Levitation Possible by Reversing Casimir Force

"In principle, you could use this repelling Casimir force to levitate heavier objects, but not with current technology. With current technology, one could only conceive of levitating very light objects." - Thomas Philbin, Ph.D., Theoretical Physicist

August 10, 2007 Fife, Scotland - Theoretical physicists work in their mind and on paper with math and formulas trying to understand the laws of the universe. Some of the greatest of those minds have been Max Planck and Albert Einstein. More than a hundred years ago in 1900, Planck was struggling to understand radiation from black bodies. Actual experiments forced him to suppose that the electromagnetic energy of the light at a given frequency could only take discrete values: it is "quantized." Planck found that if he chose the spacing between the allowed energies correctly, his equations agreed with the experiments. This spacing is determined by a number, now called Planck's constant. For that theoretical physics work - now regarded as the birth of quantum physics - Max Planck received the Nobel Prize in Physics in 1918. For that theoretical physics work – now regarded as the birth of quantum physics - Max Planck received the Nobel Prize in Physics in 1918.

Max Karl Ernst Ludwig Planck, Physicist. Born April 23, 1858, in Kiel, Germany. Died October 4, 1947. Received 1918 Nobel Prize in Physics for his quantum theory and Planck's constant related directly to the modern world's concept of "vacuum fluctuations."

Later in the 20th Century, when Planck's original idea had been developed into a comprehensive quantum theory of matter and radiation, physicists realized that Planck's constant also had profound implicatinos for the nature of empty space. There is constant unrest in this universe, a perpetual motion that even excites the vacuum of space. Physicists have learned there is no such thing as true emptiness. Imagine a humming, throbbing invisible engine behind the universe that we don't see and don't understand, but is always running. As long as that unseen engine vibrates, the vacuum of space still has resonance with that invisible engine. Even after all matter, light, radio waves and other fields are removed in a physics lab vacuum, there are still ceaseless and measurable fluctuations in what should be empty space. That strange unrest in emptiness is what physicists call "vacuum fluctuations."

Those vacuum fluctuations are like ghostly residues of the light, radio waves, strong and weak forces that were in the vacuum chamber before all matter and fields were removed. Mysteriously, those ghostly residues have a resonance with the matter and energy removed. Those resonances fluctuate and create a physical force in the space between objects.

Because the strength of the force falls off rapidly with distance, it is only measurable when the distance between the objects is extremely small. On a submicron scale, this force becomes so strong that it becomes the dominant force between uncharged conductors. Dutch physicist Hendrik Casimir first proposed the existence of that force in 1948. An experiment proved him right when two uncharged metal plates were laid parallel to each other in a vacuum. The force exerted by the vacuum fluctuations tried to pull the two plates together and that force was measured. Now called the Casimir force, or effect, it's become a problem in nanotechnology where that force is causing nano-sized elements to stick together and not work correctly.

Hendrik "Henk" Brugt Gerhard Casimir, Physicist.
Born July 15, 1909, in The Hague, Netherlands, and
died May 4, 2000. Predicted the Casimir effect.

Now, in the latest *New Journal of Physics,* comes a theoretical method to **reverse** the attraction of the Casimir force so that it **repels.** The pencil-on-paper thought experiment uses two parallel mirrors instead of metal plates in a vacuum with a "perfect lens" between the mirrors. Perfect lenses have been made and proved in lab tests to actually focus light more accurately than ordinary lenses. This newly published theory is based on focusing infrared wavelenths in the vacuum fluctuations of around 1 millionth of a meter through a perfect lens. Then the Casimir force can be tricked into reversing its attraction to repulsion and could levitate light-weight bodies. Shorter wavelengths focused through the perfect lens could levitate even heavier bodies. So far, no lab on Earth has tested this theoretical concept, but the theoretical physicists behind the idea think it is only a matter of time that experimental physicists will be able to use a reversed Casimir force to levitate matter.

