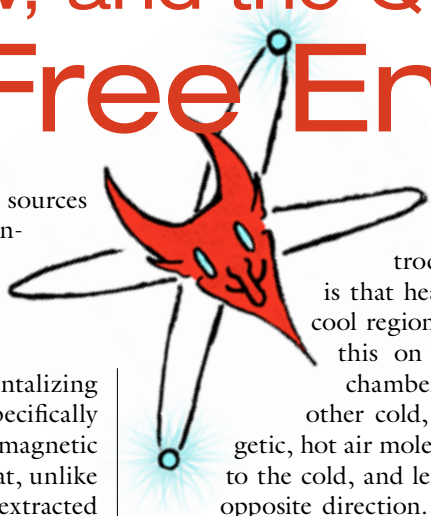
Garret Moddel **Illustrations by Benjamin Kessler**

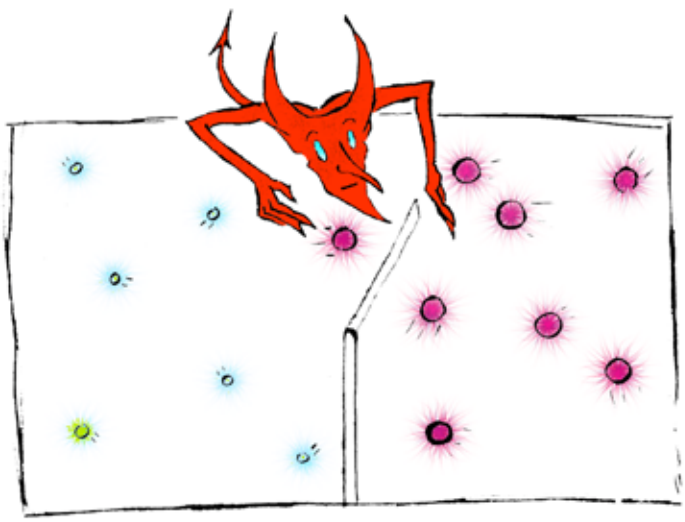
A Demon, a Law, and the Quest for Virtually Free Energy



If you believe what you read on the internet, new sources of energy now exist that can provide limitless, non-polluting, virtually free power. Supposedly these new sources have been patented and proven by scientists, but they aren't generally available because power companies or government agencies are suppressing information about them. The most tantalizing of these purported energy sources is the vacuum, specifically zero-point energy in the form of ubiquitous electromagnetic waves. The great thing about zero point energy is that, unlike many other sources of energy, it doesn't have to be extracted from the ground because it's literally everywhere around us.

What is zero-point energy? ZPE, for short, can be viewed as a consequence of the uncertainty principle in quantum mechanics. According to this principle, we cannot know both the position and speed (or more precisely, the momentum) of a particle to absolute precision. If a particle were at rest, we would know both. Therefore no particle is ever completely at rest, even at absolute zero temperature. Hence zero-point energy. Not only does ZPE make all matter vibrate, but even empty space can't escape its effects. All space is filled with this quantum vacuum energy, resulting in a huge quantity of electromagnetic waves that tantalize us, saying "Take me . . . if you can."

The question is: Can we? Can we extract this energy from the vacuum?



The Demon is in the Details

Let's step back from the hype and take a look at the fundamental underpinnings of vacuum energy extraction to see whether it makes sense. To do so, we must first understand the second law of thermodynamics. One of the ways to state this law, as introduced by Rudolf Clausius in 1865, is that heat can't flow spontaneously from a cool region to a warm region. To understand this on a microscopic level, picture two chambers filled with gas, one hot and the other cold, connected by a small hole. Energetic, hot air molecules diffuse from the hot chamber to the cold, and lethargic, cold molecules flow in the opposite direction. The effect is that heat flows from a hot region to a cold one, and not the other way around. Is there a way to reverse this process?

Let's imagine, as Scottish physicist James Clerk Maxwell did in 1867, that there's a little fellow who can. His name is Maxwell's demon and his sole mission in life is to violate the second law of thermodynamics. The demon guards a door blocking the hole between the chambers. Every time he sees an energetic molecule coming towards the hole from the hot chamber he closes the door. He does the same thing when he sees a lethargic air molecule approaching from the cold side. His devious nature emerges when he sees the occasional energetic molecule approaching from the cold side or the occasional lethargic molecule coming from the hot side. Out of spite for Clausius he lets them through. In this way the hot region becomes hotter by taking energy from the cold region, which becomes colder. The demon is the embodiment of a one-way valve for heat flow.

Can a real process exist that is represented by this demon's actions? After more than a century of creative proposals for Maxwell's demons, none has been found to exist. There really is no way to make heat flow spontaneously from a cold region to a hot one, or to provide useful energy by forming hot spots of gathered heat from a uniform temperature background. You can't get around the second law, so this little demon just can't exist.

