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REPORT

Mass Modification Experiment Definition Study (An Air Force Report)

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Abstract — This report summarizes an attempt to find an experiment that would test the Haisch, Rueda, and Puthoff (HRP) conjecture that the mass and inertia of a body are induced effects brought about by changes in the quantum-fluctuation energy of the vacuum. It was not possible, however, to identify a definitive experiment. But, it was possible to identify an experiment that might be able to prove or disprove that the inertial mass of a body can be altered by making changes in the vacuum surrounding the body. Other experiments, which do not involve mass modification, but which teach something about the vacuum, were also defined and included in a ranked list of experiments. This report also contains an annotated bibliography.

Mass Modification Experiment Definition Study Goals

The goal of this study contract was to define an experiment that could conclusively determine, one way or the other, whether the mass of a body could be modified by modifying the vacuum fluctuations around or in that body. If the mass of a body can be modified in even a small way, that fact will be of importance to science. If the mass of a body can be modified significantly, that fact will be of importance to Air Force missions.

The study was instigated by the conjectures by Puthoff (1989) and his colleagues Haisch, Rueda, and Puthoff (1994) that the gravitational mass and the inertial mass of a body are induced effects brought about by changes in the fluctuation energy of the vacuum when the body is present. The study was not limited to the Puthoff conjectures. Other theories concerning the various effects of vacuum fluctuations were also considered.

Puthoff, Haisch and Rueda were contacted in an attempt to identify a definitive experiment. This requires that the theory proposed by Puthoff and colleagues make a numerical prediction of a specific result, and requires that the experimental apparatus have the sensitivity and precision to measure the predicted result to high accuracy. If the experimental result agrees with the theoretical prediction, then the Puthoff conjecture will have been proven to be "correct" (as much as any theory can be proven to be correct), while if the experimental result does not agree with the theoretical prediction, the Puthoff conjecture will have been conclusively proven to be wrong. Unfortunately, it was not possible to identify a definitive experiment. There are experiments presently being undertaken by Puthoff, which, *f* successful, will prove the Puthoff conjecture correct. The failure of these experiments to produce a result, however, will not prove the Puthoff conjecture wrong, since the theory does not give a firm prediction of the magnitude of the effect being looked for.

It was possible, however, to identify an experiment which might be able to prove or disprove that the inertial mass of a body can be changed by making changes in the vacuum surrounding the body. The theory this experiment is based upon is the well-accepted theory of Quantum Electrodynamics. Much work needs to be done, however, both on the theoretical analysis and the experimental design, before one can say if the experiment is feasible. Other experiments, which do not involve mass modification, but which teach us something about the vacuum, were also defined and included on a ranked list of experiments.

The report also contains an annotated bibliography of the publications used in preparing the report. The papers referenced in the text by an author's name and a date, refer to entries in the bibliography.

Rationale For Study And Recommended Experiments

At first glance, it might seem that experiments to study the electromagnetic fluctuation energy of the vacuum are so esoteric and so devoid of practical applications that they should be funded solely by the National Science Foundation, if at all. Yet, experiments to study the vacuum could lead to real advances in space power and propulsion technology as well as expanding our knowledge of basic physics.

The situation is reminiscent of the field of nuclear energy in the 1930s. Scientists were only just beginning to understand the structure of the atom. The element radium had been purified. It violated the law of energy conservation by continuously giving off heat and radiation. It seemed to be an inexhaustible source of "free energy". Uranium, mostly used to give a "vaseline yellow" color to glass, was also known to give off radiation that would fog photographic plates.

Soon scientific knowledge increased. The atoms were discovered to consist of a nucleus made of protons and neutrons surrounded by a cloud of electrons. The number of protons and electrons determined the element, while the number of neutrons determined the "isotope" of that element. Finally, scientists realized that the "free energy" coming from certain isotopes of radium and other elements was not really "free" at all. Instead, a small amount of mass m was being converted into large amount of energy E according to the equation $E=mc^2$, where c is the speed of light. Using this equation, "nuclear energy" could be estimated to produce 9×10^{13} joules of energy per gram of mass.

Then, neutrons were found to be capable of fissioning certain isotopes of heavy elements, releasing "nuclear energy" on demand. Even then, "nuclear energy" was not considered very practical. It was thought that either gigantic "atom smashers" or large "atomic piles" would have to be constructed to obtain the "nuclear energy". It was only after much knowledge had been gained about the fission process, and much chemical engineering work had gone into isotope separation techniques, that it was finally realized that nuclear energy could be obtained from highly enriched uranium–235 or plutonium–239, by a technique as physically simple as putting in contact two precisely machined pieces of isotopically purified metal!

Thus, in just a few decades, the esoteric, poorly-understood phenomena of "nuclear energy of the atom" went from being a scientific curiosity into being a major technology. In addition to weapons, nuclear energy in the form of plutonium isotopes is being used as the primary power source in NASA deep space missions. Compact nuclear reactors supply larger amounts of power for classified satellites. Nuclear electric propulsion is the technologically preferred method of sending a crewed mission to Mars, and particle bed reactor rockets would be a major component of our space defense shield if we were still at loggerheads with the USSR.

We are now in the 1990s, looking at the esoteric, poorly-understood phenomenon of "electromagnetic fluctuation energy of the vacuum." We can estimate the "vacuum energy density" to be 10^{108} J/cc, and the vacuum mass density to be 10^{94} g/cc, much higher numbers than those associated with nuclear energy. In the same way that we once did not understand the atom, we presently do not understand the vacuum. We need to carry out careful experiments to accurately measure the electromagnetic fluctuations in the vacuum and how those fluctuations affect matter. That is the purpose of the two highest priority experiments. From these experiments, we expect to learn enough to propose additional experiments that will lead to a better understanding of the vacuum and how it affects the inertial and gravitational mass of bodies. This, in turn, could lead to concepts for "control" of the vacuum and control of the mass of an object. I have already shown (Forward, 1984) that it is possible to extract energy from the "electromagnetic fluctuations of the vacuum". The amount of energy that can be extracted using this technique is just a minute fraction of the 10^{108} J/cc that is calculated to be available. But as we learn more about the vacuum, it is expected that better energy extraction techniques can be found. (Perhaps a technique as physically simple as putting in contact two precisely microfabricated sandwiches of ultrafine metal-dielectric multilayers?)

One such possible energy extraction experiment is third on the prioritized list of experiments. According to our present theories about the vacuum, if we place a single proton in the center of a cold, empty vacuum chamber, then within one second that proton, driven by the electromagnetic fluctuations of the vacuum, will gain an energy of 1000 eV. Since it only cost us a few eV to ionize a hydrogen atom to obtain the proton and place the proton in the vacuum chamber, there is a substantial gain predicted. At first glance it looks like this experiment provides a source of "free energy" similar to the "free energy" that seemed to come from radium. We are sure that nature is not going to allow us to get away with this violation of the law of energy conservation. We will probably find that the energy is not "free" but is coming from somewhere else — probably from the immense energy density of the vacuum itself.

So, although the field of "electromagnetic fluctuation energy of the vacuum" is admittedly an esoteric, little-understood field, it does seem to have definite potential as an energy source. It also could have the potential of changing the mass of an object. And, since theory predicts that the vacuum has an enormous mass density as well as an enormous energy density, it might one day be possible to interact enough with the vacuum to "push" on it with a "vacuum drive." Alternatively, perhaps one day it might be possible to operate a "vacuum rocket" that uses energy obtained from the vacuum to expel reaction mass also obtained from the vacuum.

An Introductory Tutorial on the Quantum Mechanical Zero-Temperature Electromagnetic Fluctuations of the Vacuum

The main body of this report discusses a number of possible experiments to measure the effect of the quantum mechanical zero-temperature electromagnetic fluctuations of the vacuum on macroscopic objects. This introductory tutorial gives a short background survey of those parts of quantum theory that create in a supposedly empty vacuum, even a vacuum at zero absolute temperature, fluctuating electromagnetic radiation fields and even fluctuating numbers of charged-particle pairs. (This tutorial will attempt to explain "how," but not "why", because nobody knows why nature behaves in this admittedly strange way.)

Quantum Mechanics

The well-accepted Theory of Quantum Mechanics has many aspects. The two aspects that are most important for this tutorial are that:

1. Matter and energy are quantized.
2. Certain types of measurements cannot be made precisely; there is always some uncertainty in the measurement. (This is called the Heisenberg Uncertainty Principle.)

Quantization of Matter and ***Energy***

Matter is quantized. A block of matter, although seemingly a continuously divisable substance, is ultimately found to be made up of "quanta" called atoms. An atom consists of a small massive nucleus surrounded by a large cloud of electrons. The electron cloud acts as a "spring" suspension for the mass of the nucleus, and suspends it in its place in the block of matter. This mass-spring system can vibrate. The frequency of vibration is $f=(k/m)^{1/2}$ where k is the spring constant of the electron cloud and m is the mass of the nucleus. The amplitude or energy of the vibration is determined by the temperature of the block. The higher the temperature, the more energy there is (on the average) in the vibrations of the atoms.

The energy of vibration is quantized too. The vibrational energy of the atoms come in "quanta" of energy $e=hf$, where f is the natural frequency of the vibration of the mass-spring system, and $h= 6.63\times10^{-34}$ J•s is a very small constant called Planck's constant. These vibrational quanta have been named "phonons".

Now here comes the interesting part. When the equations of quantum mechanics are used to determine the "average energy" $<E>$ of the vibrations of the atoms, the answer is $<E>=[n(T)+1/2]hf$, where the number of phonons $n(T)$ is a function of temperature such that when $T= 0$ K, $n(T)=0$. Thus, even at zero temperature, quantum mechanics predicts that each of the atoms will have an average residual energy of $<E>=hf/2$. This residual energy is an average. It is not that the energy of each atom is a "half a phonon" but that roughly half the atoms have one (perhaps more) vibrational quanta or phonons, while the others have no phonon. The phonon distribution rapidly changes with time as the phonons are passed back and forth between the many atoms. This residual energy at zero absolute temperature predicted by the equations of quantum mechanics is the so-called "Quantum Mechanical Zero-Temperature Vibrational Fluctuations of Matter".

