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Test of zero-point energy emission from gases flowing through Casimir cavities

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Abstract

A recently issued patent [1] describes a method by which vacuum energy is extracted from gas flowing through a Casimir cavity. According to stochastic electrodynamics, the electronic orbitals in atoms are supported by the ambient zero-point (ZP) field. When the gas atoms are pumped into a Casimir cavity, where long-wavelength ZP field modes are excluded, the electrons spin down into lower energy orbitals and release energy in the process. This energy is collected in a local absorber. When the electrons exit the Casimir cavity they are re-energized to their original orbitals by the ambient ZP fields. The process is repeated to produce continuous power. In this way, the device functions like a heat pump for ZP energy, extracting it globally from the electromagnetic quantum vacuum and collecting it in a local absorber. This energy can be used for heating, or converted to electric power.

We carried out a series of experiments to test whether energy is, in fact, radiated from Casimir cavities when the appropriate gas flows through them. The Casimir cavity devices we tested were nanopore polycarbonate membranes with submicron pores having a density of $3x10^8$ pores/cm^2. Gas was pumped through the membranes in a stainless steel vacuum system, and emitted energy was measured using a broadband pyroelectric detector and lock-in amplifier. Emission in the infrared was clearly observed. We analyzed the emission from different gases and cavities to determine its origin. None of the conventional thermodynamic models we applied to our data fully explain it, leaving open the possibility that it is due to Casimir-cavity-induced emission from ZP fields.

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1. Introduction

Physical effects resulting from zero-point (ZP) energy are well established [2]. This has led to several proposals and reviews discussing the extraction of ZP energy to use as a power source [3] [4]. The extraction methods usually involve ZP energy in the form of electromagnetic ZP fields. Our approach makes use of a Casimir cavity. It consists of two closely-spaced, parallel reflecting plates. Because the tangential electric field is reduced (to zero for a perfect conductor) at the boundaries, limits are placed on the ZP field modes between the plates, and those modes having wavelengths longer than twice the gap spacing are suppressed to a degree determined by the plate reflectivity.

According to stochastic electrodynamics (SED), the energy of classical electron orbits in atoms is determined by a balance of emission and absorption of vacuum energy [5]. By this view of the atom, electrons emit a continuous stream of Larmor radiation as a result of the acceleration they experience in their orbits. As the electrons release energy their orbits would spin down were it not for absorption of vacuum energy from the ZP field. Accordingly, the orbital energies of atoms inside Casimir cavities should be shifted if the cavity spacing blocks the ZPF required to support a particular atomic orbital. An exploratory experiment to test for a shift in the molecular ground state of H_2 gas flowing through a 1 μm Casimir cavity was carried out, but without a definitive result [6].

A suitable term for this is the "Casimir-Lamb shift" [7]. The energy levels of electron orbitals in atoms are determined by sets of quantum numbers. However the electromagnetic quantum vacuum can change these energies, as exhibited in the well known Lamb shift. In the case of the Lamb shift the nucleus of the atom (a single proton for hydrogen) slightly modifies the quantum vacuum in its vicinity. The result is that the $2P_{1/2}$ and $2S_{1/2}$ orbitals, which should have the same energy, are slightly shifted since they spread over slightly different distances from the nucleus, and hence experience a slightly different electromagnetic quantum vacuum. The electromagnetic quantum vacuum can be altered in a much more significant way in a Casimir cavity. Hence the term Casimir-Lamb shift.

In a 2008 patent [1] Haisch and Moddel describe a method to extract power from vacuum fluctuations that makes use this effect of Casimir cavities on electron orbitals. The process of atoms flowing into and out from Casimir cavities is depicted in Figure 1. In the upper part of the loop gas is pumped first through a region surrounded by a radiation absorber, and then through a Casimir cavity. As the atoms enter the Casimir cavity their orbitals spin down and release electromagnetic radiation, depicted by the outward pointing arrows, that is extracted by the absorber. On exiting the cavity at the top left, the ambient ZPF re-energizes the orbitals, depicted by the inward pointing arrows. The gas then flows through a pump and is recirculated through the system. The system functions like a heat pump, pumping energy from an external source to a local absorber.

