum is already known to be behave-badly in terms of what we would require of virtually any other system---so why would a device that is based on it not not be just as odd?

Even in the event that the Vacuum Energy is being depleted, according to John Wheeler, there appears to be enough energy in mostly-"empty" Space to sustain the comparatively sparse matter of the Universe for quadrillions of years. (At the very least we can console ourselves with the thought that the Vacuum Energy may delay the impending thermal death of the Universe by an unimaginably large factor!)

Deriving the Casimir-Pressure Formula from the Quantum-Flux Density Formula

There is much discussion in the literature of the magnitude of the Vacuum Energy. If one accepts that the Quantum Vacuum

Energy is Lorentz-Invariant, meaning that the frequency distribution will look the same in all inertial frames, then the density D of each frequency f must conform to the equation.

$$D(f) = k \ f^3 \qquad (1)$$

Problematically, as we consider arbitrarily high frequencies, then the energy density becomes arbitrarily-large. Since higher frequencies are physically smaller this extrapolates to infinite energy at a point. Fortunately, John Wheeler, in his 1962 book on **Geometrodynamics**, [2] pointed out that Relativity limits the possible energy-density of Space, since excess energy density leads to the creation of a Black-hole. Amazingly, his calculations independently led to the conclusion that this would occur at wavelengths that are close to a Planck-Length - a remarkable result that yields a highly-plausible physical mechanism for the magnitude of the Planck Length.

Below in Table 1, we assume that two electrically neutral, grounded, conducting plates exclude all wavelengths that are equal-to or greater-than the distance d between the plates. For example, at five nm plate separation, we can deduce that the total radiation-pressure of all wavelengths, that are 10 nm or above, is greater than one atmosphere (greater than 100 k Pa or 2117 lb/f^2).

To calculate the radiation pressure that is attributable to a range of wavelengths, one simply subtracts the pressure of all wavelengths that are greater than the larger wavelength from that of the smaller wavelength. For example, the pressure that is attributable to all wavelengths between 6 nm and 5 nm is:

$$P(5\text{ nm}) - P(6\text{ nm}) = (2.08 - 1.00) \times 10^6 = 1.08 \times 10^6 \text{ Pa}$$

Assuming that we can make cavities wherein the equilibrium density of the Quantum Vacuum Energy is higher inside the cavities than the ambient density, outside the cavity **And** assuming that such magnitudes are possible in high-pressure cavities:

At d = 10 nm, this formula works out to atmospheric magnitudes of pressure on the total ceiling-area of the cavities. (The total ceiling area could easily fill fifty percent of the total area of one side of a macro-array of nanocavities.)

Frequency f in From Eq. (1) has a kinematic wavelength $\lambda = c/f$, which resonates proportionally with the distance d between the surfaces. Using this relationship, Timothy Boyer integrated over frequency density function in Eq. (1) to derive the well-known Casimir Pressure [3]

$$P(d) = \frac{\pi^2 \hbar c}{240 d^4} \quad 1.30 \times 10^{-27} / d^4 \text{ Pa} \quad (d \text{ in meters}) \qquad (2)$$

Although, positive-pressure cavities still exclude larger wavelengths, a number of effects may come into play such as optical-pumping, resonance and the fact that certain arrangements of materials and wall geometry and scale can cause the flux to appear just as often but disappear a little slower--until some higher-than-ambient, equilibrium flux density is reached. So there is every basis to at least hope that we will develop Thruster Cavities that will exceed the expectations of the Fundamental Casimir Equation.

To recap: The Quantum-Vacuum Radiation-Pressure Interpretation of the Casimir Experiments strongly suggests that the Photons of the Quantum-Flux, like any other photons, impart net energy and momentum to atoms all of the time; yet, the photons are emitted by the Quantum-Flux Process and not by the material of the cavity; in other words photons do not impart recoil to any atom as they are formed by the Quantum-Flux Process; therefore, there is no equal and opposite force imparted to the Cavity-Thruster if it is not producing its own photons.

As with a solar sail, an external source of photons is exerting net radiation-pressure on the Cavity Thruster, so there is no conflict with Newton. Ilya Prigogine received the 1977 Nobel Prize for Chemistry for proving that even totally random systems can self-organize under certain conditions. As already noted, plants use extra energy to globally increase entropy while locally decreasing it, so why couldn't Cavity-Thrusters do the same thing?

Why Thruster Cavities Will Work

The Cavity-Thruster Effect arises out of two basic facts: First, the photons of the Quantum-Vacuum obey all of the usual laws of electromagnetism; therefore, they impart momentum and kinetic energy to matter all of the time. There is truly no reason to doubt that the Casimir Effect is a Quantum-Vacuum Radiation-Pressure Phenomenon. Second, not only does the Quantum-Flux affect matter but, according to the Quantum-Vacuum Radiation-Pressure Interpretation of the Casimir Effect, matter can alter the density of the Quantum-Flux. Remarkably, Casimir Systems can induce useful Radiation-Pressure Differences, not by means of adding energy or even by removing energy, but by merely by altering the rate at which the photons appear or disappear inside a Casimir Cavity versus outside of the cavity; thus, there is one radiation-pressure magnitude acting outside the Casimir Cavity and a different radiation-pressure magnitude acting on the cavity ceiling. In other words, an energy potential appears because less energy spontaneously appears one side of a Casimir surface versus on its other side.