This quantum mechanical fluctuation energy of the atoms in matter has been measured by measuring the vibrations in a crystal as the temperature of the crystal is lowered. The experimental data agrees with the predictions of the equations of quantum mechanics, so the quantum mechanical zero-temperature vibrational fluctuations of atoms in matter is real. It is this residual quantum mechanical vibrational energy that keeps liquid helium from freezing even when it is cooled to within microdegrees of absolute zero temperature.

Uncertainty Priniciple

There is a quantum mechanical "reason" for this zero temperature fluctuation energy — the Uncertainty Principle. The Heisenberg Uncertainty Principle of Quantum Mechanics states that it is not possible to precisely measure the position x and the momentum $p=mv$ of a particle at the same time (m is the mass of the particle and v is its velocity). The accuracy of the position measurement Ax and the accuracy of the momentum measurement Ap must obey the relation $\Delta x\Delta p\geq h$. If there were no residual vibrational energy in the atoms in the block of matter to keep the nuclei in motion, then at $T= 0$ K, the nucleus of each atom would be standing still ($\Delta v= 0$) and be right in the center of its cloud of electrons ($\Delta x= 0$), which would violate the Uncertainty Principle. Needless to say, many scientists (including Einstein) have tried hard to come up with an experiment in which the position and momentum of a particle is measured at the same time to an accuracy better than $\Delta x\Delta p\geq h$. They all failed, and scientists are now pretty sure that the Uncertainty Principle is more than a "principle", it is a "law" of nature.

There is a corollary to the position-momentum uncertainty pair that will be important later. The Uncertainty Principle also states that it is not possible to precisely measure the energy E of a particle in an infinitely short time t. The accuracy of the energy measurement AE of a particle and the time interval At in which the energy measurement is made, have to obey the relation $\Delta E \Delta t \geq h$.

Electromagnetic Fluctuations of the Vacuum

With the above as background, we now get to the quantum mechanical zero temperature electromagnetic fluctuations of the vacuum. **A** region of empty space surrounded by matter at absolute zero temperature would seemingly have no energy in it. Yet, since electromagnetic vibrations (light and radio waves) can pass unhindered through the vacuum, the vacuum contains the potential to support these vibrations. If we treat this region of vacuum in the same manner as we treated the block of matter, we can say that the vacuum can support electromagnetic vibrations of frequency f. The quantum mechanical equations for the electromagnetic vibrations in the region of vacuum are identical in mathematical form to the equations for the mass-spring vibrations of the atoms in the block of matter, so the equation for the average energy $<E>$ of each of the possible electromagnetic vibrations is the same: $<E>=[n(T)+1/2]hf$. Only now, $n(T)$ is the number of photons as a function of temperature, and, as before, when T=O K, $n(T)=0$. But also, as in the atom case, even when T is at absolute zero, quantum mechanics predicts that each possible electromagnetic vibration in the region of vacuum will have a residual average energy of $<E>=hf/2$. This residual energy is an average. It is not that each possible electromagnetic vibration has a "half a photon" but that roughly half the electromagnetic vibrations have one (perhaps more) photons, while the others have no photon.

Now comes the real problem, and the major reason why we need to carry out experiments to verify that the quantum mechanical electromagnetic fluctuations of the vacuum behave as the equations of quantum mechanics predict. The block of matter has a large, but finite, number of atoms and therefore a finite total quantum mechanical vibrational fluctuation energy. The region of vacuum, however, can support an infinity of electromagnetic vibrations. The region of vacuum cannot support electromagnetic vibrations with wavelengths larger than its largest dimension, but it can certainly support those electromagnetic vibrations with wavelengths smaller than its size, such as infrared, optical, ultraviolet, x-ray, gamma-ray, etc. vibrations. There is no known limit to how small an electromagnetic wavelength can be. Each of these infinity of possible electromagnetic vibrations has an average energy of $<E>=hf/2$. So, according to this train of logic, a region of vacuum is not empty, but instead is teeming with an infinity of "half-photons" of electromagnetic energy. The famous physicist Richard Feynman estimated that if the minimum wavelength of electromagnetic vibrations was assumed to be approximately the size of a proton, the "energy density" of the vacuum would be 10^{108} J/cc or equivalently, the vacuum would have a "mass density" of 10^{94} g/cc. This is much greater than typical nuclear densities of 10^{14} g/cc. It is this high predicted energy and mass content of the vacuum that gives rise to the hopes of many that it may be possible to either: extract "free energy" from the vacuum, "push" on the mass of the vacuum, or use the vacuum mass as "reaction mass".

The quantum physicists explain away this "infinity" of energy by saying that since the vacuum pervades everything, it is only the "differences" in the vacuum energy that are produced by the presence of matter that counts. Needless to say, although the quantum physicists have been able to adjust their equations to cancel out this "infinity" and get the right answers, this is not a philosophically satisfactory solution.

Charged-Particle Pair Fluctuations of the Vacuum

Not only does quantum mechanics predict that the vacuum is teeming with electromagnetic energy, the uncertainty principle predicts that the vacuum is also teeming with pairs of charged particles called electron-positron pairs. Since the fluctuation photons in the vacuum have energy, then no matter what their energy is supposed to be, there is a finite probability that for a very short time At their energy will be "uncertain" by an amount ***AE*** that is sufficient to create a positron-electron pair. This event, of course, volates the law of conservation of energy, but quantum mechanics allows the violation to take place provided the positron-electron pair annihilates back into the original low energy photon in a time shorter than the time At allowed by the uncertainty relation $\Delta E \Delta t \geq h$. This means that the supposedly empty vacuum is not only full of photons, but also has a tenuous "plasma" of charged positron-electron pairs. This "plasma" makes the vacuum have an index of refraction slightly different than unity and makes it respond non-linearly to strong electromagnetic fields.

Verification

It would be simple to say that since this train of logic concerning the effect of quantum mechanics on the vacuum has lead to such ridiculously high estimated energy density levels for supposedly empty space, that there is something wrong with the logic, and the vacuum does not have quantum mechanical electromagnetic fluctuations at zero temperature. Yet experiment after experiment has been carried out whose results can be explained by assuming that the quantum mechanical zero temperature electromagnetic fluctuations of the vacuum are real. One such experiment is the Casimir experiment, described in more detail in the main body of the report. In this experiment, two uncharged conducting plates are put near each other with a vacuum between them. Prior to the introduction of the plates, the region of vacuum between the plates had an infinity of possible electromagnetic vibrations and an infinite amount of quantum mechanical electromagnetic fluctuation energy. Since the plates are conducting, they will short-circuit those electromagnetic vibrations that do not have zero (transverse) electric field at the position of the conducting plates. In effect, this cuts down the "infinity" of electromagnetic vibrations allowed in the region of vacuum between the plates. The vacuum now has less energy than it did before the plates were introduced. This "negative energy" in the region of vacuum produces a force on the plates that pulls the plates together. A similar result is predicted when the plates are made of dielectrics instead of conductors. This attractive force can be quite large and has been accurately measured using dielectric plates. These experiments show that, indeed, the vacuum does contain quantum mechanical zero-temperature electromagnetic fluctuations. Experiments using conducting plates are more difficult and have yet to be done accurately. Such an experiment is at the top of the priority list in the body of the report.

Another important experiment was the Lamb-Retherford experiment, where the frequency of microwave radiation emitted by an excited hydrogen atom was compared with theory. The theory only agreed with the experiments when the theorists assumed that the vacuum between the proton nucleus and the orbiting electron in the hydrogen atom had a tenuous plasma of positron-electron pairs in it, that shifted the electron orbital energy just the right amount to agree with experiment. Thus, this experiment shows that, indeed, the vacuum does contain quantum mechanical charged-particle pair fluctuations at zero temperature.

There are many other experiments and phenomena that can only be explained by assuming that the quantum mechanical zero temperature electromagnetic fluctuations of the vacuum are real. Even such mundane phenomena as the surface tension of liquids and the clumping of smoke particles are explained by assuming that the vacuum contains residual electromagnetic fluctuations even at zero absolute temperature.

Alternate Theory

There does exist an alternate theory. In this "Fluctuating Charged Particle Source Field Theory", it is assumed that although the quantum mechanical zero temperature vibrational fluctuations of atoms in matter do exist, the quantum mechanical zero temperature electromagnetic fluctuations of the vacuum do ***not*** exist. (The theory does not explain why one type of fluctuation is allowed and the other is not allowed, it just assumes it.) The theory then goes on to say that all the experiments to date, including the Casimir experiment and the Lamb-Retherford experiment can be explained by saying that:

1. The quantum mechanical zero-temperature vibrational fluctuations of matter cause the charged particles in the apparatus to undergo random vibrational fluctuations.

2. These fluctuating charged particle "sources" emit electromagnetic radiation fields that travel through the vacuum where they are "received" by all the other charged particles in the apparatus.
3. The electromagnetic radiation field acts on the receiving charged particles to cause them to move "in phase" with the transmitting charged particle "sources".
4. The "in phase" motions of the two widely separated charged particles produce correlated forces between the "source" particle and the "receiving" particle that in turn produce the observed experimental results.

Amazingly enough, this alternate theory where the vacuum is assumed to have no fluctuations, seems to make the same predictions as the quantum theory where the vacuum fluctuations are assumed real. There is an experiment that can possibly distinguish between the two theories. It is described in the report.

Summary

There is a lot more to quantum mechanics than quantization of mass and energy and the Heisenberg uncertainty principle, but I hope this introductory tutorial has been enough to help one understand why it is important to learn more about the quantum mechanical zero-temperature electromagnetic fluctuations of the vacuum. Hopefully, the experiments proposed in the body of the report, if successfully carried out, can increase our knowledge and eventual applications of this "enigma cloaked in nothingness" called the vacuum.