The authors of this reversed Casimir work are Ulf Leonhardt, Ph.D., and Thomas Philbin, Ph.D., theoretical physicists in the School of Physics and Astronomy at the University of St. Andrews in Fife, Scotland. I talked with Dr. Philbin recently about their potential breakthrough in which ghostly vacuum fluctuations could be engineered to do work for human technologies.

Left: Ulf Leonhardt, Ph.D., Professor in Theoretical Physics.
Right: Thomas Philbin, Ph.D., Theoretical Quantum Optics.
School of Physics and Astronomy, University of St Andrews, Fife, Scotland.

Interview:

Thomas Philbin, Ph.D., Theoretical Physicist and Research Fellow, School of Physics and Astronomy, University of St. Andrews, Fife, Scotland: "The Casimir force is a mysterious force due to the quantum properties of empty space. In the 20th Century, it was discovered that there really is not such a thing as completely empty space. You can say this space is empty, there is not matter or material there. However, there are things called 'fields,' such as light and radio waves, and they are not matter. You can think, 'Well, then take those out of the empty space as well.'

But then quantum mechanics came along and it was discovered that these fields cannot really be exactly zero. There's a fuzziness, a fluctuation in the fields, even in empty space. That fluctuation cannot be removed in any way. It is these vacuum fluctuations, or quantum fluctuations, that cause the Casimir force.

In the Casimir effect, it is the vacuum residue of the vibrating fields that is all pervasive. Pervasive because you cannot remove the residue. There is no way to take it out. Even if space is empty, the vacuum residue of vibrating fields is still there. That's what 'vacuum fluctuations' are.

IT SEEMS THAT WHEN YOU ARE TALKING ABOUT THE VACUUM FLUCTUATIONS THAT SOMETHING IS SUSTAINING A VIBRATION OR RESONANCE EVEN IN THE VACUUM. WHAT DOES THE SUSTAINING?

One way to understand why quantum mechanics requires the all-pervasive vibrations in the fields, or fluctuations in them, is to take the Heisenberg Uncertainty Principle.

Werner Karl Heisenberg, Physicist.
Born December 5, 1901, in Würzburg, Germany, and
died February 1, 1976. Received 1932 Nobel Prize in Physics
for his pioneering work on the Uncertainty Principle in quantum mechanics.

> [Editor's Note: *Wikipedia:* - "According to Heisenberg's Uncertainty Principle, it is impossible to have a particle that has an arbitrarily well-defined position and momentum simultaneously. For example, the pattern (probability distribution) produced by millions of photons passing through a diffraction slit can be calculated using quantum mechanics, but the exact path of each photon cannot be predicted by any known method.
>
> "It is this interpretation that Einstein questioned when he said, 'I cannot believe that God would choose to play dice with the universe.' Physicist Niels Bohr responded, 'Einstein, don't tell God what to do.' Bohr himself acknowledged that quantum mechanics and the uncertainty principle were counter-intuitive when he stated, 'Anyone who is not shocked by quantum theory has not understood a single word.']

People are perhaps familiar in hearing about this in terms of particles – that a particle essentially cannot sit still doing nothing. That violates the Heisenberg Uncertainty Principle because the particle's position and momentum cannot be exactly known. So, it cannot have a definite position and at the same time, a definite momentum of zero, which would be sitting there not moving. The particle must be jiggling about in some way.

Now, what is probably less familiar to a general audience is that when you talk about fields, such as the electromagnetic field, the same thing applies to them. When you apply quantum theory to fields you find that they also cannot rest.

Zero Point Energy

But because of the Heisenberg Uncertainty Principle, there's a certain Zero Point Energy (ZPE), it's called, that is required by the principle. This prevents one from saying in quantum physics that the vacuum is entirely devoid of fields. There always has to be some fuzzy presence of the fields. That's the vacuum fluctuations. The vacuum fluctuations are present for all fields in the universe, not just the electromagnetic fields. There are fields that govern forces in nuclear physics and all the fields have their own ghostly presence in the vacuum.