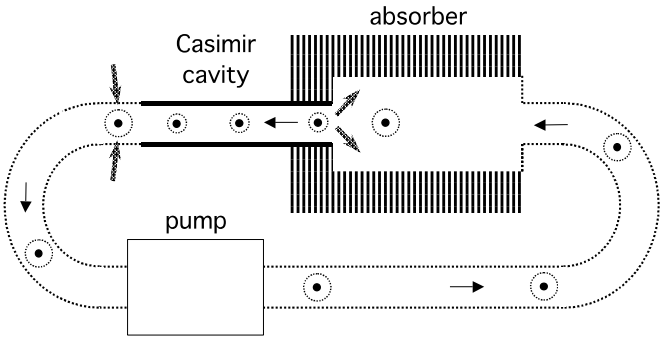


Fig. 1. Schematic representation of the vacuum-energy extraction process. Gas circulates through the system. The electronic orbitals of the gas atoms spin down to a lower level as the gas enters the Casimir cavity, radiating the excess energy to the absorber. Upon exiting the cavity the orbitals are re-energized by the ambient zero-point field. In this way, energy is collected from the ambient zero-point field and deposited on the absorber.

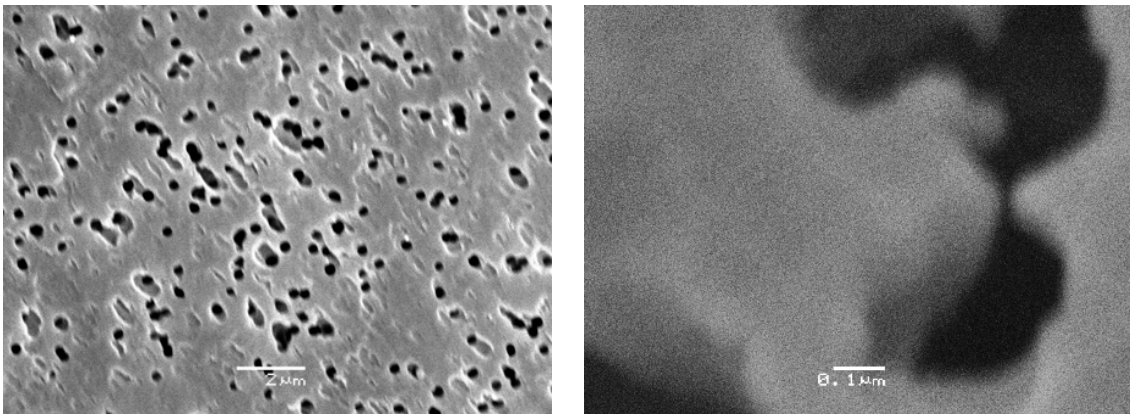
According to the initial analysis [1], for an electronic orbital to be suppressed inside a Casimir cavity its orbital frequency should match the frequency of a ZP field mode that is suppressed inside the cavity. For most atoms this corresponds to a Casimir-cavity gap spacing of less than 0.1 micron. So that the spacing is sufficiently large to be practically obtainable an atom with a relatively low-frequency outer orbital is required. The orbital frequency for large atoms like Xe, which has a relatively low-energy outer orbital, is lower than that for small atoms like He, where the outer orbital energy is larger. Therefore we expected that the emission would be stronger for a Casimir cavity having 0.1 μm gap and Xe gas, rather than for larger cavity spacings or smaller atoms.

In this paper we describe a test of the ZP energy harvesting concept. A series of experiments was carried out to measure radiation produced from gas flowing through Casimir cavities. The results and analysis are presented in the following sections.

2. Experimental

2.1. Choice of Casimir cavity

To form Casimir cavities we used Whatman polycarbonate Nuclepore track-etched flexible membranes with pore sizes of 0.1, 0.2, and 0.4 μm. These membranes withstand 180° C temperature stress without any visible deformation, so that they can be easily coated with metal in our thermal evaporator. The membranes are 2.54 cm in diameter, which makes them easy to handle. Gold was thermally evaporated at two angles to enhance coverage of the pore walls. The coverage was confirmed by scanning electron microscope (SEM) inspection, as shown in Figure 2. We chose gold as a coating metal since it is commonly used in the field of Casimir force measurements [8].



