INTRODUCTION

The Condensed Matter Casimir Effect is a macroscopic effect that is the result critical fluctuations in mixtures at the critical points of second order phase transitions. The CM Casimir effect is an example of second order, microscopic forces becoming macroscopic near the phase transitions of liquid mixtures. The function of microscopic, entropic forces in generating macroscopically observable effects is of particular interest to condensed matter physicists, and may have practical applications in the controlled flocculation of nanoparticles in materials processing.

Since the CM Casimir effect can only be studied near the phase transition, we propose to build a DC scanning calorimeter to perform high-precision measurements of the heat capacity of liquid mixtures. The heat capacity shows a distinctive power-law divergence at the phase transition, with the value of the power-law giving important information about the character of the phase transition. In this paper, we discuss the essentials as well as the specifics of building such an instrument; we talk about the precautions taken, and the difficulties encountered.

THEORY AND MOTIVATION

The CM Casimir effect takes its name from the fact that it is analogous to the more well understood electromagnetic Casimir effect. The EM Casimir effect is caused by the geometric constraints and boundary conditions imposed on the electromagnetic fluctuations of "virtual" photons in a vacuum. When uncharged conducting plates are placed close together in vacuum, long-wavelength virtual photons (i.e. photons with wavelengths comparable to or longer than the distance between the plates) cannot exist

between the plates with wave-vectors normal to the plates. Hence, there are more particles outside the plates exchanging momentum with the plates than in between the plates, and there is a net small force pushing the plates together. This is called the EM Casimir effect. The plate separation required is on the order of 10^{-7} meters for this effect to be detectable.

The force driving the CM Casimir effect is not caused by virtual electromagnetic particles, but by the contribution to the entropy of the system from critical fluctuations accompanying the second order phase transition of a liquid mixture. At the immiscibility transition, which is second-order, a mixture undergoes order parameter fluctuations whose length scale exhibits a power-law divergence as the critical temperature is approached. The coherence lengths of critical fluctuations in an usual immiscibility transitions (for example water+picoline) are limited to a maximum of about 10^{-7} meters because of limitations of sample purity, differences in pressure between the top and bottom of the sample due to gravitational effects, and because of the difficulty in ultra-high-precision temperature control at elevated temperatures. Thus, if we immerse two plates in a critical liquid a few hundred nanometers apart, the boundary conditions set by the geometry of the plates on the entropy of the system are predicted to have a macroscopically observable effect. The plate separation is on the same order in length as the fluctuations, so there is less entropy, and thus more free energy between the plates, therefore there is a tendency for the plates to push apart in an attempt to make the entropy throughout the system uniform. The effects of this entropic force are supposedly macroscopic, and this is called the CM Casimir effect.

We can only see macroscopic forces caused by entropic fluctuations if the fluctuations are large, i.e. only if we have critical fluctuations. Thus, to study the CM Casimir effect, it is crucial that we conduct our experiment at the correct temperature, i.e. T_c, the temperature corresponding to the second order phase transition of our mixture. This task is non-trivial as the temperature region of the phase transition is small, and it is difficult to conduct an experiment at a very stabilized temperature. In order to characterize our liquid mixtures to verify the existence of and characteristics of the immiscibility transitions, we propose to make heat capacity measurements. We know that one of the signatures of the phase transition is that heat capacity diverges at T_c. Furthermore, for certain fractional compositions of three-phase mixtures, the immiscibility transition has a double critical point. That is, for these mixtures, the heat capacity critical exponent doubles as we approach the phase transition, a characteristic that makes the approach to the phase transition more obvious to heat capacity measurements. Additionally, for these compositions, the coherence lengths of the critical fluctuations can be as large as 10^{-6} meters, which makes them more desirable as samples in experiments meant to detect the CM Casimir effect. Hence, in order to identify compositions with double critical points and investigate the CM Casimir effect, we propose an instrument that could accurately measure and find the divergence in the heat capacity of a sample, and that could temperature control the sample to remain at T_c once its value has been established. For this instrument, we propose to build a DC scanning calorimeter.

INSTRUMENT DESCRIPTION

The device is a DC scanning calorimeter, which means that the instrument is meant to steadily scan through temperature and measure the heat capacity at many points of temperature. The temperature range for our instrument's purposes is from 20 degrees Celsius to 100 degrees Celsius. Our apparatus consists of double, concentric aluminum cans operating in a vacuum chamber (figure 1) for the purposes of maximum thermal insolation from the outside world, as well as for providing a uniform radiative environment. The sample sits inside of both cans. Each aluminum can is wrapped in resistive wire that is connected to a DC power supply, which supplies a DC voltage. The power dissipated in the wires is the heat in, Q_{in}, to the calorimeter. The tops and bottoms of the cans are heated by the same resistive wires as the ones on that are wrapped around the outside of the cans, but the wires heating the tops and bottoms are wrapped around heater spools, which are screwed into the tops and the bottoms. We have calculated equal heat per unit surface area for the heating of both cans.

We monitor the temperature on different locations of the calorimeter with five thermometers placed at different locations on the cans. Each thermometer is a resister to which the temperature to resistance function is known through calibration. We control the temperature manually using the PID temperature control algorithm.