THERE ARE THE STRONG, WEAK, ELECTROMAGNETIC AND GRAVITATIONAL FIELDS.

Yes. However, I would stress that it is the electromagnetic one that is causing the Casimir effect, not the others.

THE DIFFERENCE BETWEEN PHOTON ENERGY IN ALL OF ITS FREQUENCIES AND THE VACUUM FLUCTUATIONS IS WHAT?

The difference is that the photons that we can detect and others we see as light are *real* in the sense that we can detect them. They can hit a detector and leave a signal. The vacuum fluctuations – we would not describe them as being real photons. They are sometimes called 'virtual photons.'

It's very mysterious and strange and I would say it's not something we understand fully yet, the nature of the quantum vacuum, what it actually is. However, we have some ideas about what it is and more importantly, we have ways of calculating the effects the quantum vacuum has and the Casimir force is an example of it. And we're finding now that we can even engineer these vacuum fluctuations. But what they are is not something we have a really good picture of.

What Would 'Perfect Lens' Do to Casimir Force?

WHAT PROVOKED YOU AND PROF. ULF LEONHARDT TO TRY REVERSING THE CASIMIR FORCE SO IT WOULD REPEL RATHER THAN ATTRACT?

We were thinking about what are called 'perfect lenses.' It was shown that these lenses were theoretically popssible to build in 2001 by an English physicist called Sir John Pendry from Imperial College in London.

An ordinary lens will form an image of an object. However, there is a limit to how sharp that image can be in a normal lens. Essentially the limit is given by the wavelength of light that is being focused to form the image. It turns out that any structure, any detail in the object being imaged that is smaller or finer than the wavelength of light will not be imaged sharply. It will be fuzzy. You cannot pick out any details in the image that are closer together than the wavelength of light. They will just be blurred.

However, Sir John Pendry predicted that you could build a lens that did not have this limitation and would image objects to an accuracy, a sharpness, finer than the wavelength of the light. These are called 'perfect lenses.' In practice, the perfect lens can only be built to operate at a certain wavelength of light. Then if you have an image of an object that is radiating at that particular wavelength, you send that radiation through the perfect lens and it will focus that radiation and form an image of the object. In that object, you will be able to see details of the object that are closer together than the wavelength of the light. That is the perfect lens trick. That is what ordinary lenses cannot do.

Subsequently, since 2001, those perfect lenses have been built experimentally and they have been shown to have this property of imaging objects more accurately than normal lenses.

Both Ulf Leonhardt and I were thinking about ways to understand how a perfect lens operates. Having done that, we thought about what we could use this way of visualizing how the perfect lens operates to discover new properties. An obvious one to try would be the Casimir force – what would happen if you put one of these perfect lenses between the mirrors? How would it affect the force?

The perfect lens is imaging light so even though there is empty space between the mirrors and the perfect lens is in between, there are the vacuum fluctuations going on between the mirrors. Those vacuum fluctuations will also be imaged by the perfect lens.

The question we asked ourselves is: What effect will the vacuum fluctuations have on the Casimir force?

What we discovered is that if the distances are arranged properly, the Casimir force can turn from an attractive force into a repelling force.

WHY?

One thing I could say to try to get an idea of the effect the perfect lens has is to say that because it's imaging the light, the light sees the mirrors as being closer together than they actually are due to the lensing effect of the perfect lens.

Therefore, if the mirrors are sitting in physical space at a certain distance apart with the perfect lens between them, the vacuum fluctuations – as far as they are concerned – they see the mirrors as being closer together than they really are.

And if you can imagine – and this is the difficult bit now - pushing the mirrors actually closer together in physical space, then you get to a stage where as far as the vacuum fluctuations are concerned, the mirrors are sitting on top of each other.

Now push them together even further in physical space, they sort of move past each other as far as the vacuum fluctuations are concerned. It is this that causes the reversal of the Casimir force. The mirrors are sitting separated with the lens in between. But as far as the vacuum fluctuations are concerned, they are on the opposite sides of each other. They are sort of swapped around the positions of the mirrors.