Ranked List of Possible Experiments

The following is a list of possible experiments ranked in order in terms of:

1. Improving our understanding of the vacuum.
2. The feasibility of carrying out the experiment.
3. Producing a modification in the gravitational or inertial mass of a body.

In the pages following are more detailed discussions of the selected experiments.

1. Measurement of Casimir Force on Conducting Plates

The Casimir force on closely spaced *conducting* plates has never been measured accurately over a wide range of spacings or a wide range of conducting materials. Such experiments need to be done to verify that the force predicted by Casimir (1948) is real and applies to all conducting plates despite their composition. This experiment is ranked first because it is fundamental and relatively easy to carry out with modest funding.

2. Casimir Stress Induced Anisotropic Inertial Mass Measurement

Scharnhorst (1990) used quantum electrodynamics to predict that the speed of light between two conducting plates is anisotropic, with the speed perpendicular to the plates being greater than *c*. The anisotropic inertial mass experiment assumes that the mass of a body between two conducting plates will also be anisotropic, and proposes to measure that mass anisotropy using a nuclear magnetic resonance technique developed by Drever (1961). This experiment is ranked second despite its great difficulty, because the theory will give a definite prediction of the magnitude of the mass anisotropy expected, so either a positive or negative experimental result will provide a definitive test.

3. Generating "Subcosmic Rays" in a Cold Vacuum Chamber

Rueda, Haisch, and Cole (1995) predict that the electromagnetic fluctuations in the vacuum will accelerate isolated charged particles to high speeds. The theory predicts energy gains of a proton of the order of 1000 eV per second. This should be easily measured by "releasing" a "cooled" antiproton in a cryogenically cooled electromagnetic trap and measuring how fast it reaches the walls and annihilates. This experiment is ranked third, despite its complexity and cost, because a positive result would "prove" that you can continuously extract unlimited amounts of "free energy" from the vacuum. We know, of course, that nature is not going to let us violate the law of energy conservation, but finding out how nature enforces the energy conservation law will teach us new physics.

4. "Inertia Wind" Experiment

Puthoff, in unpublished work that extrapolates from the paper by Haisch, Rueda, and Puthoff (1994), predicts that a pair of 40 kg masses rotating in a 1-m radius circle at 20 rpm will create an "inertia wind" that will "push" on a sensing mass. He originally predicted the magnitude of the "inertia wind" force would be comparable to the magnitude of the Newtonian force produced by the 40-kg masses. His coauthors are skeptical of the predicted magnitude, and Puthoff is reworking the calculations to obtain a more definitive prediction. This experiment, despite its simplicity and direct relevance, is ranked fourth because, while a positive result will "prove" the theory, a null result will prove nothing. There are also grave doubts that a large effect of this type would have gone unobserved before now.

In addition to the ranked experiments, there are two additional experiments that are described in the main body of the report, but which are not recommended for consideration because the Principal Investigator was not able to identify an experimental approach that would be able to carry out the desired measurement at the signal-to-noise levels required. Perhaps someone reading this report can devise an experimental approach that will make a measurement feasible.

Nonlinearity of Vacuum Experiments

Ding and Kaplan (1989) proposed to generate second-harmonic photons by focusing laser light on a vacuum containing a magnetic field. This is the only experiment known that can distinguish between the two alternate models for vacuum fluctuation effects, the model where the vacuum itself has electromagnetic fluctuations, and the model where the charged particles in the experimental apparatus are doing the fluctuating. Unfortunately, recent estimates by Kaplan and Ding (1995) on the laser power and magnetic field strengths needed have resulted in numbers that are beyond the capabilities of present lasers and magnets.

Making and Weighing "Casimatter"

Schwartz has recently proposed over the Internet that it might be possible to physically "weigh" the Casimir energy in a sample of "Casimatter" composed of thousands of layers of 80-nm thick aluminum alternating with 50-nm thick magnesium fluoride (MgF_2). The Casimir energy generated between the conducting aluminum plates would make a finite (negative) contribution to the energy and thereby the mass of the Casimatter sample. He proposes weighing the sample of Casimatter, heating the Casimatter to destroy the layer separation, thus eliminating the Casimir energy contribution, then weighing it again. The mass measurement accuracy required is estimated to be greater than a part in 10^{17}. The force sensitivity levels are beyond the present capabilities of available atomic force microscopes and the accuracy required for a frequency measurement is beyond the capabilities of available clocks.

Measurement of Casimir Force on Conducting Plates

In a difficult to find, but widely quoted paper entitled, "On the attraction between two perfectly conducting plates" Casimir (1948) predicted that the quantum fluctuations of the vacuum should produce a pressure P or force F per unit area **A** on two perfectly conducting uncharged plates given by:

$$P = \frac{F}{A} = \frac{\pi h c}{480 L^4}, \tag{1}$$

where $h = 6.63 \times 10^{-34}$ J•s is Planck's constant, $c = 300$ Mm/s is the speed of light, and L is the separation distance between plates. The appearance of Planck's constant indicates that the effect is due to a quantum mechanical phenomenon. The amazing aspect of the equation is that the predicted force is independent of the material of the plates, as long as they can be considered "perfectly conducting." This means that the equation should be good down to separation distances L that are comparable to the cutoff wavelength of the material.

Everyone assumes that the Casimir force between two conducting plates has been "experimentally demonstrated." It has not. Nearly all the published

"Casimir force" experiments used dielectric plates such as glass, quartz, or mica instead, with the most accurate data obtained using cylindrically curved mica surfaces (Israelachvili and Tabor, 1972).

Barton points out that these experiments on dielectrics are not tests of the Casimir force, but instead are tests on the allied but significantly different Van der Waals forces. The Van der Waals force between two dielectric plates is predicted by an equation in the paper by Lifshitz (1956):

$$\frac{F}{A} = \frac{\pi hc}{480L^4}\left(\frac{\varepsilon - 1}{\varepsilon + 1}\right)^2 \Phi(\varepsilon), \tag{2}$$

where ε is the dielectric constant of the plates, and $\Phi(\varepsilon)$ is a function that varies from 0.35 when $\varepsilon = 1$, to 1.0 when $\varepsilon \to \infty$. It is true the Lifshitz equation turns into the Casimir equation when the dielectric constant is allowed to go to infinity, but anything involving an infinity is suspect.

The last experiments on *highly conducting metal plates* were carried out by Sparnaay (1958). His measurements on two chromium or two chromium-steel plates did "not seriously deviate from Casimir's predictions, although the attractions found are somewhat too large. No attractions could be measured between two aluminum plates." The data in the Sparnaay paper is of poor quality. Not only was the magnitude of the Casimir coefficient poorly determined, but because of the experimental difficulties the $1/L^4$ behavior with separation distance L was not firmly established, and there was no attempt to show a failure of the Casimir force law at small plate separations when L is smaller than the cutoff wavelength of the conductor.

The most recent experiments using "conducting" plates were published by Arnold *et al.* (1979). These experiments used semiconducting silicon plates rather than highly conducting metal plates. Arnold found a change when the silicon was illuminated to make it more conducting, but the experimental results did not agree well with the Casimir theory.

Sen (1995) at the University of Washington is presently attempting to measure the Casimir force between two gold-plated quartz flats 5 cm in diameter. The experiment is an undergraduate honors project, which will impact on the time and money available to make thorough measurements. There will also be no attempt to make measurements at close plate separations. Serry *et al.* (1995) at the University of Illinois at Chicago are planning Casimir force experiments using aluminum plates embedded in and supported by a silicon-fabrication-based microelectromechanical structure. The minimum separation distances obtainable using this fabrication technique should be better than $L = 20$ nm. The Casimir forces on the supported aluminum plates can be measured using a modification of a commercially available atomic force microscope. The first goal of the UIC group is to build an "Anharmonic Casimir Oscillator" that will oscillate about an equilibrium between the Casimir force and the force of a spring. Such structures could be used to make precise measurements of the Casimir force at different separation distances L and for different conductors. Onofrio and Carugno (1995) in Italy are also planning a Casimir force experiment between conducting plates using a tunneling electromechanical transducer.

It is recommended that the first priority in proposed experiments to study the properties of the vacuum is an experiment to measure the Casimir force between two conducting plates. The experiment should be carried out with a number of different metals over a wide range of plate separations with an accuracy that can determine not only the coefficient in the Casimir equation, but the $1/L^4$ variation in the force.

The experiments should also be designed to show that the Casimir coefficient and the $1/L^4$ law are independent of the type of conductor used — down to the point where the separation distance becomes comparable to the cutoff wavelength of the metal. That minimal separation distance, in turn, should be a predictable function of the cutoff wavelength of the conductor being used.

The experiments should investigate other structures than parallel plates, since the Casimir force between conductors is not always attractive. A hollow conducting sphere experiences an outward repulsive force [the most accurate recent calculation is by Milton (1978)]. Ambjørn and Wolfram (1983) have derived the Casimir energy per unit volume for conducting rectangular boxes. Cubes have positive energy and repulsive forces on the walls, long rectangles or parallel plates have negative energy and attractive forces on the walls, while a rectangular box of relative dimensions 1 by 1 by 3.3 has zero Casimir force. It would be desirable to verify these predictions.

Casimir Stress Induced Anisotropic Inertial Mass Measurement

The Casimir stresses on the vacuum space between two conducting plates are anisotropic. Scharnhorst (1990) and Barton (1990) [see also Barton and Scharnhorst (1993)] used this stress anisotropy to predict an anisotropy in the velocity of light. According to their theoretical calculations, the velocity of light parallel to the conducting plates has the speed of light in an unbounded vacuum, $c_{||}=c_0$ while the velocity of light perpendicular to the plates has a speed greater than c by the amount:

$$c_{\perp}/c_o = 1 + \frac{11\pi^2}{8100}\frac{\alpha^2}{(L/L_e)^4}, \qquad (3)$$

where L is the spacing between the Casimir plates, the fine structure constant a=11137, and $Le=h/2\pi m_e c= 3.86\times10^{-13}$ m/rad= 0.386 pm/rad is the reduced Compton wavelength of the electron. Numerically, this amounts to a difference of:

$$c_{\perp}/c_o = 1 + \frac{1.59 \times 10^{-56}}{L^4} \left[\mathrm{m}^{-4}\right], \tag{4}$$

which implies that the speed of light perpendicular to the conducting places is greater than c.

