Detecting Helium Vapor Pulses in Low Temperature Transmission Experiments

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Introduction

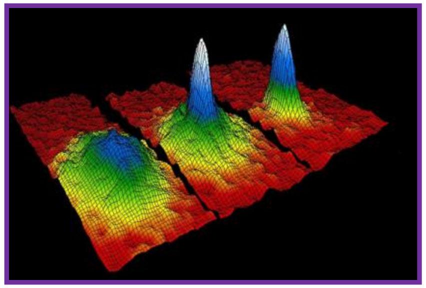
Bose-Einstein condensation, originally predicted in 1924 by S. Bose and A. Einstein, refers to a quantum configuration at low temperatures in which a large portion (the condensate fraction) of particles collapse into the ground state. *Figure 1* shows the phenomena in Rb-87, a less complicated system that superfluid 4He, but the first experimental evidence of BEC .

A superfluid is described as a phase of matter with zero viscosity, infinite conductivity, quantized vortices, and zero entropy. It is also characterized by the Cooper pairing of atoms and not electrons. It is generally accepted that superfluidity exhibited in Helium-4 is a consequence of composite boson exhibiting behavior that is associated with Bose-Einstein condensation.

It has been proposed that experiments observing the transmission characteristics of a slab of Helium-4 superfluid that is subjected to a pulse of Helium-4 vapor. *Figure 3* shows the set-up of our experimental cell. In the current experiment, we use a fiber optic cable to heat a slab of Helium-4 superfluid, which results in a pulse of vapor. This pulse of vapor is then allowed to impinge on the bottom of a slab of suspended Helium-4 atoms. The resultant atomic flux is then observed on a series of superconducting bolometers, which allow us to see the energy levels of transmitted Helium-4 atoms. Bolometers are essential for the detection system in this experiment because they are designed to function at the low temperatures needed to carry out this experiment, and allow for detection speeds on the order of 1 µs.

Our experiment aims at pinning down Helium-4 superfluid as a Bose-Einstein condensate by observing the transmission characteristics of a Helium-4 superfluid slab. The purpose of my research was to understand and test the detection system being used to measure these transmission characteristics.

Figure 1: *Bose Einstein condensation in Rb87. The images were made at 400, 200 and 50 nK in Colorado in 1995. The graph shows the velocities of particles in the system as a function of temperature. White represent the slowest moving particles while red represent the fastest. BEC occurs when a large number of the particles have collapsed into the ground state and are therefore the slowest moving.*



Detection System

The detection system consists of a series of superconducting bolometers at various heights, located above the suspended superfluid slab. In order to measure any effects in the experiment, we make use of the sharp transition edge that superconducting bolometers exhibit. This behavior is shown explicitly in *Figure 2.* The bolometers used in the experiment consist of a film of titanium that is thermally deposited onto a sapphire substrate and then etched in the Micro-Technologies Lab. This design allows for exceptional bolometer performance and response times on the order of 1µ second.

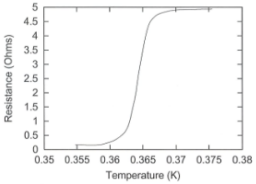


Figure 2: *Superconducting bolometer resistance v. temperature graph. Note the sharp transition edge.*

By implementing a self balancing bridge circuit (*Figure* 4) in conjunction with these bolometers, we intend to detect characteristics of transmission through the superfluid slab via resistance changes in the bolometers due to the impinging flux of atoms on the bolometers. The bolometers are heated to their transition temperature by the circuit and held there until they are struck by an incoming particle flux. By introducing thermal pulses to the cell, superfluid vapor pulses are caused to strike the bottom of a suspended slab of superfluid Helium-4. The resulting reemission of atoms from the slab heat up the bolometers as they condense on their surfaces, causing a rapid change in the bolometers' resistance. The voltage that is induced on the bolometer

$$V_{bolo} = n < v > (E + E_A)$$

is counteracted by a reduction in power delivered by the circuit

$$P = \frac{\{V(G-1)\}^2 R_{bolo}}{[R_{bolo} - R_0\,(G-1)]^2}$$

Assuming full condensation on the detector, the voltage induced on the bolometer is proportional to the power reduction supplied by the circuit,, from which it is possible to determine characteristics of the atoms incident to the detector as well as transmission characteristics of the superfluid.

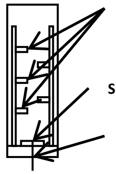
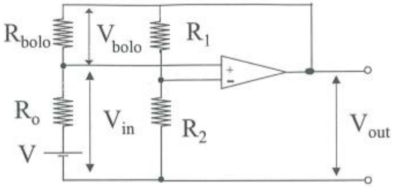


Figure 3: *Diagram showing experimental set-up of the cell.*

The Circuit

The circuit being used in combination with the bolometers is a self balancing bridge circuit, analyzed in more detail by Sherlock and Wyatt. The set-up of the circuit can be seen in Figure 4.

Figure 4: *Self balancing bridge circuit that would be used to control the bolometers used in our experiment.*



This circuit operates in its negative feedback regime, which means that the quiescent state of the circuit is given by:

$$\frac{R_{bolo}}{R_0} = \frac{R_1}{R_2}$$

Balanced in this way, the quiescent state gives rise to a regime in which there is no net feedback to a first approximation. With an applied positive offset, the circuit will enter the desired negative feedback regime if the resistance on the bolometer increases. We then monitor both V_{out} as it changes with time and V_{bolo} on an oscilloscope to analyze the transmission properties of the slab. This circuit was build on a Radio Shack 276-0150 patterned perfboard and driven with a PMI OP37EP op-amp, a low noise, high speed amplifier. A coaxial plus was used with V_{out} so that it can interface with an oscilloscope. Clarostat 73JB precision 10 turn potentiometers were used for R_0 (1K Ω), R_1 (100Ω) and V_{bias} (100Ω). Four lantern batteries power this circuit, giving it the needed 24 V potential that is stepped down through a voltage divider. This circuit is mounted in a chasis box on an equipment rack in our laboratory, ready for use.

Results and Conclusions

My part in the group involved running leak checks on our IVC and experimental cell and testing the circuit that would be used with the detection system. In order to make sure that this circuit operates properly, we ran room temperature tests where a resistance box was substituted for the bolometer. As the resistance in the resistance box was increased rapidly to the high end of the resistances in *Figure 3*, the circuit responded by delivering less power abruptly. At room temperature, though, we cannot evaluate the negative feedback effects of the circuit because this requires a smooth transition from low resistance to high resistance: the resistance box cannot accomplish this. We made several attempts to cool down and test the circuit at approximately 100 mK, but we are still running into leaks in our dilution refrigerator. Once we can fix these leaks, we will run more tests on the circuit to make sure it appropriately responds to a smooth change in resistance across the bolometer. Thus, a large portion of our time is currently devoted to trying to find and fix leaks in our IVC, so that we can cool down and run the necessary tests to check that the circuit works properly.

Once the leaks in our refrigerator are fixed, we also plan to create vapor pulses beneath the helium slab using a black coated fiber optic cable. This source should provide a coherent pulse that will allow us to analyze the transmission characteristics of the slab. These transmission characteristics will then hopefully offer proof that the superfluid characteristics of Helium-4 are a results of Bose-Einstein condensation.

Acknowledgements:

I would like to acknowledge the help of J. Woods Halley and Andy Schofield in carrying out this research.

Sherlock, R. A. *"Frequency Response Optimisation of the Constant Temperature Detector System."* (1983)