But even proposals that claim not to be based on Maxwell's demon to extract energy from the vacuum actually do depend on the little devil—and therefore fail.

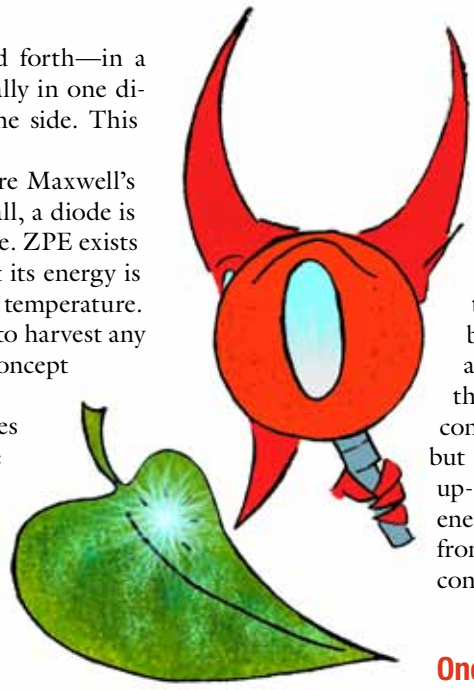
No Way for One-Way Valves

In a talk presented at the 2009 "Workshop on Future Energy Sources" with proceedings published by the American Institute of Physics, an investigator proposed using a diode, a one-way valve for electrical current, to harvest ZPE because these electromagnetic waves not only fill all of space, they also produce electrical oscillations in electronic components. The idea is that the uniform background ZPE would cause

oscillations—electrical charge moving back and forth—in a diode. And since a diode allows flow preferentially in one direction, electrical charge would build up on one side. This build-up could then be used to charge a battery.

Can this really be done? Or does this require Maxwell's demon and is therefore really impossible? After all, a diode is just a one-way valve, the demon's area of expertise. ZPE exists in a state of true equilibrium, which means that its energy is as evenly distributed as if it were at a uniform temperature. But Clausius already told us that there is no way to harvest any energy from a uniform distribution. So this concept cannot work.

How can we be so sure that one-way valves cannot harvest energy from equilibrium? Maybe Clausius got it wrong and someone will come along someday to correct his version of the second law, just as Einstein came along and corrected Newton's law of gravitation. Unfortunately, these are two very different types of situations. Newton's law was based on observation and abstraction. If Newton had been observing the effects of gravitational forces with sufficient precision and at cosmic scales, he might have come up with Einstein's more accurate picture instead. The second law of thermodynamics is different. Although it may have originated from observations, it has been re-developed using statistical mechanics, an application of probability and pure logic, and it is now supported by a foundation stronger and more accurate than any observation. Einstein wrote that classical thermodynamics "is the only physical theory of universal content which I am convinced will never be overthrown…"



What Goes Down Must Come Up

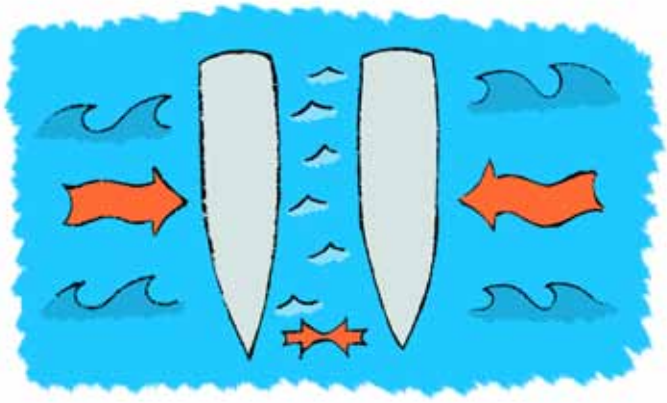
One of the problems with extracting zero-point energy from the vacuum is that the vast majority of this energy is in the form of extremely high-frequency electromagnetic waves. There is not much energy at radio and television-wave frequencies (around 100 million cycles per second) or even at microwave frequencies (around 10 billion cycles per second). Only when you get up to the frequencies of visible light (around 1 million billion cycles per second) is there enough energy to be useful as a power source. The problem is that today's electronics can't work at those high frequencies. For that reason, two U.S. Air Force researchers proposed a system intended to down-convert the high-frequency ZPE waves to lower frequencies, where they could be harvested for use in electronics. The researchers received a patent for this in 1996 (U.S. # 5,590,031).