Some important features of this result are (Barton, 1990):

1. This anisotropy of the vacuum space between Casimir plates is calculated to be greater than any dispersion effect, so the phase and group velocities of the light are both given by the same equation and both are greater than c, causing concerns about violation of causality. Fortunately for the sensibilities of those worried about this, Milonni and Svozil (1990) show that the Heisenberg uncertainty principle will probably work to prevent the use of faster-than-c propagation for the reliable transmission of information back in time.
2. The size of the effect is the same everywhere between the plates except perhaps very near to the surface of the plates where some of the approximations used might not be valid. By very close, Scharnhorst (1990) states "near denotes a distance of a few Compton wavelengths apart from the plates". An electron Compton wavelength is $2\pi L_e$= 2.43 pm, much smaller than proposed Casimir plate separation distances, typically measured in nm.

Estimate of Anisotropy Magnitude

It is possible (although difficult) to use ion beam lithography and other submicron microelectronic fabrication and processing techniques to construct microelectromechanical structures, such as Casimir volumes, electromagnetic antennas and guides, and atomic force microscopes, with dimensions, spacings, and control of motion accurate to distances of 1 nm (10 Å) or less. Our real limit to the spacing distance L, however, is not our ability to fabricate the required Casimir structures. The theory behind equation (3) assumes that the Casimir plates are conducting at all frequencies of the electromagnetic spectrum. Real metals become transparent in the ultraviolet. The broadest band reflector is aluminum, which has a reflectance of 99% in the long infrared, a reflectance of 90% at a wavelength of 120 nm, and becomes transparent at 10 nm [AIP Handbook (1972), see Table 6g-1, pp 6-124ff and Table 6g-2, pp 6-157]. Little data exists between the available 120 nm and the 10 nm data points, but I would estimate that the minimum wavelength at which the Casimir plates can be considered conducting is about λ= 60 nm/cycle, or a reduced wavelength of about $\lambda/2\pi$= 10 nm/rad.

If the theorists agree that equation (3) can be applied to aluminum Casimir plates at a separation distance of L= 10 nm, then the maximum magnitude of the Scharnhorst effect achievable in a fabricatable piece of apparatus becomes:

$$c_{\perp}/c_{o} = 1 + 1.59 \times 10^{-24}. \quad (5)$$

The question now is: Is it possible to measure such a small anisotropy?

Measurement of the Schamhorst Effect on Light Speed

I have been unable to conceive of a method for measuring an anisotropy in the speed of light between two conducting Casimir plates at the level of parts in 10^{-24}. One could think of converting the velocity measurement into a frequency measurement by finding the resonant frequency of a tuned cavity for different Casimir plate spacings, but there are many things other than the Scharnhorst effect that will cause the resonant frequency of a cavity to change.

In addition to the experimental difficulties of making a speed-of-light measurement, there are theoretical problems that must be addressed first. There have been papers published [Milonni and Svozil (1990) being just one example] which show that the Heisenberg uncertainty principle will produce timing uncertainties in the atoms used to generate and detect the light photons used in the speed measurement. These timing uncertainties will prevent the accurate measurement of the speed of light or the sending of information faster than c.

Effect of Casimir Stresses on Inertial Mass

As Landis pointed out in the NASA/JPL Workshop on Advanced Quantum/Relativity Theory Propulsion (Bennett *et al.*, 1995), if the velocity of light is anisotropic between Casimir plates, then since $m=E/c^2$, perhaps the mass of an object will be anisotropic too. If this is true, it might be easier to measure the anisotropy of inertial mass between Casimir plates than the anisotropy of the velocity of light.

We are not sure that the Casimir stresses will affect the inertial mass of an object. The theory behind the Scharnhorst effect is a perturbation analysis of the inherent nonlinearities in the postulated quantum fluctuations of the electromagnetic fields in the vacuum. Using a simplified model: The fluctuation photons in the vacuum, no matter what their energy, have a finite probability of producing a virtual electron-positron pair with a rest mass energy of 2x511 keV, as long as the pair recombines back into the original photon in a time *At* shorter than that allowed by the Heisenberg uncertainty principle for the energy difference ***AE***. In this model, the vacuum has a weak virtual "plasma" of charged particle pairs in it, which makes the vacuum polarizable, and gives the vacuum an index of refraction that is not unity. Scharnhorst's actual calculation was not of the speed of light, but of the index of refraction of the vacuum between Casimir plates. He found that the index of refraction was anisotropic, with the index equal to unity in the directions parallel to the plates and slightly less than unity [see equation (24) of Scharnhorst (1990)] perpendicular to the plates. Scharnhorst then converted this anisotropy in the index of refraction into an anisotropy in the speed of light [see equation (25) of Scharnhorst (1990)]. Since an index of refraction less than unity means a speed of light greater than c, this result gave the Scharnhorst effect its world-wide notoriety.

The important message is that the Scharnhorst calculations showed only that the electromagnetic index of refraction between two conducting Casimir plates is anisotropic. I think everyone agrees that the calculation of the anisotropy in the index of refraction is correct. I also think everyone agrees that an anisotropy in the index of refraction will result in an anisotropy in the speed of light. *It is not obvious, however, that an anisotropy in the index of refraction for electromagnetic radiation for the vacuum between two conducting plates will produce an anisotropy in the inertial mass of a body. This needs to be verified by a competent theoretician.*

Estimate of the Scharnhorst Effect on Inertial Mass

I will now assume that the theorists ultimately conclude that, indeed, two conducting Casimir plates will not only produce an anisotropic index of refraction between the plates, and an anisotropic speed of light for photons traveling between the plates, but also an anisotropy in the inertial mass of a body placed between the plates.

The magnitude of the inertial mass anisotropy difference can be estimated by assuming that the total relativistic energy E in the famous equation $E=mc^2$ is a constant that is not affected by the Casimir stress. Substituting the two values for the velocity of light from equation (3) and solving for the mass results in

$$m_{\parallel} = E/c_{\parallel}^2 = E/c_0^2 = m_0 \tag{6}$$

and

$$m_{\perp} = \frac{E}{c_{\perp}^2} \approx \left[1 - 2\frac{11\pi^2}{8100}\frac{\alpha^2}{(L/L_e)^4}\right] m_0 \tag{7}$$

Here, m_0 is the scalar inertial mass (assumed to be equal to the scalar rest mass) of the body in an unconstrained vacuum where there are no Casimir stresses, and $m_{\perp}$ and m,,are the perpendicular and parallel components of the inertial mass tensor postulated to exist when the body is subjected to Casimir stresses produced by the electromagnetic field constraints resulting from the presence of the two conducting plates.

The assumption that the total relativistic energy of the body, E, is not affected by the presence of the Casimir plates needs to be checked by a competent theoretician. Even if E *is also affected by the Casimir stress, it could still turn out that the resultant inertial mass is still an anisotropic tensor, but perhaps by a different factor than that in equation (7).*

Under the assumption that equation (7) is valid, and that the calculated

Casimir stresses apply for plate separation distances as small as L= 10 nm, the predicted numerical value for the maximum anisotropy that can be expected in the inertial mass of a body between two conducting Casimir plates is:

$$m_{\perp}/m_{\parallel} = 1 - 3.17 \times 10^{-24}. \quad (8)$$

This is a small difference, but 35 years ago, using relatively crude equipment, Drever (1961) measured the anisotropy of the inertial mass of the nucleus of a lithium–7 atom and found the anisotropy to be zero at a sensitivity level of 5×10^{-23}. If the Drever technique, or something similar to it, could be applied to a sample confined between two conducting Casimir plates, and the sensitivity of the detecting apparatus could be improved by a few orders of magnitude, then it should be possible to measure the anisotropy of inertial mass caused by two conducting plates at the level predicted by the well-accepted theory of quantum electrodynamics. The experiment would thus conclusively demonstrate, one way or the other, whether anisotropic Casimir stresses between two conducting plates can produce a change in the inertial mass of a body.

Hughes-Drever Anisotropic Inertial Mass Null Experiment

The motivation for the Drever experiment [first carried out by Hughes in 1960 at a lower sensitivity] was an experimental test of Mach's principle — that the inertial mass of a body may arise from a gravitational coupling with distant matter. Since there is a concentration of matter at the center of our Galaxy, then, depending upon what physical and mathematical models one used for Mach's principle, this excess of nearby matter might result in an anisotropy of inertia along the (bi-)direction to the mass excess, which could be detected experimentally as the Earth rotated the apparatus with respect to the Galactic center. According to some theories referred to by Drever (1961), this anisotropy in inertial mass should cause shifts in the energy levels of atoms and nuclei subjected to a magnetic field. Specifically, in a nucleus with spin I = 312, the energies of the states with magnetic quantum numbers m, = ± 312 would be increased slightly if the magnetic field were parallel to the direction of the center of the Galaxy, while the energies of the states with m, = ±1/2 would be decreased by an equal amount. If the magnetic field were perpendicular to the direction to the center of the Galaxy, the energies would be shifted in the opposite directions. For the models of inertia being proposed at the time, the predicted ratio of the anisotropy in inertial mass for the nucleus was in the order of 10^{-13}. Drever found it was zero to a sensitivity of 5×10^{-23}.

The isotope used was lithium–7, with a nucleus of spin I = 312, caused by an unpaired $p_{3/2}$ proton. The four energy levels of a nucleus of spin 3/2 in a magnetic field are normally equally spaced. The three resonant frequencies between the four states are the same and there is a single resonance. If the m,= ±3/2 energy levels are shifted with respect to the m_I = ±1/2 levels, then the single resonance is split into a triplet. The minimum splitting detectable is usually limited by inhomogeneities in the magnetic field, so a weak uniform field is desirable. The magnetic field used in the experiment was the earth's field.

