

The Casimir Effect

So far, I have had the pleasure of talking to you about dark energy and extra dimensions. Next, I would like to talk about a phenomenon that I have been fascinated by for some time; namely, the Casimir Effect. And later, I will discuss how all these subjects could be related.

Typically, everything that happens in the universe is a consequence of one of the four basic forces: gravity, electromagnetism, the weak nuclear force, and the strong nuclear force. However, in 1948, the Dutch physicist Hendrik B. Casimir published a profound paper in which he predicted that two parallel conducting plates, if placed in a perfect vacuum, would attract each other with a force $F \propto \frac{1}{a^4}$, where a is the plate separation. Casimir also predicted that this force is not explainable in terms of the four known forces, but is due to the modification of the quantum vacuum itself.

First, let's discuss what we mean by the term 'quantum vacuum'. The most successful physical theory that physicists have developed is called quantum field theory (QFT). QFT accurately describes the subatomic realm with unprecedented precision, and has been verified by particle accelerators for decades. QFT has also predicted the existence of an array of previously unknown particles, which have since been proven to exist; one such particle is the top quark. The large hadron collider (LHC) being built on the Swiss-Geneva border is being built primarily to try and prove the existence of the Higgs boson, which is another prediction of QFT.

The basic 'building block' in QFT is a quantum field. This means that everything in the universe (electrons, quarks, photons, neutrinos etc.) can be described fundamentally as a field with a specific frequency and wavelength. These fields can be described mathematically as an oscillator occupying every point in space and time. One way to visualize this is to picture a tiny pendulum occupying all points in the universe, and the different amplitudes and frequencies of this pendulum's vibration correspond to the matter and energy we observe.

One interesting prediction that came out of quantum mechanics is the Heisenberg Uncertainty Principle (HUP), which tells us that no field oscillator can ever be completely at rest. What this means is that these ‘pendulums’ which occupy all points in the universe always have some residual vibration, and are never perfectly still. Because of this, these pendulums are constantly emitting radiation, much like when an electron accelerates. This radiation is called ‘zero point radiation’. Another prediction of QFT is that this radiation is free to take all frequency values from zero all the way up to infinity, and so what we understand to be the vacuum is not the classical picture of emptiness, but instead a sea of zero point oscillations.

Now that we have acquired some insight into the vacuum, let us now turn to understanding the Casimir effect. The basic idea is this: when two parallel conducting plates are placed in a vacuum, their very presence modifies the quantum vacuum fluctuations. Only resonant modes, or ‘standing waves,’ are free to exist within the boundaries. These are waves that fit *exactly* within the confines. This is most easily pictured by looking at Figure 1. We see that on the exterior region of

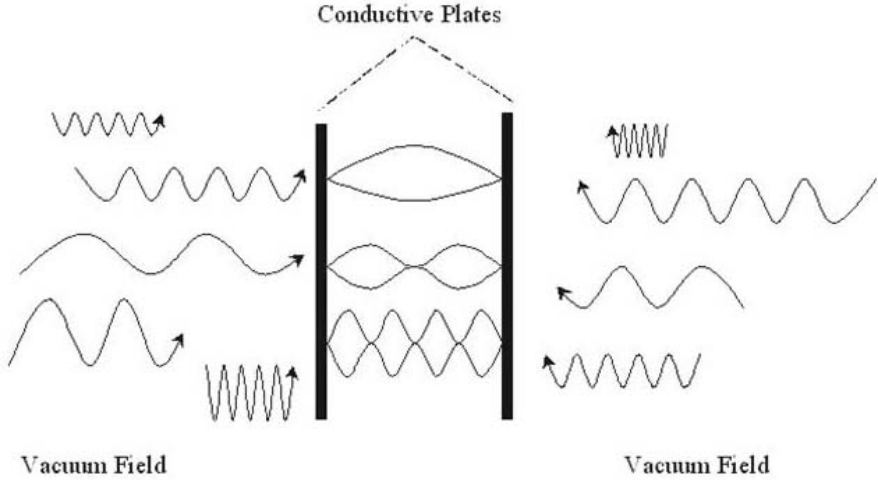


Figure 1: *The presence of the plates modifies the quantum vacuum, ensuring that only standing waves form in between the plates.*