Frequency down-conversion, like the use of diodes to convert electrical oscillations into direct current, makes use of what is called a nonlinear substance or device. Many minerals and all living material are nonlinear to some extent. If a nonlinear substance were sufficient to down-convert electromagnetic waves of ZPE then we would see hot spots wherever there was such a material. This is because the low-frequency oscillations that resulted from the down-converting of these fields would end up as heat. Maxwell's demon would have a heyday producing these hot spots from the background energy. But we don't see such hot spots, once again because the energy in the vacuum is uniformly distributed; it's in equilibrium. Based on this, Einstein developed a detailed balance description of emission and absorption in 1916. According to this balance, there is in fact down-conversion of vacuum energy into heat, but there is an exactly equal amount of up-conversion of the heat into vacuum energy. So there is no net flow of energy from the vacuum. The proposed down-conversion can't work, unfortunately.

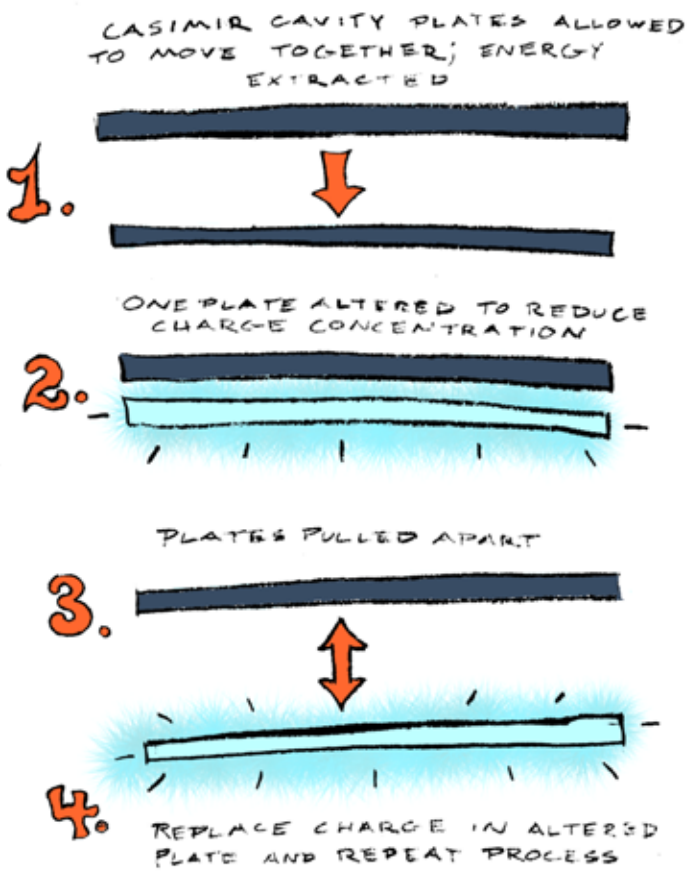
One-Trick Casimir Cavities

Another attractive approach to harvesting vacuum energy involves Casimir cavities. In 1947, the Dutch physicist Hendrik Casimir was developing a theory that predicted the existence of previously unknown forces between two closely spaced objects. He described his findings to Niels Bohr, the grandfather of quantum mechanics, as they took a walk together. In response to Casimir's description, Bohr mumbled something about zero-point energy. Casimir had the answer he needed.

The two plates on either side of a Casimir cavity are like two ships at sea. Waves pushing against the starboard sides of each ship are balanced by waves pushing against the port sides. But when the two ships move too closely alongside each other, they block the waves between them. Waves on the open-sea sides of the ships are no longer balanced by waves on the other sides, with the result that the ships are pushed together. Similarly, ZPE electromagnetic waves push against the Casimir plates. When the plates are spaced closely enough they block some of the long wavelength waves from forming between them, with the result that the plates are pushed together. This effect becomes noticeable only for spacings that are less than one millionth of a meter.



In 1999 and the early 2000s, a physicist published a paper in *Physical Review B,* received several patents (including U.S. # 6,665,167), and started a company, all dealing with the extraction of energy from the vacuum using the attractive force between the plates of Casimir cavities. According to the invention, he allows the plates to come together and extracts energy in the process. But if he then simply pulls the plates apart to repeat the process, the pulling apart would use all the energy gained in allowing the plates to come together and there would be no net energy gain. So, instead, he turns off one of the plates after they come together, then pulls them apart, turns on the plate, and repeats the process.