In the experiment, the lithium−7 sample, in the form of a solution of lithium nitrate, was contained in a plastic bottle surrounded by a coil placed with its axis perpendicular to the direction of the earth's field. A direct current through the loop produced a field of about 200 gauss. When this field was switched off rapidly, the resultant nuclear magnetic moment precessed about the earth's field and an alternating e.m.f. signal was generated in the coil. With no anisotropy to cause shifts in the energy levels, there would be a single resonant frequency present and the signal would decay exponentially with a time constant equal to the transverse relaxation time of the spin system. If, however, an anisotropy in inertial mass exists, the resonance response would be split into a close triplet, and the signal would exhibit beats, corresponding to interference between the oscillations at the three resonance frequencies. Very long beat periods would show up as changes in the decay curve shape and lle time as the experimental parameters that changed the anisotropy were varied. In Drever's null experiment, the rotation of the earth changed the direction with respect to the Galactic center once per sidereal day. No variation was found. This corresponds to (Drever, 1961): "an upper limit for the ratio of the anisotropic part of the inertial mass of a proton to the isotropic part of the order of 5×10^{-23}."

It should be noted at this point that the lithium−7 nuclei being measured were in a non-symmetric chemical compound, were surrounded by non-symmetric polar water molecules, and a large fraction of them were up against container walls, yet these non-symmetric surroundings did not induce shifts in the magnetic energy levels that would mimic a differential shift in the energy levels caused by an anisotropic inertial mass of the nucleus.

The fundamental beauty of the Drever experiment is that the nucleus is "self-referencing" in that the $m_I = \pm 3/2$ and ±112 nuclear magnetic states produce identical transition frequencies *despite large and non-symmetric changes in the surrounding environment that can produce large changes in the absolute energies of the magnetic states, but do not produce differential shifts between the 3/2 and 1/2 states.* This probably occurs largely because the nucleus is small in size compared to the distances to neighboring perturbing atoms. *It is only when the nucleus itselfchanges, by developing an anisotropy in inertial mass, that the transition frequencies change with respect to each other and produce the beat notes.* The beat notes are the signal that something has happened.

Caveats Concerning Other Effects Masking Scharnhorst Effect

Barton and Scharnhorst point out that there are other effects that may produce a mass anisotropy that may mask the mass anisotropy produced by the Scharnhorst effect. These effects are of *first* order in α, and therefore much larger. How precisely they might influence any specific measurement would need to be thought through. There are papers available that discuss these effects, such as G. Barton, "Quantum mechanics of charged particles near a plasma surface", J. *Phys.* A10, 601 (1977), and for particles between two mirrors in G. Barton, *Proc. Roy. Soc. (London)*A320, 251 (1970), and an update with applications to a neutral atom in *Proc. Roy. Soc. (London)*A410, 141 (1987). All of these need to be investigated by a competent theorist before much time is spent on designing experiments.

I suspect, however, that these papers will either produce an "effective mass" or an "effective mass anisotropy" that comes about due to the interaction of the charges in the atoms under consideration with the charges in the plasma or mirrors. These are not fundamental changes in the inertial rest mass of the atom, just an "effective mass" induced by the coupling of the atom to its surroundings. I would suspect that these non-symmetric effects, just like the non-symmetric effects in the original Drever experiment, will not cause a change in the magnetic level spacing. This, however, needs to be proven.

Applying Free Precession to a Casimir Anisotropy Experiment

The Drever measurement was made by using a nuclear magnetic free precession technique on a bottle of water containing lithium nitrate, which gave better relaxation times than other compounds. The frequency of precession in the earth's magnetic field was 800 Hz and the decay time of the signal was 3.7 s. In practice, the signal was weak and it was necessary to use 2.5 liters of sample to obtain an adequate signal-to-noise ratio. It is obvious that much thought and work needs to be done to convert this experiment into one that can be done within the confines of two closely spaced conducting plates.

Extracting the Signal. The free precession signal in the Drever experiment was a radio-frequency signal of about 800 Hz. The radio frequency is proportional to the applied magnetic field. It might be thought that the nearby presence of the conducting Casimir plates would prevent extraction of the signal. It should be possible, however, to design the radio-frequency portions of the detection circuit so that the conducting Casimir plates are part of the circuit. For example, the Casimir plates could also be the capacitor plates of an RLC circuit resonant at the desired radio frequency. Alternatively, the plates could be designed with spiral conductive pattern, so they could simultaneously be a "pickup coil" at the desired radio frequency signal band and a "mirror" at optical wavelengths. In another approach, the applied magnetic field could be increased until the signal frequency is in the microwave band. The Casimir plates could then be designed as a "waveguide" with a very small height-to-width ratio, operating in the transverse-electric (TE) mode, to extract the signals in the desired microwave band in the direction parallel to the conducting plates, while acting as a mirror at optical frequencies in the direction perpendicular to the plates.

Drive signals can be inserted into the sample either by modifying the structure of the conducting plates as mentioned before, or by simply driving the conducting plates hard with a high power signal and having a small portion of the drive power leak through the conducting plates into the sample inside by evanescent wave propagation.

Sample Size. Drever used a 2.5 liter (2.5×10^3 cc) sample in order to get sufficient signal. The volume in between two 5 cm by 5 cm Casimir plates separated by 10 nm is 2.5×10^{-5} cc, or a factor of 10^8 reduction in sample size and expected signal, even if we used the entire volume, since the Scharnhorst effect is constant everywhere in the region between the plates. Unless some other complication arises, I would propose filling the volume between the Casimir plates entirely with sample in the form of a high resistivity, low loss dielectric (either liquid or solid). A solid dielectric containing the desired I = 3/2 spin nuclei would be especially easy to work with. Starting with a flat substrate, the deposition of a layer of aluminum, a layer of the dielectric with the desired thickness, and another layer of aluminum (perhaps with some structure to allow electromagnetic coupling to the sample), would result in an encapsulated sample ready to test.

The sample volume and output signal can increased by designing the radio frequency portion of the structure as a long, possibly folded, waveguide, or as a series or folded parallel multiplate capacitor, with the capacitor plates acting also as the conducting Casimir plates.

Effect of Sample on Casimir Stress. The theorists who calculate the expected mass anisotropy effect should be asked to look at the case where the space between the conducting plates is not a vacuum at zero temperature, but a dielectric with a finite index of refraction, a finite (but very high) resistivity, and a finite temperature. Barton (1990) has already done this for the vacuum between conducting plates at a finite temperature. I expect the results of the theoretical calculations will be that the anisotropic Casimir stress remains, although the magnitude may be changed slightly. One expected side effect of filling the cavity with a dielectric sample medium is that although the speed of light will still be anisotropic, the speed of light perpendicular to the plates will no longer be greater than c.

Measurement Sensitivity. The sensitivity of electronic amplifiers has improved substantially in the past 35 years. It is not known whether that improvement has been enough to not only compensate for the decreased sample size, but to also provide additional margin to close the gap between the 5×10^{-23} sensitivity of the Drever measurement and the 3.17×10^{-24} sensitivity needed to measure the Casimir stress induced inertial mass anisotropy as given by equation (8). To improve the signal-to-noise ratio, experts in NMR need to be consulted as to the best nucleus to use, the best compound to put it in, the best host lattice or solution, the optimum magnetic field strength to be applied, the best radio frequency circuit/amplifier combination to extract the response signal, and the best NMR technique to be used (driven resonance or free precession).

Summary

Theorists using the well-accepted theory of Quantum Electrodynamics to calculate the effects of the quantum fluctuations in the vacuum predict that the velocity of light can be changed by Casimir stresses induced in the vacuum by the presence of a pair of closely-spaced conducting plates. It is not yet known, but it is suspected, that the same Casimir stresses will cause a change in the inertial mass of an object. The effect is minute, but it may be possible to design an experiment using a nuclear magnetic resonance free precession technique to measure that change in the inertial mass. The result of the experiment will either be that the inertial mass of a body can be changed, or that our theories of the vacuum must be changed. The implications for either experimental result will be significant.

Generating "Subcosmic Rays" in a Cold Vacuum Chamber

Calculations by Rueda (1978), Cole (1995) and Rueda, Haisch and Cole (1995), indicate that in a very empty region of space with few particles and weak magnetic fields, the vacuum fluctuations will randomly push charged particles to higher and higher speeds until they approach the speed of light. This might be the cause for cosmic rays. According to Haisch, there is a quite large effect on protons, of the order of 1000 eV increase in energy per second. This level of energy is much greater than the thermal energy of a gas of $3/2\ kT$ (0.04 eV at $T=300\ K$), and larger than any stray "patch" voltages that may exist in a piece of experimental apparatus.

It might be possible to set up a very empty, very cold vacuum chamber, with a single charged particle in it, and monitor the velocity of the charged particle with time to see if it is accelerated. Haisch has suggested that instead of a proton, that an antiproton be used. This suggestion has many advantages over attempting to use any other particle. Since the theory gives a definitive prediction for a proton, the result should be the same for an antiproton. A single antiproton can be trapped, cooled to millikelvin temperatures, and its presence and initial position in the trap confirmed before the trap voltages are turned off. A sealed cryogenically cooled trap has essentially *no* residual air molecules in it. This has been proven by keeping 100,000 antiprotons in a trap for over a month *without losing any* since an annihilation of an antiproton by a nucleus would have produced easily detectable gamma rays or high energy pions. The traps can be made with a large working area along the axial direction. The antiproton can be "dropped" from essentially zero starting velocity and let fall a number of centimeters. Longer "drop" times can be obtained using a drop tower.

When the antiproton finally strikes the wall of the trap, it will annihilate with the wall nuclei. The annihilation produces 2–6 gamma rays and 3–7 high energy pions, all of which are easily detected by a surrounding complex of radiation detectors. The pion tracks and the gamma ray events can be triangulated back to determine the annihilation point to a mm or so, so the exact time and place of the annihilation event can be determined.