1. The PID Algorithm:

The PID (Proportional Integral Derivative) algorithm is a temperature feedback control loop algorithm that allows us to tune the temperature of the calorimeter to some desired temperature setpoint. An error term e(t) is created by taking the difference of our temperature setpoint and the measured temperature of the calorimeter:

$$e(t) = T_{set}(t) - T_{actual}(t)$$

For the first runs of the experiment, we plan to control off of the readings of just one of the thermometers at a time, and to input power to one can at a time. The PID algorithm involves computing the sum:

$$p = k_c(e(t) + k_i \int e(t)dt + k_D \frac{de(t)}{dt})$$

and tuning the constants to appropriate values based on our physical knowledge about the system and on tuning tests. The sum corresponds to the fraction of maximum power that will be the next output power from the power supply. For the purposes of this experiment, we drop the derivative term of the PID due to its noise sensitivity. We run this algorithm on Labview, a programming package that interfaces well between the computer and the instruments taking the measurements.

2. Thermometers

The platinum wire thermometers (figure 2.) placed in the calorimeter are resisters of approximately 100 ohms. Their resistance is measured by sending an AC voltage through them. An AC voltage generator sends a voltage to a high-bandwidth constant current AC supply that outputs five equal AC currents through five channels. The current in each channel is measured by measuring the voltage across a resistor known to be temperature stable and to have a resistance of exactly 100 ohms. The voltage across the thermometers and the known resistors is measured using an AC resistance meter method. This method involves taking the sine and cosine integrals of the voltage signal over a large number of periods; this gives us the sine and cosine components of the signal; the amplitude of the voltage signal is the vector modulus of the components. The principle achievement of this method for measuring voltage is that it gives us minimum noise, as

almost all signals of frequencies other than the desired frequency, including any DC offset, integrates to zero.

Thermometers are calibrated using a thermocouple: the thermometers are placed in close proximity to a thermocouple, and both are baked in an oven. Temperature measurements using the thermocouple and resistance measurements using the thermometers are taken simultaneously as the oven cools, and thus we have a temperature to resistance correspondence, which is fitted to a polynomial function.

PRECAUTIONS AND DIFFICULTIES

Almost all of the precautions concerning the building of this instrument have to do with achieving thermal isolation from the outside world, as well as providing an uniform radiative environment inside the instrument. Thus, we operate in vacuum, and good thermal conductance between various parts of the apparatus, along with vacuum compatibility of components, are promptly considered. One of the hardest parts about building a sensitive instrument is maintaining the stability of the instrument itself in the lab environment. So we are required to consider the temperature stability of each measurement-taking instrument, and to test whether they are sensitive to the temperature changes in the room. Stray inductances between the many wires, parts, and instruments involved could also pose a small problem, and precautions need to be taken.

The challenges to putting together the instrument also involve the machining of small parts to accommodate the positioning and anchoring of wires and thermometers. These parts, along with the heater spools on the tops and bottoms of the cans (figure 3) were machined using the student machine shop at the University of Washington. The

constructiom of the calorimeter is nearly finished, and the testing of the calorimeter will shortly take place.

CONCLUSION

The CM Casimir effect is interesting to physicists in that it is a macroscopic effect driven by microscopic forces, namely the entropic fluctuations of a liquid mixture undergoing a second order phase transition. To study this effect, we need a) to able to find the temperature of the phase transition for any given mixture, and b) to have a temperature stable environment in which to conduct an experiment to investigate this effect. We propose that a DC scanning calorimeter that does heat capacity measurements serves the above purposes.

We have built this instrument using layers of aluminum cans in vacuum, heated by resistive wires, and temperature controlled using the PID algorithm. Heat capacity measurement tests using this instrument using gadolinium and chromium are soon to be performed, and experiments for the observation of the critical divergence of the heat capacity at the immiscibility phase transition of liquid mixtures are soon to be conducted.
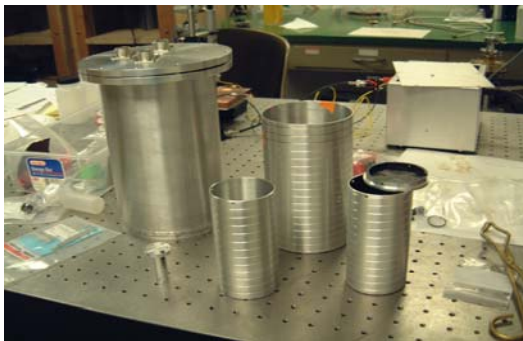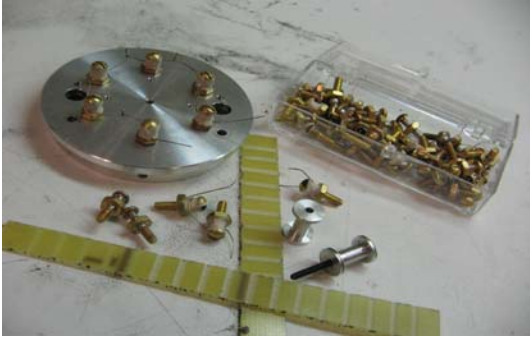

figure1. aluminum cans

figure 2. platinum wire thermometers

figure 3. heater spools and other small parts