(a) (b)

Fig. 2. SEM images of the Nanopore polycarbonate membrane coated with 70 nm of palladium metal, shown at two magnifications. In (a) the white line corresponds to a length of 2 μm, and in (b) to 0.1 μm. From (b) it can be seen that top surface and the upper parts of the sidewalls are covered with metal.

Ideally, the metal coating should be highly reflective in the near-ultraviolet wavelength range to satisfy the Casimir cavity condition, since that range corresponds to twice the cavity spacing. However, modifications to the Casimir force formulation done by Lifshitz have shown that the effect occurs also for dielectric surfaces [9]. Our initial assumption was that if we were to see any quantum energy radiation from the nanopore membrane it would be only for metal-coated filters, but we cannot exclude the

possibility of observing radiation from uncoated filters, due to the Lifshitz formulation. Therefore we experimented with both, coated and uncoated membranes.

2.2. Experimental apparatus

We used a custom-machined copper holder, shown in Figure 3, to secure the filter inside the vacuum chamber.

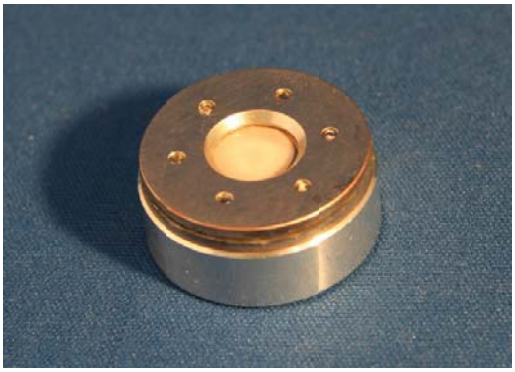


Fig. 3. Copper holder with an uncoated nanopore polycarbonate membrane mounted in it.

The experimental set up is shown in Figure 4. Gas entered into the vacuum chamber and passed through the filter. The main chamber was made of stainless steel and used copper gaskets for sealing. It was pumped by a mechanical pump and could achieve a base pressure of 10^{-3} torr. Before each experimental run the chamber was evacuated for 20 min.

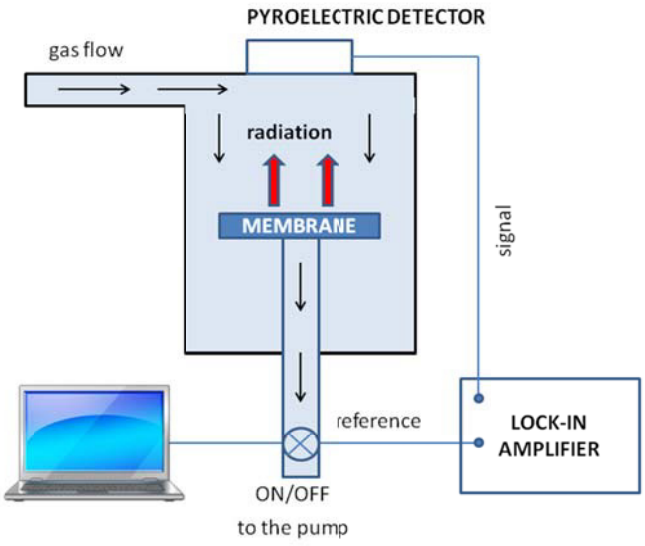


Fig. 4. Measurement setup for detection of radiation.

The flow was modulated by closing and opening the valve to the vacuum pump. We chose this approach, rather than modulating the input flow, to obtain a sufficiently small time constant, which is the inverse product of the volume and the gas flow at the given pressure. The volume of the main chamber was 320 cm^3. In contrast, the volume of the gas line to the pump was only 4.6 cm^3. Therefore, we obtained an almost 100 times faster system response by modulating the flow from the vacuum pump side than we would have by modulating the input gas flow. The main chamber pressure remained virtually unchanged while the drop of the pressure in the vacuum line modulated the flow of gas through the membrane.