The experiment would then be repeated a number of times until a pattern of annihilation events is obtained. If the pattern is concentrated at the trap bottom, then only gravity accelerations are involved. If the pattern is concentrated at a few spots on the trap walls, then there are "work function patches" on the walls that are attracting the antiprotons to the patches by their electrical potential. If however, the pattern is random in space and very short in time, then this is good evidence that the vacuum electromagnetic fluctuations are the acceleration mechanism. One important aspect of this experiment, is that if the acceleration mechanism is found to operate, then this demonstrates at least one mechanism for the continuous extraction of limitless amounts of "free energy" from the vacuum.

"Inertia Wind" Experiment

According to unpublished studies by Puthoff, accelerating and decelerating inertial masses interact with the surrounding vacuum fluctuation field and create an "inertia wind" that propagates out through the vacuum. If a test mass is placed near the source, the outspreading inertia wind will interact with the test mass, pushing or pulling it, and causing it to respond. Puthoff originally calculated that a pair of 40-kg source masses rotating in a 1-meter radius circle at about 20 rpm can create an attractive or repulsive inertia wind force on a test mass comparable in amplitude to the attractive Newtonian gravitational force of the source masses. Puthoff has built some apparatus and is presently conducting experiments. The output of his sensing apparatus is presently dominated by large noise signals, such as ground noise and magnetic coupling to the rotating steel beam holding the generating masses.

There is yet no publication which describes the experimental apparatus and which outlines in mathematical detail the physical model used to predict the experimental result. Such information that exists can be obtained by contacting Puthoff directly.

Although Puthoff feels that the "inertia wind" theoretical model he is using to design the experiment and predict the experimental results is a straightforward extrapolation of the theory in the paper by Haisch, Rueda and Puthoff (1994), his co-authors on the original paper are skeptical of the predicted magnitude, and Puthoff is now reworking the calculations to obtain a more definitive prediction. Rueda, in particular, feels that any "wave" generated by an accelerating mass would stay attached to the mass as a "solitonic type" wave, and would not create an "inertia wind" to detect.

The reason this experiment is placed low on the priority list is that Puthoff's colleagues on his theoretical paper do not agree with Puthoff's inertia wind theoretical extension of their joint paper. Thus, this experiment fails the criteria that a null result will disprove the theory.

It would seem to me, that a force this large would have been noticed before, especially during gravity antenna calibration experiments carried out by Forward and Miller [*J. App. Phys.*, 38, 512-518 (1967)] using rotating masses and Sinsky [*Ph.D. Thesis, University of Maryland* (1967)] using vibrating masses. These experiments should be reanalyzed using the Puthoff "inertia wind" model to see if the "inertia wind" effect should have been seen in those papers. Puthoff and Little are presently analyzing the Forward paper.

Also, according to Puthoff, rapidly rotating gyroscopes should produce an inertia wind. This should lead to measurable forces and torques of one gyroscope on another. It would seem that these forces would have easily been seen by now, especially if torques are generated, since the gyroscopes on precision inertial platforms are fairly close to each other. Again, calculations need to be done.

Nonlinearity of Vacuum Experiments

In the paper, "Nonlinear Magneto-Optics of Vacuum: Second-Harmonic Generation," Ding and Kaplan (1989) proposed to generate second-harmonic "doubled" photons by focusing intense pulsed laser light on a region of the vacuum that had a strong magnetic field in it. According to classical electromagnetic theory, the electromagnetic field is completely linear, so there should be no interaction between the laser photons and the magnetic field. But if the fluctuations of the vacuum are taken into account, then the virtual positron-electron particle pairs created by the fluctuations result in a polarizable "plasma" in the region that can provide the nonlinear coupling mechanism needed to generate the second-harmonic photons.

This experiment is important since it can distinguish between two existing physical models for the vacuum. In the standard quantum mechanical model, not only do atoms in matter undergo residual vibrational fluctuations even at zero absolute temperature, but the vacuum itself contains residual electromagnetic fluctuations. In the alternative "Fluctuating Charged Particle Source Field Theory" model, it is assumed that although atoms undergo residual vibrational fluctuations, there are no electromagnetic fluctuations of the vacuum and especially, there are no charged-particle positron-electron pairs being created in the vacuum. All the effects that occur in this model are produced by the vibrational fluctuations of the charged particle "sources" in the apparatus creating electromagnetic fields that pass through the vacuum to the other charged particles in the apparatus, causing them to vibrate in phase with the "source" particles. This "in-phase" sympathetic vibration produces forces which produce the experimental results.

The interaction region in the proposed experiment by Ding and Kaplan will contain only laser light, magnetic fields, and vacuum. It will contain no charges, no polarizable particles, and no conductors, so there is no mechanism to explain a successful experimental result from the fluctuating charged-particle source field point of view — unless one cannot ignore the currents in the source of the magnetic field, even though that source is distant from the interaction region. A positive result from the experiment of the right magnitude would "prove" that the vacuum itself contains quantum fluctuations of the electromagnetic field. A null result from the experiment would "prove" that the fluctuation charged-particle source field model is the more "correct" model, and the idea that the vacuum itself has fluctuations is not a correct physical picture.

This experiment would be difficult to do, since it requires high laser intensities and high magnetic fields at the same time. The field intensities required to produce a detectable number of doubled photons were recently re-estimated by Kaplan and Ding (1995) to be 10^{22} W/cm^2 of pulsed laser flux focused on a 1000-T pulsed magnetic field. These required laser intensities are far beyond those projected to be available in the near future, so this experiment is not recommended for consideration at the present time.

There is an alternate way to do the experiment. Instead of concentrating a large number of laser photons of moderate photon energy into a small region to obtain the required high photon energy density, the energy of the individual photons can be increased so as to obtain the required high energy density with fewer photons. An Italian group (Bakalo, et al. 1994) has proposed an experiment using a 9T magnetic field and high energy photons produced by a particle accelerator rather than a laser. A successful measurement would amount to a direct observation of the "polarization" of the vacuum produced by the production of charged-particle positron-electron pairs in the vacuum. This experiment is being funded as part of the Italian high energy physics program.

Making and Weighing Casimatter

Alan M. Schwartz has recently proposed over the Internet that it might be possible to physically "weigh" the Casimir energy in a multigram sample of "Casimatter", composed of thousands of layers of 80-nm thick aluminum alternating with 50-nm thick magnesium fluoride (MgF_2), which is a good dielectric that is easy to deposit. The Casimir energy generated between the conducting aluminum plates would make a finite (negative) contribution to the energy and thereby the mass of the Casimatter sample. He proposes weighing the sample of Casimatter, heating the Casimatter to destroy the layer separation, thus eliminating the Casimir energy contribution and turning the Casimatter into ordinary matter, then weighing it again. His internet message did not go into great detail and did not give an estimate of the size of the effect to be expected. It is, however, relatively easy to take his idea, push it to the extreme, and see if the maximum calculated mass difference is within the reach of possible future measurement techniques, and thus is a possible candidate for a mass modification experiment.

Aluminum has a reflectance of 90% at a wavelength of $\lambda = 120$ nm [AIP ***Handbook,*** 3rd Ed. (1972), Table 6g-1, 6-124] and drops after that, but there is no handbook information what the cutoff wavelength is. (Elsewhere in this report, on page 15, I estimate it at $\lambda = 60$ nm.) The minimum thickness of aluminum film needed to give that high 90% reflectance is about 40 nm [AIP Handbook, 3rd Ed. (1972), Table 6g-4, p. 6-159], although the reflectance of a thin aluminum film is still 87% at 30 nm thickness and 76% at 20 nm thickness, so thinner films can be considered if desired.

I will assume (as I did on page 15), that the appropriate Casimir plate spacing L for a given cutoff wavelength is not the wavelength ($L=\lambda$), or half the wavelength ($L=\lambda/2$), but instead the reduced wavelength given by $L=\lambda/2\pi$. (This assumption needs to be verified by a competent theorist, and if not correct, then the following analysis needs to be revised with new numbers.)

Given the above, let us consider an extreme version of Casimatter, consisting solely of a very large number of very thin aluminum film layers at very close spacings. I will make the conservative assumption that the reflectance cutoff wavelength for aluminum is $\lambda = 120$ nm (90% reflecting), which means that we can consider a spacing between the aluminum plates in the Casimatter of $L=\lambda/2\pi$ –20 nm, and the thickness of the aluminum films as 40 nm. To simplify things, I will assume that the 20 nm spacing between the aluminum films will be filled with an ideal dielectric with index of refraction of 1 and density of 1 g/cc.

The Casimir formula for the energy per unit area between conducting plates of area ***A*** and spacing L is:

$$u = \frac{U}{A} = -\frac{\pi h c}{1440 L^3} \qquad (9)$$

where $h = 6.63\times10^{-34}$ **J•**s and $c = 300$ **M**m/s. From this, it is easy to calculate the energy density ***e*** in the volume between two of the plate pairs of area ***A*** and separation L that make up one of the layers.

$$e = \frac{u}{L} = \frac{U}{LA} = -\frac{\pi h c}{1440 L^4} \qquad (10)$$

For a spacing of L = 20 nm, the (negative) energy density is -2.7 **kJ/m**^{3} or -2.7 **mJ/cc**. This energy density gives the vacuum a relativistic mass density ρ_v of:

$$\rho_v = \frac{e}{c^2} = -\frac{\pi h}{1440 c L^4} \qquad (11)$$

which for a layer spacing of $L = 20$ nm results in a negative mass density for the vacuum of -3.0×10^{-14} kg/m^3 or -3.0×10^{-17} g/cc.