nm	Pascal	Lbs/f^2	nm	Pascal	Lbs/f^2	nm	Pascal	Lbs/f^2	nm	Pascal	Lbs/f^2
1	1.30E+009	2.71E+007	11	8.88E+004	1.85E+003	30	1.60E+003	3.34E+001	700	5.41E-003	1.13E-004
2	8.13E+007	1.69E+006	12	6.27E+004	1.31E+003	40	5.08E+002	1.06E+001	800	3.17E-003	6.61E-005
3	1.60E+007	3.34E+005	13	4.55E+004	9.48E+002	50	2.08E+002	4.33E+000	900	1.98E-003	4.13E-005
4	5.08E+006	1.06E+005	14	3.38E+004	7.05E+002	75	4.11E+001	8.56E-001	1000	1.30E-003	2.71E-005
5	2.08E+006	4.33E+004	15	2.57E+004	5.35E+002	100	1.30E+001	2.71E-001	1100	8.88E-004	1.85E-005
6	1.00E+006	2.09E+004	16	1.98E+004	4.13E+002	200	8.13E-001	1.69E-002	1200	6.27E-004	1.31E-005
7	5.41E+005	1.13E+004	17	1.56E+004	3.24E+002	300	1.60E-001	3.34E-003	1300	4.55E-004	9.48E-006
8	3.17E+005	6.61E+003	18	1.24E+004	2.58E+002	400	5.08E-002	1.06E-003	1400	3.38E-004	7.05E-006
9	1.98E+005	4.13E+003	19	9.98E+003	2.08E+002	500	2.08E-002	4.33E-004	1500	2.57E-004	5.35E-006
10	1.30E+005	2.71E+003	20	8.13E+003	1.69E+002	600	1.00E-002	2.09E-004	2000	8.13E-005	1.69E-006

Table 1. The Radiation Pressure of the Quantum Vacuum

Again, please bear in mind that the point is not to even argue that any of these assertions are actually true, but rather: It is argued that we must perform this experiment before allowing our limited understanding to recklessly persuade us either way. The dramatic possibilities amply justify doing this experiment, even if one considers this a fairly remote long-shot. Besides, it is a scientifically-interesting experiment, regardless of the practical outcome.

Quotes from Scientific Literature

NOTE: Some of these quotes refer simply to the normal Casimir effect in which the radiation pressure from outside the cavity tends to collapse the cavity. The reverse effect, a Casimir repulsion, whereby the radiation pressure inside the cavity tends to expand the cavity, is only achieved under special conditions. It is this Casimir repulsion which is the focus of this paper and which is specifically the topic in items # 1, 3, 6, 8, 10, 11 and 12 below.

1. Repulsive Casimir forces result from vacuum radiation pressure

"We study the Casimir force between a perfectly conducting and an infinitely permeable plate with the radiation pressure approach, used by earlier authors for the case of two perfectly conducting plates. This method illustrates in a very simple context how a repulsive force arises as a consequence of the redistribution of the vacuum-field modes corresponding to specific boundary conditions." [4]

2. Energy and heat extractable from the vacuum

"If some asymmetric variation of the Casimir force could be identified, though, then one could in effect sail through space as if propelled by a kind of quantum fluctuation wind. Unfortunately, at this point this is pure speculation since it requires an invention to contrive such a means. " [5]

3. Repulsive Casimir forces produced in rectangular cavities: possible measurements and applications

"We perform a theoretical analysis of a setup intended to measure the repulsive(outward) Casimir forces predicted to exist inside of perfectly conducting rectangular cavities. We consider the roles of the conductivity of the real metals, of the temperature and surface roughness. The possible use of this repulsive force to reduce friction and wear in micro and nano-electromechanical systems (MEMS and NEMS) is also considered. " [6]

3. Assessment of proposed electromagnetic quantum vacuum energy extraction methods

"In more than a century of theory and experimentation we have not been able to extract usable energy from thermal fluctuations, and it might seem that we are destined to find ourselves in a similar situation with attempts to extract usable energy from ZPE. There is, however, a distinction that can be drawn between the two cases, which has to do with the nature of the ZPE equilibrium state. The equilibrium ZPE energy density is a function of the local geometry. Two thermal reservoirs at different temperatures that are in contact with each other cannot be in equilibrium; heat will flow from one to the other.

"Two ZPE reservoirs having different energy densities that are in contact with each other can, however, be in equilibrium. For example, a Casimir cavity can be in direct contact (open at its edges) with the free space surrounding it such that the ZPE density inside and outside the cavity are different without any net flow of energy between the two regions. Furthermore, extracting ZPE from the vacuum does not violate the second law of thermodynamics. " [7]

4. Engine cycle of an optically controlled vacuum energy transducer

"An idealized system composed of two parallel, semiconducting boundaries separated by an empty gap of variable width is considered. A Gedanken Experiment is discussed to show that, in general, the total work done by the Casimir force along a closed path that includes appropriate transformations does not vanish. It is shown that, in the limit of an engine cycle bringing the two boundaries to a relatively small distance, positive net exchange of energy associated with the Casimir force field could quite possibly be achieved.