A wide bandwidth SPH-49 pyroelectric detector from Spectrum Detectors Inc. was used for the radiative output measurements. The detector had a responsivity of 1.9×10^4 V/W and could detect signals at the level of nanowatts. Since the detection was based on a bolometric effect, the spectral response of the detector was flat over a wide range of wavelengths. Our device had a chromium coating, so that its response was constant from 0.6 μm to 5 μm. To reduce noise the detector was mounted inside a grounded metal box. The pyroelectric detector was placed outside the chamber facing the sample through an infrared-transparent ZrSe window. The distance between the sample and the detector was 9 cm. We looked for a difference in the detector output, as measured using the lock-in amplifier, between the flow-on and flow-off conditions. Pressure inside the chamber was in the range of 1-10 torr. The modulation frequency for the ZPE experiment was 0.5 Hz.

At such low pressure the mean-free path length of the gas atoms was comparable to the thickness of the membrane and greatly exceeded the pore diameter. Under these conditions the flow through the filter was not laminar and can be considered to be thermal random bouncing of atoms entering and exiting the cavities with some net drift flow induced by the opening and closing the valve to the pump. If we assume that the radiation was emitted every time the atom entered the cavity, we would not be able to correlate this emission with the reference signal that modulates the flow. On the other hand, if the atom that went into the pore (or another equivalent atom) bounced back and reabsorbed the radiation it had just shed, we need to account only for the signal from the atoms that went all the way through the filter due to the net flow. In this case the emitted radiation would have the on/off frequency measured with the lock-in amplifier. We have based our experiment on this assumption.

3. Results and discussion

Both coated and uncoated membranes were tested with four different gases (He, Ar, N_2, and Xe). The measured radiation for filters with a 0.2 μm pore size is shown in Figure 5. The goal was to measure the effect of gas type on the radiation. We found clearly measureable radiation from the gases flowing into the membranes with Casimir cavities through them. However, one cannot jump to the conclusion that we found evidence for ZP energy extraction. Instead, we went to great lengths to investigate conventional mechanisms that might give rise to the observed signals.

The original expectation was that ZP radiation would be strongest and most likely to be observed when using gold-coated filters because Casimir cavities are commonly formed from metals, and Xe gas because the lower frequency atomic orbital in Xe is a closer match to the suppressed ZP energy mode in our Casimir cavities than that for the lower-mass atomic gases. Any other gas in combination with either a coated or uncoated filter would give a smaller signal, if any at all. The results we obtained directly contradict this. The highest radiated power was observed with He gas, the smallest atomic number among four gases, and with uncoated filter. A possible explanation of the observed phenomena is presented in the following sections.