If we assume the thickness of the aluminum plates to be $T = 40$ nm and the separation between the plates to be $L = 20$ nm, then two-thirds of the volume will be aluminum with density 2.7 glcc and one-third will be the ideal dielectric with density 1 glcc, for an average density of the matter in the Casimatter of 2.23 glcc. The one-third containing the dielectric will also contain the negative Casimir mass density of -3.0×10^{-17} glcc, for an average density of the vacuum energy in the Casimatter of 1.0×10^{-17} g/cc.

For an experiment, we would want to fabricate about a cubic centimeter of Casimatter, probably in the form of a plate 10 cm by 10 cm by 0.01 cm thick. Since the thickness of a layer pair is 40 nm of aluminum followed by 20 nm of dielectric, or 60 nm overall, there would be 1667 layer pairs, not that difficult to fabricate. The real question would be whether it is possible to measure a sample and its container vial with a mass of a few grams to an accuracy of 10^{-17} g or better. Right now, I can not think of a way to do it, since the force levels are beyond the present capabilities of available atomic force microscopes and the accuracy required for a frequency measurement is beyond the capabilities of available clocks.

People thinking about working on this idea should appreciate that the energy density levels involved are smaller than chemical energies and an experiment must include accurate calorimetry. For example, since aluminum has a specific heat of about 0.9 $JK^{-1}g^{-1}$, in order to measure the estimated Casimir energy density of the Casimatter of -2.7 mJ/cc, a 1 cc sample would have to be temperature controlled to better than a millikelvin, and the heat flow into or out of the sample would have to be known to better than a millijoule. In fact, a useful first experiment would be to fabricate some Casimatter and measure how much it cools off as the negative Casimir energy in the Casimatter is eliminated by destroying the internal structure. This thermal-type experiment would show that the Casimir effect produces measurable negative energy, but it would not give any definitive experimental evidence for a mass modification effect.

Annotated Condensed Bibliography

This bibliography is not complete. It merely contains the more important papers that I used in writing this report.

Ambjørn, J. and Wolfram, S. (1983). Properties of the vacuum. 1. Mechanical and thermodynamic. ***Annals Physics,*** 147, 1. [Paper derives Casimir energy per unit volume for conducting rectangular boxes. Cubes have positive energy and repulsive forces on the walls, long rectangles or parallel plates have negative energy and attractive forces on the walls. See especially Fig. 4.2 on page 16. Be careful in using this paper since the calculations are for many different types of fields — scalar, vector, etc, and many different boundary conditions. Make sure you get the right one for the electromagnetic field and electromagnetic boundary conditions. See also Hacyan (1993).]

Arnold, W., Hunklinger, S., and Dransfeld, K. (1979). Influence of optical absorption on the van der Waals interaction between 'solids. ***Physical Review,*** B19,6049: Erratum, ***Physical Review*** (1980). B21, 1713. [Last measurement of the Casimir force (15 years ago!). Crystalline quartz, borosilicate glass, and silicon. Good agreement with data, but the experiments only ranged from 80 to 1000 nm and didn't get very far into the $1/L3$ unretarded region. The Casimir force between two silicon surfaces increased when the silicon was illuminated. However, silicon seemed to behave differently than expected at close distances. Reason for difference not known.]

Bakalov, D., et al. (1994). PVLAS - Vacuum birefringence and production and detection of nearly massless, weakly coupled particles by optical techniques. Nuclear Physics, B S35, 180. [PVLAS is an experiment designed to measure the vacuum magnetic birefringence. It is based on a very sensitive ellipsometer and a 9T superconducting dipole magnetic. See also Cantatore (1991).]

Barton, G. (1990). Faster-than-c light between parallel mirrors: the Scharnhorst effect rederived. Physics Letters, B237, 559. [Rederives the Scharnhorst effect from another viewpoint and ends up agreeing with Scharnhorst. See also Milonni and Svozil (1990).]

Barton, G., and Scharnhorst, K. (1993). QED between parallel mirrors: light signals faster than c, or amplified by the vacuum. J. Physics, A26, 2037. [Either the high-frequency index of refraction of the vacuum between parallel mirrors is less than one, indicating that light travels faster than c, or at some range of the higher frequencies, the imaginary part of the index of refraction becomes negative, which means that the vacuum is an amplifier of light.]

Bennett, G. L., Forward, R. L., and Frisbee, R. H. (1995). Report on the NASA/JPL workshop on advanced quantum/relativity theory propulsion. *AIAA* Paper, 95, 31st AIAA/ASME/SAE/ASEE Joint Propulsion Conference, San Diego, CA (10-12 July 1995). [See page 10 for discussion of the Scharnhorst effect.]

Black, W., de Jongh, J. G. V., Overbeek, J. T. G., and Sparnaay, M. J. (1960). Measurements of retarded van der Walls' forces. Trans. Faraday Society, 56, 1597. [Measured $1/L^4$ force for two flat glass plates and $1/L^3$ force for flat plate and spherical surface. Data full of scatter. Lots of information on experimental techniques and problems that must be avoided. This paper supersedes previous papers by Sparnaay, 1957 and 1958, and Overbeek and Sparnaay, 1954.]

Boyer, T. H. (1979). Equilibrium distributions for relativistic free particles in thermal radiation within classical electrodynamics. Physical Review, A20, 1246. [Calculates that free charges acted on by zero-point radiation will randomly diffuse to higher and higher velocities. Used by Cole (1995) and Rueda, Haisch and Cole (1995) for their astrophysical papers.]

Cantatore, G., Dellavalle, F., Milotti, E., Dabrowski, L., and Rizzo, C. (1991). Proposed measurement of the vacuum birefringence induced by a magnetic-field on high-energy photons. Physics Letters, B265, 418. [Proposes an experimental set-up to observe and measure the interaction between high energy photons and a strong magnetic field. The successful measurement of such an effect would amount to a direct observation of QED vacuum polarization. See also Bakalov (1994).]

Carlip, S. (1993). Comment on 'Gravity as a zero-point-fluctuation force'. Physical Review, A47, 3452. [Puthoff's reply follows. Carlip says that Puthoff did his calculations wrong and Puthoff replies that he did them right.]

Casimir, H. B. G. (1948). On the attraction between two perfectly conducting plates. Proceeding Koninklijke Nederlandse Akademie van Wetenschappen, Amsterdam, 51, 793 [in English]. [The paper that started it all. It is an extrapolation of the more detailed paper, Casimir and Polder (1948).]

Casimir, H. B. G. and Polder, D. (1948). The influence of retardation on the London-van der Waals forces. Physical Review, 73, 360. [Applies retardation to the London van der Waals calculations of the attraction between a neutral atom to a wall and two neutral atoms. London and van der Waals got $1/R^3$ $1/R^6$ (which didn't agree with experiment). Retardation makes the forces drop off as $1/R^4$ and $1/R^7$. The "correction factor" had Planck's constant in it, indicating the extra factor of $1/R$ had something to due with quantum theory. Casimir then wrote his paper (1948) on the attraction between two conducting plates.]

Cole, D. C. (1995). Possible thermodynamic law violations and astrophysical issues for secular acceleration of electrodynamic particles in the vacuum. Physical Review, E51, 1663. [See Rueda (1978), Boyer (1979) and Rueda, Haisch and Cole (1995). Tries to explain away the thermodynamic problems associated with the unrestrained growth of the speed of charged particles driven by vacuum fluctuations.]

Deriagin, B.V., Abrikosova, I. I. (1958). Direct measurements of molecular attraction of solids. *J.* Phys. Chem. Solids, 5, 1. [A summary of previous papers. Data on quartz surfaces, glass surfaces, and chromium-quartz, using a spherical surface against a flat surface. Good deal of information about experimental procedures to get rid of electrical patch effects and dust.]

Ding, Y. J., and Kaplan, A. E. (1989). Nonlinear Magneto-Optics of Vacuum: Second-Harmonic Generation. Physical Review Letters, 63, 2725. [Predicts that a high power laser beam focused on a strong magnetic field will produce second-harmonic photons due to the nonlinearity of the photon-photon scattering in the vacuum. Milonni agrees that if not successful, then this shows that the vacuum itself has no fluctuations and the source model is a more correct physical model of the vacuum. The estimated laser power required was increased substantially in the recent paper by Kaplan and Ding (1995).]

Drever, R. W. P. (1961). A search for anisotropy of inertial mass using a free precession technique. ***Philosophical Magazine,*** 6,683. [Experiment done to test Mach's Principle of inertia. Can detect anisotropy of inertial mass to 5×10^{-23}.]

Forward, R. L. (1984). Extracting electrical energy from the vacuum by cohesion of charged foliated conductors. ***Physical Review,*** B30, 1700. [Proposes to convert the "surface energy" of a foliated conductor into electrical energy by cohering the leaves of the foliated conductor into a solid block (with less surface energy) under the control of a bi-directional power supply that extracts energy in the form of electricity. Does not violate energy conservation laws.]

Hacyan, S., Jauregui, R., and Villarreal, C. (1993). Spectrum of quantum electromagnetic fluctuations in rectangular cavities. ***Physical Review,*** A47, 4204. [Calculates Casimir energy and pressure in rectangular cavities. Agrees in general with Ambjørn and Wolfram (1983), but finds slight differences. See Fig. 1.]

Haisch, B., Rueda, A., and Puthoff, H. E. (1994). Inertia as a zero-point-field Lorentz force. ***Physical Review,*** A49, 678.[One of the two papers that initiated the study. States that the inertia of a body is caused by the fluctuations of the vacuum. No objections to this paper have been published yet.]

Hawton, M. (1994). One-photon operators and the role of vacuum fluctuations in the Casimir force. ***Physical Review,*** A50, 1057. [Proposes that spontaneous emission and the Casimir force can be explained by creation of single photons at the positions of charged particles.]

Hessels, E. A., Arcuni, P. W., Deck, F. J. and Lundeen, S. R. (1992). Microwave spectroscopy of high–L, $n=10$ Rydberg states of helium. ***Physical Review,*** A46, 2622. [Long, detailed experimental paper. Although the electron and the rest of the helium atom is charged, so that electric forces are dominant, the Casimir-Polder retarded forces must be included in the theory to get the right result. For example, the separation between the $10G$ and $10H$ levels is 491,005.2 kHz, while the theory predicts 491,007.5 kHz, of which 42.2 kHz is the retardation effect. The residual of 2.27 ± 0.5 kHz (5 sigma) is not understood.]