the plates, the vacuum energy is free to take all possible frequencies,

but on the interior region of the plates, the vacuum is restricted to standing waves. This asymmetry of the vacuum creates an energy gradient which generates a force of attraction between the plates. This energy gradient is purely *quantum* in nature. One interesting feature of this Casimir energy is that it is *negative*. In classical physics negative energies are strictly forbidden.

This force, first predicted in 1948, remained unknown for many years. However, from the 1970's onward, the Casimir effect received increasing attention, and over the last decade it has become very popular. Many attempts have been made at measuring this force, and the most accurate-to-date was performed by Steven Lamoreaux at the University of Washington in the late 1990's, who used an atomic force microscope. The experiment validated the theoretical predictions to within 1% accuracy (see Figure 2). The Casimir effect is far more

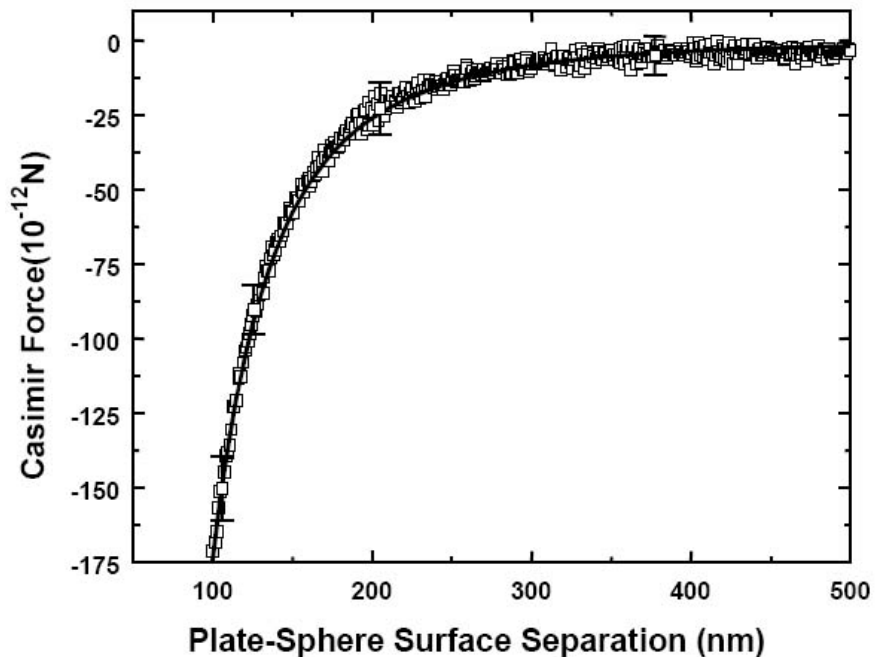


Figure 2: *The solid black line shows the predicted force of attraction using the Casimir equations. The data points acquired using the AFM closely follow the predicted values.*

than just a theoretical curiosity, and is studied in the context of a wide variety of fields in physics. These include gravitation and cosmology,

condensed matter physics, atomic and molecular physics, quantum field theory and even nanotechnology. My own interest in the Casimir effect is its possible role in explaining dark energy. Another interest of mine regards the stability of compact extra dimensions. In previous articles we have discussed the fact that extra dimensions, if they exist, must be very small. One important question regarding these dimensions is, what keeps them small and stable? Why do they not perpetually shrink, or conversely, why do they not expand like our familiar macroscopic dimensions? It is possible that the Casimir effect plays a role here. I hope to continue to discuss these compelling ideas with you in future articles.