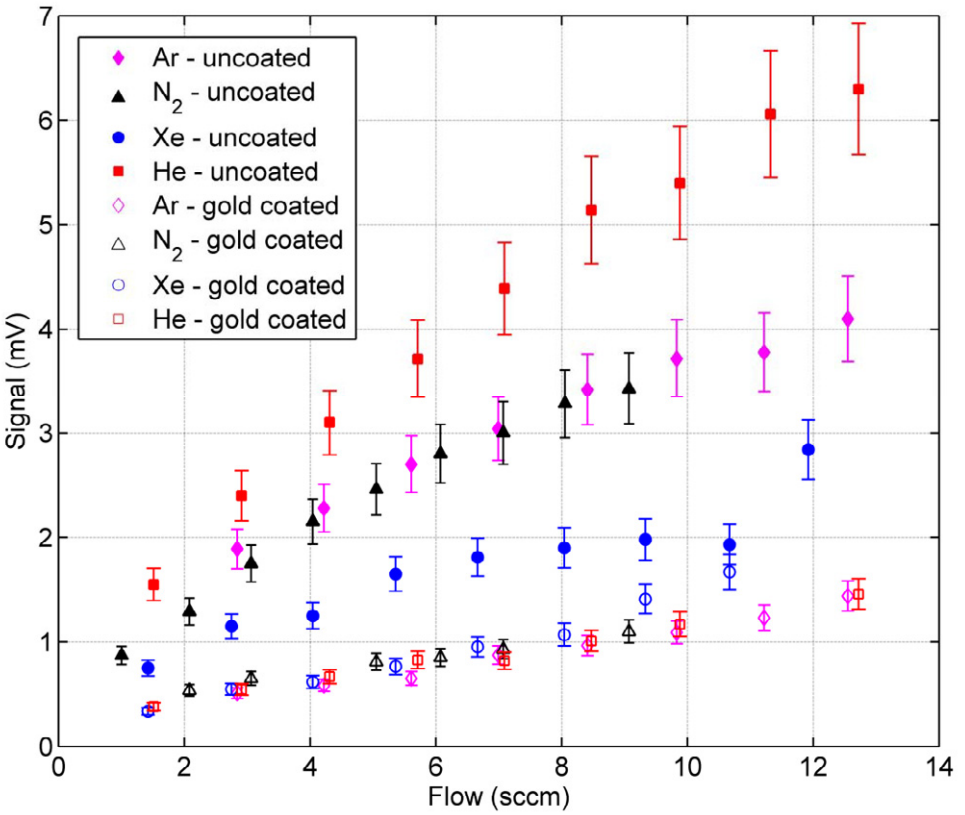


Fig. 5. Emitted radiation measured for N_2, Ar, Xe and He gasses flowing through uncoated and gold coated polycarbonate filters having 0.2 μm pore size.

3.1. Power balance and heat transfer

To analyze the power balance of the system we calculated the power provided to the system and the radiated power measured by the detector. The power in was calculated as the product of the gas flow and the pressure drop across the membrane. For a 5 sccm flow and a pressure drop of 4 torr the resulting power is ~2 x 10^{-5} W. The radiated power measured over the area of the detector at these conditions was ~10^{-7} W. If we assume that the location of the radiation source is the filter surface, then we need to account for the distance of 9 cm that separates the filter from the detector and the solid angle of 2π over which the power is radiated. The total power output would then have been two orders of magnitude higher, bringing the number up to ~4 x 10^{-5} W and making it higher than the power in. This would mean there was source of power inside the chamber in addition to that from gas pressure. In reality, the stainless steel walls of the main chamber reflected a substantial portion of the IR radiation striking the chamber walls, making it available for detection. We analyze this quantitatively in the section on the Joule-Thomson model. At this point it appears that the power out was less than the power in and there is no need to invoke an additional power source, e.g., from ZP energy emission, inside the chamber.

Since gases were flowing inside the chamber, we must consider not only purely radiative but also conductive and convective heat transfer mechanisms. Therefore, the differences in the heat conduction

coefficients of gases and their diffusivity are likely to have contributed to the measured temperature variation. It can be seen from Figure 5 that the signal levels for the different gasses flowing through the uncoated membrane followed the order of the thermal conduction coefficients and diffusivity of the gases (highest for He, lowest for Xe with N_2 and Ar in between). However, this trend is qualitative, not quantitative. The difference in the thermal conduction coefficients for He and Xe is close to 30 (He: 0.142 W/m/K, Ar: 0.018 W/m/K, N_2: 0.024 W/m/K, Xe: 0.00565 W/m/K), but the difference in the detected signal from an uncoated membrane is an order of magnitude lower, as evident from Figure 5.

For the case of metal-coated membranes, we introduce one more component into our heat transfer analysis. It is the thin gold film, which has a thermal conductivity of 30 times that of helium. An interesting observation is that with the gold-coated membrane we cannot distinguish between the signals from the different gases within measurement error, as shown in Figure 5. In this case the heat could have been conducted away through the metal film and further through the massive copper holder, and such heat transfer is no longer limited by the properties of the gases.