BUT WHY ARE THE FIELDS, FROM THE FLUCTIONS' POINTS OF VIEW, ON OPPOSITE SIDES?

As far as the fields, the vacuum fluctuations, are concerned, they are bringing the mirrors closer together than the mirrors actually are in physical space. So, there is still room in physical space to bring the mirrors even closer to each other when the vacuum fluctuations think the mirrors are actually on top of each other. So, when you physically move the mirrors closer together in physical space, as far as the vacuum fluctuations are concerned, the mirrors move past each other and swap positions. That is the key thing that will reverse the Casimir force.

Perfect Lens Focuses Vacuum Fluctuations, Causing Casimir Force to Reverse

The perfect lens is focusing the vacuum fluctuations. This is the incredible and mysterious thing! There is nothing there. It's vacuum. But as we were just discussing, in quantum physics, it's not completely a vacuum. There are the fluctuations taking place in the electromagnetic field and the perfect lens is imaging those fluctuations. The fluctuations see the perfect lens and they adjust to it. So, if you like, the perfect lens is altering the quantum properties of empty space.

THE PERFECT LENS DOES NOT NEED PHOTONS TO FOCUS?

Correct. It will focus the vacuum fluctuations. The vacuum fluctuations will see this lens and be focused by it. This is the remarkable thing. Even though there are no REAL photons there, the vacuum fluctuations in the field – sort of like virtual photons – are seeing the lens.

WHAT IS THE PERFECT LENS MADE OUT OF?

They can look rather different from each other, depending upon the wavelength of light they are engineered to operate at. One of their features is that they don't do this focusing trick, the perfect imaging trick, for all wavelengths of light. In practice, they are limited to a very narrow frequency band.

What they look like is they are essentially repeating regular structures made of metal. So, there are certain metal shapes that are repeated in a sort of lattice-like arrangement.

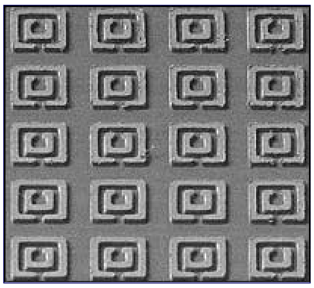
Metal lattice of "perfect lens." Image courtesy University of California, San Diego.

WHAT IS THE METAL THAT THE PERFECT LENSES ARE MADE OUT OF?

Some that are made for the bending light the wrong way that I spoke about, gold is used. The metals don't have to be exotic. It's the shapes that the metal takes in the repeating structures that's important. The lenses work by finding the right shape and having the shape repeated in a lattice-like structure. You can melt gold, put it into a mold, and you get a shape.

SO WHAT DOES HAPPEN IN MAKING THE PERFECT LENS OUT OF GOLD?

One of the shapes is a kind of horseshoe-like shape to achieve this bending light in a strange way. So, you just have a repeating structure of horseshoe-shaped gold.



Perfect lens can focus on and engineer vacuum fluctuations with a lattice of repeating geometric structures in a gold metamaterial such as the "horseshoes" above, which are about 50 microns wide, less than the thickness of a human hair. Photomicrograph courtesy St. Andrews University.

Normal lenses are made out of glass and they bend light and focus things. The glass they are made of is a nice homogeneous sort of material, right? But the perfect lens is something completely different in terms of its structure and what it looks like. Instead of being a nice smooth, uniform material, it’s actually engineered to be composed of lumps, repeating lumps of material. This is how it does this trick. The lumps are acting as the fundamental unit in the material, as far as the light is concerned. Of course, in matter the real fundamental unit is the atom. However, in these perfect lenses, one builds structures much bigger than the atom and has them repeating in a lattice. In normal solids, you have atoms which are the lumps repeating. But in the perfect lens, you build much bigger repeating structures made of metal and it is these arrangements, which cause the perfect imaging trick.

How Does Perfect Lens "Trick" Casimir Force Into Reversing?