"Viable technological implementations of this idealized system are analyzed in some quantitative detail, in particular, in the case of doped and un-doped c-Si boundaries. For the purpose of direct experimentation, measurements with both macroscopic and micro-electromechanical devices are suggested. A full theoretical and experimental study of systems of this kind on every scale will greatly contribute to a much deeper understanding of the nature of the Casimir force and associated concepts, including the possible manipulation of semiconducting nanostructures and the noninvasive optical characterization of semiconducting samples. In the event of no other alternative explanations, one should conclude that major technological advances in the area of endless, by-product free-energy production could be achieved. " [8]

5. Repulsive Casimir forces prevalent and significant

"Repulsive Casimir forces may be found in a large range of parameters, and we suggest that the effect may be realized in known materials. The phenomenon of repulsive Casimir forces may be of importance both for experimental study and for nanomachinery applications." [9]

6. z-Function method for repulsive Casimir forces

"We compute the Casimir pressure between an unusual pair of parallel plates, namely, a perfectly conducting plate and an infinitely permeable one with the generalized -function method. The result for this problem, which has been rarely discussed in the literature, is a repulsive Casimir force.

"We analyze some consequences of the Casimir-type zero-point radiation pressure. These include macroscopic "vacuum" forces on a metallic layer in between a dielectric medium and an inert one. Ways to control the sign of these forces, based on dielectric properties of the media, are thus suggested. Finally, the large positive Casimir pressure, due to surface plasmons on thin metallic layers, is evaluated and discussed." [11]

7. Electromagnetic field correlators, Maxwell stress tensor, and the Casimir effect for parallel walls

"We evaluate the quantum electromagnetic field correlators associated with the electromagnetic vacuum distorted by

the presence of two plane parallel conducting walls and in the presence of a conducting wall parallel to a perfectly magnetically permeable one. Regularization is performed through the generalized zeta function technique. Results are applied to re-derive the attractive and repulsive Casimir effect through Maxwell stress tensor. Surface divergences are shown to cancel out when stresses on both sides of the material surface are taken into account." [12]

8. Repulsive Casimir force in chiral metamaterials

"Quantum electromagnetic field correlators associated with the electromagnetic vacuum distorted by the presence of two plane parallel conducting walls and in the presence of a conducting wall parallel to a perfectly magnetically permeable one. Regularization is performed through the generalized zeta function technique. Results are applied to re-derive the attractive and repulsive Casimir effect through Maxwell stress tensor. We demonstrate theoretically that one can obtain repulsive Casimir forces and stable nanolevitations by using chiral metamaterials. By extending the Lifshitz theory to treat chiral metamaterials, we find that a repulsive force and a minimum of the interaction energy possibly exist for strong chirality, under realistic frequency dependencies and correct limiting values (for zero and infinite frequencies) of the permittivity, permeability, and chiral coefficients." [13]

9. Comparison of chiral metamaterial designs for repulsive Casimir force

"In our previous work [Phys. Rev. Lett. 103, 103602 (2009)], we found that repulsive Casimir forces could be realized by using chiral metamaterials if the chirality is strong enough. In this work, we check four different chiral metamaterial designs (i.e., Twisted-Rosettes, Twisted-Crosswires, Four-U-SRRs, and Conjugate-Swastikas) and find that the designs of Four-U-SRRs and Conjugate-Swastikas are the most promising candidates to realize repulsive Casimir force because of their large chirality and the small ratio of structure length scale to resonance wavelength." [14]

10. Tunable Casimir repulsion with three dimensional topological insulators

"Switching between repulsive and attractive Casimir forces by means of external tunable parameters could be realized with two topological insulator plates. We find two regimes where a repulsive (attractive) force is found at small (large) distances between the plates, canceling out at a certain critical distance between the plates where the net force is zero. Furthermore, we suggest that switching between repulsive and attractive regimes could be also controlled." [15]

11. The Casimir Force for a Perfectly Conducting Rectangular Parallelepiped at Finite Temperature

"Quantized electromagnetic field inside a rectangular parallelepiped surrounded by perfectly conducting parallel walls is studied. The Casimir energy and the Casimir force at finite temperature are calculated by the mode summation method, and it is found that the sign of the Casimir force depend on both the shape of a cavity and the temperature. The temperature at which the Casimir force change from the attractive force to the repulsive force is shown as a function of the separation of walls." [16]

12. Analogue Casimir radiation using an optical parametric oscillator

"We establish an explicit analogy between the dynamical Casimir effect and the photon emission of *a thin non-linear crystal pumped inside a cavity***.** This allows us to propose a system based on a type-I optical parametric oscillator (OPO) to simulate a cavity oscillating in vacuum at optical frequencies. The resulting photon flux is expected to be more easily detectable than with a mechanical excitation of the mirrors. We conclude by comparing different theoretical predictions and suggest that our experimental proposal could help discriminate between them." [17]

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