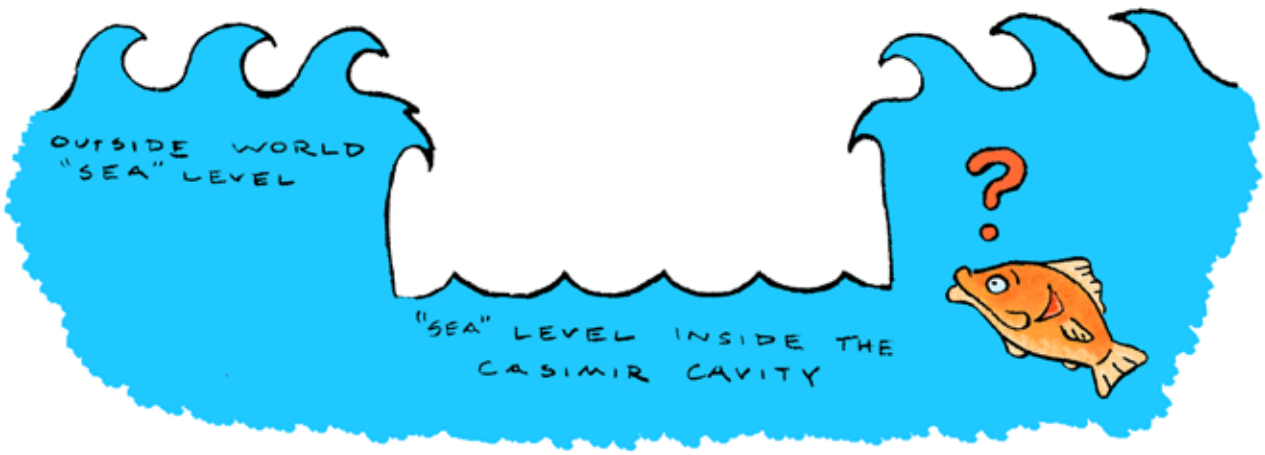
This process is like allowing a bucket of water to drop to the ground while it pulls a rope attached to a generator. You extract energy from the bucket on its way down. But to raise it up again would require as much energy as you obtained by letting it drop, and so you pour out the water to make it lighter. You then raise the empty bucket, fill it with water, and repeat the process. The problem, of course, is that any energy that you extract from the dropping bucket is lost in lifting up the water to fill the raised bucket. The process provides net energy only once, during the initial drop. This is because gravity is a conservative force.

The Casimir force resulting from zero-point energy is also conservative. Pulling the plates apart uses the energy that was obtained by letting them come together. Without expending energy there is no way to turn off the ZPE to allow the plates to separate without having to pull them apart. Casimir cavity attraction works once, but can't be used to obtain cyclic power.

Have we been left on the Casimir sea without a paddle? Is there any hope left for extracting energy from the vacuum?

Go with the Flow

There is one strange quirk of vacuum energy that opens up a possibility. In a thermal system at rest, the temperature is uniform. There are no differences in temperature that would allow energy extraction. But vacuum energy is different: it depends upon *local* structures and boundaries. Both in open space and inside a Casimir cavity, the state of lowest available energy is the zero-point energy state. As described earlier, however, the cavity rejects some of the ZPE, and so there is a difference between the energy levels inside and outside the plates. It's as if sea level were constant, *except in some locations.* On a real sea, the water would spill from the higher level to the lower, but for a Casimir cavity the local difference in "sea" levels is stable.



There may be a way to take advantage of this natural step in the lowest available energy. Gas flowing into the cavity from outside experiences this drop in ZPE. The gas atoms may drop into a lower-energy state inside the cavity. On the way in, they could emit the difference in energy in the form of electromagnetic waves, according to a patent that was issued in 2008 (U.S. # 7,379,286). After flowing through the Casimir cavity and exiting on the other side, the atoms would be re-energized to their initial state by the ambient ZPE field. The gas could be pumped through the Casimir cavity many times, so that the emitted energy would provide a continuous power source.

This is not like the contracting Casimir cavity described previously, which required the energy gained to separate the plates again. The function of pumping the gas is only to move it through the system, and is not directly related to the energy obtained from the vacuum. The pumping energy required is much less than what could be extracted from the gas emission. The overall function of the system would be to transfer ZPE from the environment and deposit it locally, where it could be used. This approach of using gas flowing through Casimir cavities circumvents the violations of thermodynamics that blocked the earlier approaches.

Can this work, or is there a hidden Maxwell's demon somewhere, meaning that a fundamental law has been violated? Standard quantum electrodynamics is consistent with the step in ZPE at the entrance to Casimir cavities, but no one has used it to predict a big change in the atomic energies of atoms flowing past the step. An alternative theory, called stochastic electrodynamics, does predict such a change. Does the concept work? My laboratory is now carrying out experiments to test the idea.

Whether this technique or others that have been proposed will work is an open question. What is not in question is the absence of Maxwell's demon. A successful zero-point energy extraction technique cannot rely on the little fellow to circumvent the second law of thermodynamics. Sleep, little demon, sleep.

Garret Moddel is a professor at the University of Colorado at Boulder investigating new energy technologies and psi phenomena. He currently serves as president of the Society for Scientific Exploration, and is co-founder of Jovion Corp., which patented the gas flow ZPE technology.