Hunklinger, S., Geisselmann, H., and Arnold, W. (1972). A dynamic method for measuring the van der Waals forces between macroscopic bodies. ***Rev. Sci. Instruments,*** 43, 584. [Reasonably accurate measurement of $1/L^4$ law at distances of 80 to 800 nm. Uses speaker cone modulation of one plate to measure the derivative of the Casimir force as a function of separation distance.]

Iacopini, E. (1993). Casimir effect at macroscopic distances. ***Physical Review,*** A48, 129. [Proposes using confocal mirror resonator structure to measure Casimir force at a few centimeters. Predicts that the Casimir force on the mirrors will be periodic with change in mirror separation. I don't think the analysis has been done carefully enough. Needs to be verified by a good vacuum theorist.]

Israelachvili, J. N., and Tabor, D. (1972). Measurement of van der Waals dispersion forces in the range 1.5 to 130 nm. ***Proc. Roy. Soc.,*** A331, 19. [Very good experimental results showing both $1/L^4$ and $1/L^3$ laws. Done with mica cylinders rather than metal plates. Supersedes Tabor and Winterton, 1969.1

Kaplan, A. E., and Ding, Y. J. (1995). Field-Gradient-Induced Second Harmonic Generation in Magnetized Vacuum. [Submitted to JOSA B (1995). New calculations increase the estimated laser power required to 10^{22} W/cm^2 from the estimated power of 10^{14} W/cm^2 in their previous paper by Ding and Kaplan (1989).]

Kitchener, J. A., and Prosser, A. P. (1957). Direct measurement of the long-range van der Waals forces. ***Proc. Royal Soc.,*** A242, 403. [Reasonably good measurement of $1/L^4$ law. Experimental technique shows that "mosaic" charges on the plates are a problem error source.]

Latorre, J., Pascual, P., and Tarrach, R. (1995). Speed of light in non-trivial vacua. ***Nuclear Physics,*** B437, 60. [Interesting paper that shows that the speed of light in vacuum is given by a very general formula $c/c_o = 1-44a^2p/135m^4$, where a is the fine structure constant, ***m*** is the mass of the electron, and ρ is the energy density of the field being considered. This seems to hold for electric, magnetic, gravitational, temperature, and Casimir fields, including the mysterious factor of 11. If the energy density ρ is negative, as it is in the gravitational and Casimir field cases, then the speed of light is faster than c,] Levi, B. G. (1993). New evidence confirms old predictions of retarded forces. *Physics Today,* 18, editorial summary. [Readable summary of what was going on in the field of long range interatomic forces as of 1993.]

Lifshitz, E. M. (1956). The theory of molecular attractive forces between solids. *Soviet Physics JETP,* 2, 73. [Zh. Eksp Teor. Fiz 29, 94 (1955)]. [Good theoretical paper deriving the Casimir force for dielectrics instead of conductors.]

Milonni, P. W. (1982).Casimir forces without the vacuum radiation field. *Physical Review,* A25, 1315. [One of many papers by Milonni showing that there are two alternative physical models for the various Casimir effects — vacuum fluctuation fields and charged particle source fields. This paper calculates the Casimir-Polder attraction of a neutral atom and a plate, and the van der Waals force between two neutral atoms.]

Milonni, P. W., and Svozil, K. (1990). Impossibility of measuring faster-than-c signaling by the Scharnhorst effect. *Letters,* B248, 437. [Calculates that quantum uncertainties in turning on an electromagnetic signal will create errors in timing larger than the time difference created by the signal propagating "faster-than-light". It is not that Scharnhorst is wrong, it is just that a simple propagation time measurement will not lead to a violation of causality because of basic quantum uncertainties.]

Milonni, P. W. and Shih, M. L. (1992). Source theory of the Casimir force. *Physical Review,* A45, 4241. [A more recent paper that does the calculation for the Casimir force between plates using many different physical models. This paper intimates that it might be possible to modify or modulate the van der Waals interaction by spatially coherent laser radiation.]

Milonni, P. W. (1994). *The Quantum Vacuum: An Introduction to Quantum Electronics.* New York, N. Y.: Academic Press. [Book containing highly mathematical discussion of many quantum vacuum fluctuation phenomena including a number of experiments. Very good on the "history" of the field, but not an easy read for experimentally oriented types.]

Milton, K. A., DeRaad, L. L. Jr., and Schwinger, J. (1978). Casimir self-stress on a perfectly conducting spherical shell. *Annals Physics,* 115, 388. [Recalculates the repulsive stress on a sphere to higher accuracy.]

Mostepanenko, V. M. and Trunov, N. N. (1988). The Casimir effect and its applications. *Soviet Physics Usp.*, 31,965. [Usp. Fiz. Nauk 156,385-426(1998), in Russian[General review paper of the Casimir effect. Authors make the point on page 980 that the Casimir force experiments shows the physical reality of the fluctuations of the electromagnetic fields in the vacuum, while the Lamb-Retherford experiments show the physical reality of the fluctuations of the virtual particles (positron-electron pairs) in the vacuum.]

Onofrio, R., and Carugno, G. (1995). Detecting Casimir forces using a tunneling electromechanical transducer. *Physics Letters,* A198, 365. [Authors mention on page 369 that the gravity force of the Casimir disks are larger than the Casimir forces.]

Puthoff, H. E. (1989). Gravity as a zero-point-fluctuation force. *Physical Review,* A39, 2333. [One of the two papers that started this study effort. Takes an idea by Sakharov and puts some mathematical flesh on it. The major problem with the paper is the assumption that ALL matter is made up of charged point-mass particles, such as electrons and quarks. This is nearly true, but electromagnetic fields and gluons do contribute to the gravity of an object, but they are not made of charged point-mass particles.]

Rueda, A. (1978). Model of Einstein and Hopf for protons in zero-point field and cosmic-ray spectrum. *Il Nuovo Cimento,* 48A, 155. [It is proposed that the acceleration of cosmic-ray protons is caused by the zero-point electromagnetic fluctuations of the vacuum.]

Rueda, A., Haisch, B., and Cole, D. C. (1995). Vacuum zero-point field pressure instability in astrophysical plasmas and the formation of cosmic voids. *Astrophysical J.,* 445, 7. [Amplifies what is said in Rueda (1978), Boyer (1979) and Cole (1995). The fluctuations of the vacuum in empty space will accelerate charged particles in regions of space of low density and low magnetic fields until the particles become very high energy cosmic rays.]

Sassaroli, E., Srivastava, Y. N., and Widom (1994). A. Photon production by the dynamical Casimir effect. *Physical Review,* A50, 1027. [See also Srivastava, Widom, and Friedman (1985). They show that it is possible to create intense photon radiation when two conducting plates are modulated periodically. Widom reports they are planning on doing experiments to look for this effect.]

Scharnhorst, K. (1990). On propagation of light in the vacuum between plates. *Physics,* B236, 354. [Calculates that the velocity of light between two Casimir plates is anisotropic, with the velocity of light perpendicular to the plates being greater than the velocity of light in unconfined space. See Barton (1990), Barton and Scharnhorst (993), and Milonni and Svozil (1990).] {K. Scharnhorst wishes to point out that Eq. (26) in this paper should read $\Delta c/c \sim 1.5 \times 10^{-56} a^{-4}$.}

Sen, D. (1995). Casimir force measurement between two gold-plated quartz flats at large separations. Oral paper at meeting of the *APS Division of Atomic, Molecular, and Optical Physics,* Toronto, Canada (15-19 May). [Viewgraphs copies only. No "paper" was prepared. The only ongoing experiment attempting to measure the Casimir force between conducting plates. Dev Sen is doing the experiment as an undergraduate honors project at the Unversity of Washington under the supervision of Prof. Steve K. Lamoreaux. He has recently achieved a plate separation of 8 μm during setup, but still has a long way to go before starting to take data.]

Serry, F. M., Walliser, D., and Maclay, *G.* J. (1995). The anharmonic Casimir oscillator (ACO): The Casimir effect in a model microelectromechanical system. *IEEE/ASME J. Microelectromechanical Structures.* [Analysis of a microelectromechanical structure that should oscillate about an equilibrium between the Casimir force and the force of a spring, and a voltage activated mechanical "switch" that uses the Casimir force to hold the switch closed. The group plans on fabricating the structures analyzed.]

Sidles, J. A., *et al.* (1995). Magnetic resonance force microscopy. *Review of Modern Physics,* 67, 249. [Reviews a possible method for measuring a small force on a small body. Basically an atomic force microscope modified to measure nuclear magnetic moments by measuring the force on the sample.]

Sparnaay, M. J. (1958). Measurements of attractive forces between plates. *Physica*, 24, 751. [Last measurement made of Casimir force between metal plates. Data poor in quality. Chromium-steel and chromium plates produced attractive forces, but all author could say was "The observed attractions do not contradict Casimir's theoretical prediction." Was not able to measure forces between aluminum plates. Often got repulsion (probably due to dust or oxide) instead of attraction.]

Srivastava, Y., Widom, A., and Friedman, H. M. (1985). Microchips as precision quantum-electrodynamic probes. *Physical Review Letters,* 55, 2246. [Calculates that the QED fluctuations for present metal-oxide-semiconductor field-effect transistors is typically 0.1 of the electrostatic energy. See also Sassaroli, Srivastava and Widom (1994).]

Sukenik, C. I., Boshier, M. *G.*, Cho, D., Sandoghdar. V., and Hinds, E. A. (1993). Measurement of the Casimir-Polder Force. *Physical Review Letters,* 70, 560q. [Fairly convincing measurement of attraction of a neutral, unexcited sodium atom to a conducting wall, showing retardation must be taken into account.]