WHY IS IT THAT THERE IS A MISINTERPRETATION OF HOW FAR APART THE MIRRORS ACTUALLY ARE AND SUDDEN FLIP TO THE OPPOSITE FOR THE VACUUM FLUCTUATIONS?

We found that the way of thinking about what the perfect lens does to light is that it acts as sort of a negative distance. I can explain this with a well-known example. If you view an object in water, it can look closer to you than it actually is. For example, the bottom of a swimming pool looks a bit closer than it is. The water in the swimming pool is actually deeper than it looks from the surface. The reason for that is the light from the bottom of the swimming pool does not get to your eye in a straight line. It follows a bent path.

One way in optics that we understand how light chooses the path to take is to say it does not choose the shortest path in space. It measures distance in a different way. The light takes in the properties of the different materials. Certain materials act as if they have longer distances (for the light to travel) than other materials. Light takes the shortest distance the way it calculates distance, which is different than our standard way of measuring distance. This will explain the bending of light, why it follows a bent path.

Of course, the distance between two points in space is a straight line. But light does not measure the distance that way. Light measures the distance depending upon the properties of the material. The light wave calculates the distance and followed the shortest path according to the way the light calculates it. That’s one way of explaining these optical effects such as refraction, mirages in the desert.

What we discovered is that a way of viewing what the perfect lens does is that it acts as a negative distance for light. The perfect lens constitutes a negative path length for the light. Therefore, when you have the two mirrors a distance apart, if you put in a perfect lens, it acts as a negative distance as far as light is concerned. So, the total distance between the mirrors as far as light is concerned is the distance apart in space, but then there is the negative distance you have to add in and so the distance light sees is smaller.

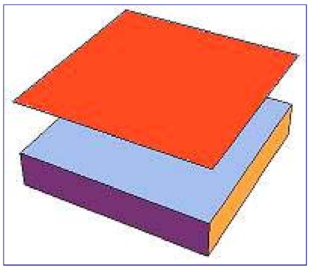
THAT’S THE OVERLAP.

Yes. And so it is smaller as far as light is concerned. Therefore, you can push the mirrors together in physical space such that they are on top of each other as far as light is concerned because of the negative bit you have to add in. You can push them together further so they swap over positions. That's when you get the repelling Casimir force.

THE REPULSION IS BECAUSE OF THE CONFUSION AT THE FIELD LEVEL BECAUSE FROM THE FIELD POINT OF VIEW THAT SWAP SUDDENLY MEANS THEY ARE STILL TRYING TO PUSH TOGETHER THOSE MIRRORS. BUT IN FACT, IN SWAPPING POSITIONS, THEY ARE NOW REPULSING THE MIRRORS.

Yes, that is precisely it. You could say that the vacuum fluctuations have been tricked into thinking that they are pushing the mirrors together, which is what they have to do. That's what the Casimir force is. It attracts things together. So the vacuum fluctuations think they are trying to pull the mirrors together, but because of the swap over, in fact, in the real physical space, they are pushing the mirrors apart.

So, we have this way of reversing the Casimir force. Then we have to ask: Can the perfect lens be built that will do this trick (beyond theoretical pencil on paper)? First, it would require a special type of perfect lens. We put in some numbers into the calculations and we estimated that with current technology what we could conceive humans could use this repelling force to levitate an extremely thin metal foil.



Artist's impression of a thin mirror being held up above another mirror by the quantum levitation effect. Image courtesy St. Andrews University, Fife, Scotland.

So, the idea is that you would have a mirror on the table. Then you would have one of these perfect lenses sitting on top of that mirror.

Then some distance above the lens in mid-air floating would be this extremely thin metal foil that would be held in place against its own weight of gravity because the repelling Casimir force would balance the force of gravity pulling down the foil and it would levitate in mid-air. So, that's the picture from our paper.

IN THAT EXAMPLE, WOULD YOU NEED A PARALLEL MIRROR? OR IS THE THIN METAL FOIL TAKING THE PLACE OF THE PARALLEL MIRROR?