One factor that likely affects the magnitude of the signal is the emissivity of the material. The gases that we used in our experiment do not emit thermal radiation in the range of interest [10]. The emissivity of the gold at long wavelengths is nearly zero (0.01 to 0.1 at 1.6 μm and longer), while the emissivity for plastic materials is approximately 0.95. This could explain why we see higher signals from the uncoated polycarbonate filter compared to the gold-coated one, as shown in Figure 5.

3.2. Heat production inside the chamber: non-Casimir-cavity-induced mechanisms

We examine several non-Casimir-cavity-induced mechanisms that might account for the observed radiation to see if there is a plausible explanation that requires only conventional thermodynamics.

3.2.1. Joule-Thomson model

To assess whether the Joule-Thomson effect [11] could be the source of the signal we first address whether we have observed it. In one of our modified experiments we were able to distinguish heating from cooling with the measurement system.

We conducted a modified experiment where the filter was replaced by a 12.5 μm thick Mylar film having a single hole 3 mm in diameter. The gas expanded through this hole into the gas line leading to the vacuum pump. The phase measured by the lock-in amplifier was positive and 180° off from the phase measured in the experiment with the nanopore filter, indicating cooling. This is how we knew the effect that we observed with gases flowing through the Casimir cavities was not due to the Joule-Thompson effect.

The signal amplitudes for the different gases followed the sequence of the gases' Joule-Thomson coefficients (highest for Xe). Based on literature values [12] Xe possesses the highest coefficient, 1.87 ºC/atm at 1 atm, while He has the smallest, –0.0625 ºC/atm at 200 atm, with Ar (0.372 ºC/atm at 1 atm) and N_2 (0.2217 ºC/atm at 1 atm) in between. These numbers, however, are for pressures higher than in our experiment. We make that assumption that for the lower pressure these coefficients follow the same trend (Xe > Ar > N_2 > He). In fact, the signal from He was so small we were not able to obtain reliable measurements from this gas.

By knowing the pressure drop at the point of gas expansion, ~2 torr, and using the above values for the Joule-Thomson coefficients we calculated the associated temperature changes. For Xe gas this temperature drop was 4.9×10^{-3} ºC. Translating the detected signal to the temperature change using black body spectrum calculations, the number comes out to be ~0.001 K. We noted earlier that not all the radiated power reaches the detector. Our calculated value for Joule-Thomson cooling is close to the measured one for the 3 mm hole assuming that we measure 20% of total emission, rather than the reduction by two orders of magnitude calculated earlier on the assumption that there was no reflection by the inner walls of the stainless steel chamber.

3.2.2. Frictional losses model

In this model we assume that our filter works as a passive element dissipating heat in analogy with a resistor in an electrical circuit. Using this analogy the gas flow is analogous to the current and the pressure drop across the filter is similar to the voltage drop across the resistor. The pressure drop depends linearly on gas flow and the slope is different for different gases, with Xe being the most "resistive" and He being the most "conductive". These results are in agreement with the studies done by Roy and Raju on the gas flow through microchannels [13].

If these frictional losses are what produced the heating effect and gave rise to the detector signal, the power should depend quadratically on the gas flow (in the same way that electrical power depends quadratically on the electrical current passing through a passive element). In our case the power depends on the flow linearly. This does not automatically disqualify the frictional losses approach. Our system tended to stay in thermal equilibrium with the environment, with the gas in the chamber exchanging energy with the external environment through the walls and providing a channel for the heat/energy to escape. This may have affected the way power depends on the flow, causing it to show a more linear dependence.

Looking now at the variation of radiant power over different gases, the fact that the largest pressure drop at a given flow rate was associated with Xe means that this gas should have dissipated more heat than any other gas according to the frictional losses model. However, taking the heat conduction into account can dramatically change the picture. The magnitude of the signal can be affected by thermal conductivity and diffusivity of the gases, which are the highest for He and lowest for Xe. That could explain why we observed the most radiation from He and the least from Xe, even though the frictional losses model predicts the opposite outcome.

Based on the lack of a quadratic power dependence on flow and the opposite gas order for frictional losses and measured power, it appears that the frictional losses model does not explain the observed behaviour. However, as noted above, it may be possible to explain the result if the heat conduction and diffusivity of the gases are included. To better assess whether these factors can account for the observed behaviour will take additional experimental and analytical investigation.