It is the parallel mirror, yes. It is a very light mirror, is the point. Since the Casimir forces, in general, are very small, and the repelling force will be very small, the only weight it could balance with current technologies would be very light like a thin piece of aluminum foil.

In principle, you could use this repelling Casimir force to levitate heavier objects, but not with current technology. With current technology, one could only conceive of levitating very light objects.

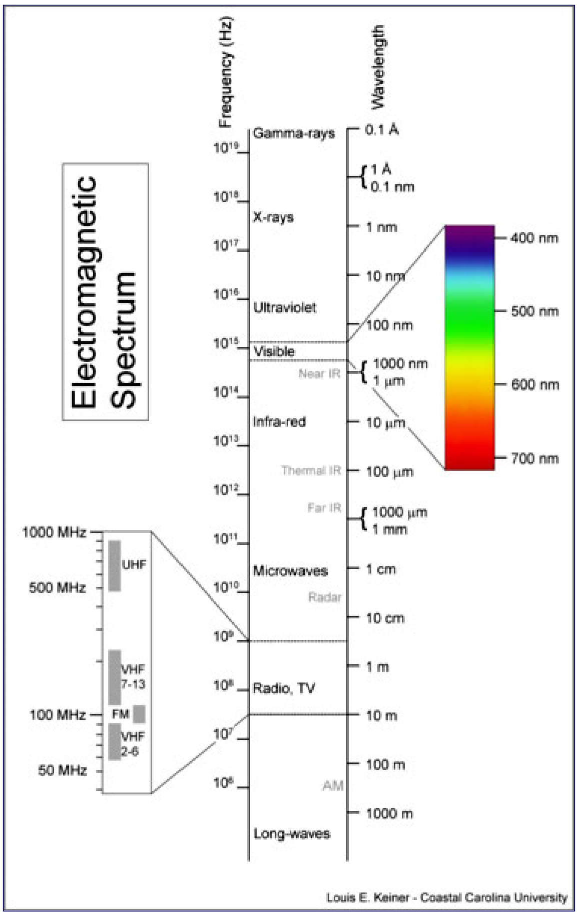
WHAT WOULD BE NECESSARY TO SCALE UP THE PRINCIPLES YOU HAVE BEEN WORKING WITH TO LEVITATE PEOPLE AND CARS AND LARGER OBJECTS?

These perfect lenses only operate over a very narrow frequency range. They only do the trick of perfect lensing for only a single wavelength of light. It turns out that the wavelength in which the perfect lens operates determines how heavy an object you can levitate.

Making perfect lenses that do this focusing trick for very short wavelengths is very difficult. So, there is a limitation with current technology as to how short a wavelength you can make a perfect lens work. As I said, the shorter the wavelength, the heavier the object you can levitate. So, to levitate heavier objects, you would need to have a perfect lens operating at much shorter wavelengths than can be done with present technology.

But in principle, if you could build one that could operate at extremely short wavelengths compared to what has been achieved so far, then you could levitate heavier objects.

The exciting thing is to realize that one can engineer the properties of empty space, the vacuum fluctuations, to achieve very interesting physical effects and in nanotechnology in the future, perhaps some very important applications."



Physicists Ulf Leonhardt's and Thomas Philbin's theoretical proposal to reverse the Casimir force uses a single frequency of infra-red light that is 1 millionth of a meter in wavelength. Electromagnetic spectrum by Louis Keiner, Coastal Carolina University.

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Websites:

St. Andrews University: http://www.st-andrews.ac.uk/~www_pa/News_Activ.shtml

Prof. Ulf Leonhardt: http://www.st-andrews.ac.uk/~ulf/

Max Planck: http://en.wikipedia.org/wiki/Max_Planck

Hendrik Casimir: http://en.wikipedia.org/wiki/Casimir_effect

Werner Heisenberg: http://en.wikipedia.org/wiki/Werner_Heisenberg

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