3.2.3. Absorption/adsorption and release model

When a gas is brought into contact with a solid, molecules are pulled from the gas and are either absorbed inside of the solid, or adsorbed on the outside, attached to the surface. The absorption/ adsorption process is exothermic. It may be possible that the heating we see is due to adsorption on the membrane when the gas pressure rises. In the absence of gas flow we would then observe desorption, which is an endothermic process. Adsorption is proportional to the pressure of the gas and the number of vacant sites for adsorption. The number of such sites depends on the surface area. We used three different pore size filters, 0.1 μm, 0.2 μm and 0.4 μm, which have surface area of 9.42 cm^2, 18 cm^2 and 12.56 cm^2, respectively. Signal from these different filters measured at pressure of ~5 torr did not follow the expected trend of surface areas. Based on this result we have rejected the absorption/adsorption model as a possible explanation for the radiation we observed.

3.2.4. Turbulence model

Turbulence is another possible heat source. The theory of energy dissipation in locally isotropic turbulence was developed in the early 1940s by Kolmogorov [14]. In our experiment the rate at which the gas flowed through the nanopore cavities was below 2 cm/s. The resulting Reynolds number is far below what would be required to cause turbulence at the exit. Also, the viscosities of the gases used in the experiment have values that are very close to each other (Ar: 2.1×10^{-4} poise, N_2: 1.66×10^{-4} poise, Xe: 2.1×10^{-4} poise, He: 1.86×10^{-4} poise). This means that even if turbulence did cause the radiation from the filter it alone could not explain the differences in signal levels for the different gases.

3.3. Heat production inside the chamber: Casimir cavity-induced model

After failing to explain the observed radiation using conventional thermodynamics, we analyze the data as if the signal were the result of ZP energy emission. If we assume that each atom releases on the order of 10% of its energy, approximately 1eV per transaction upon entering the cavity, it is straightforward to calculate how much output power we should see from the gas flowing through a given nanopore filter. It is on the order of milliwatts, which is thousands times larger than the measured power, assuming that we detect at least 20% of emitted radiation.

If the radiation is due to Casimir cavity effects there are several factors that are likely to have reduced the radiated power and would account for its being lower than expected:

- The filters contain a range of nanopore sizes and shapes, as shown in Figure 2. Given that only a small fraction of the nanopores within the filter satisfy the Casimir cavity conditions, the number of atoms experiencing a large change in ZP field density was reduced substantially. Thus, the amount of power radiated by the atoms passing through the membrane was reduced.
- Atoms may need to undergo a collision in order to radiate power. Since we were running our experiments at low pressure (several torr), the mean-free path length of the gas atoms inside the cavity is on the order of 10 μm, which exceeds the dimension of the cavity itself. This means a fraction of the atoms could have passed through the cavity undisturbed, retaining their electrons in their initial unperturbed states without radiating any power.

Because the underlying SED theory is still under development, we cannot predict precisely what wavelengths of the ZPE field support the atomic orbitals, and hence what the optimum Casimir cavity dimensions are for shifting the orbitals. We cannot predict the emission wavelengths, and so the majority of the emission may lie outside the range of our detector. There may be other factors that can influence the change in the orbital size inside the Casimir cavity. Therefore the fact that the measured power was far below that expected from ZP energy-induced radiation does not disqualify that as a possible source for the observed radiation.

4. Conclusions

A clear infrared signal has been measured for gases flowing through polycarbonate Casimir cavity nanotubes, both when uncoated and when coated with gold. The signal was obtained for all gases tested, N_2, Ar, Xe and He. In an attempt to explain the results in terms of conventional thermodynamics, we analyzed them to see if Joule-Thomson cooling, frictional heating, adsorption/absorption heating, or turbulence could account for the results. None of these clearly fit the data, but it is possible that a combination of effects could. At this point it appears that ZP energy extraction from the quantum vacuum remains a possible explanation for the observed radiation. More experimental work will be required to determine if this is the correct explanation.

Acknowledgements

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