

# Preparation and Design of a Quantum Turbulence Experiment

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## Abstract

This paper describes the work accomplished in the lab of Dr. Ihas during the summer of 2009 at University of Florida, Gainesville. All the work was geared towards the progress of the lab's goal of conducting a major quantum turbulence experiment in the fall. The first project was the calibration of a thermistor for the lab. The second project was assisting in the design of the cell quadrupole holders, and overall cell holder. The final project was developing a velocity control program for the lab's quantum turbulence grid device.

## 1 Introduction

The research of the Ihas lab is in the field of low temperature physics. The goal of this summer's work was to prepare the lab for new quantum turbulence experiments that will most likely be conducted in the fall. My particular projects in the lab have been geared towards assisting the lab in this goal, rather than a single, independent project of its own right. To this end, I have accomplished several smaller tasks in the lab. These will be described in detail later in the paper.

The Ihas lab's work is primarily conducted with extremely low temperatures on superfluid helium 4 ( $He^4$ ). The lab primarily tests the properties of

turbulence within a quantum fluid—more specifically, the effect of quanta of circulation on decay in turbulent behavior.  $He^4$  is chosen for this line of research due to its special properties: it is a noble gas and thus is safely nonreactive, and, unless pressure is applied, it never solidifies even theoretically at absolute zero. In addition, helium has the lowest critical point of all fluids at  $T_c = 5.2$  K and  $p_c = .226$ . This aspect is useful, especially in gas traps because gases with higher liquefaction temperatures can be condensed out, thus purifying the desired helium gas. The most important property for these experiments is a state known as superfluidity. For  $He^4$ , this transition point occurs at 2.172 K at saturated vapor pressure [1].

## 1.1 Superfluid Helium 4

The unique properties of superfluid helium are a topic in their own right. In short, once  $He^4$  reaches its lambda point, it undergoes a phase transition from classical fluid to quantum fluid. One of the most significant traits is that the fluid has zero viscosity. Below the transition temperature, the superfluid helium exists in a superposition of states—part classical and part quantum. At the temperatures at which the experiment will be done, the fluid is essentially entirely quantum.

It should be noted here that the Ihas lab only uses helium 4 for its experiments because  $He^4$  has a much higher superfluid transition point than  $He^3$ . The transition function for helium 4 is called its lambda line. We are primarily interested in the low pressure end of the curve. Though  $He^3$  is beyond the scope of this paper, the primary difference between  $He^4$  and  $He^3$  is the addition of an extra neutron in the  $He^4$  atom, giving it an integer spin, and thus making it a boson.  $He^3$  has two protons and a neutron, giving the atom half integer spin and making it a fermion. This characteristic allows  $He^4$  to undergo a form of Bose-Einstein condensation at  $T=2.172$  K [1], whereas the quantum transition for  $He^3$  is more complicated.

## 1.2 Quantum Turbulence and Set Up

Aside from the already mentioned zero viscosity, when laminar, superfluids are perfect newtonian fluids. From the Landau two fluid model, the divergence of the velocity field must be zero:

$$\vec{\nabla} \cdot \vec{v} = 0 \tag{1}$$

[3]

This follows from the idea that the phase of the quantum wave functions must be continuous in any simply connected volume. It follows from this that the vorticity is zero, and the superfluid cannot support circular flow. However, despite this, turbulence has been observed in a superfluid. Theoretically, this turbulence is due to vortex cores appearing where the superfluid density goes to zero. These cores have been observed experimentally, but the oscillations and motions of the vortex lines are not well understood. Understanding their properties is one major goal of the experiment.

In order to test the quantum turbulence effects, the lab uses a device called a dilution refrigerator to obtain temperatures below 100mK for the experiment. The most relevant part to my project is the test cell that will be attached to the cryostat. The test cell will drag a grid through a superfluid filled chamber to create turbulent effects. The resulting turbulence will be measured by thermal or pressure sensors on the bottom of the cell.

## 2 Project: Calibration of Thermistor

The first project I undertook this semester was a failed attempt to measure second sound resonance in superfluid helium 4. Second sound in superfluid helium is actually not a pressure (sound) wave at all, but rather an entropy wave. In order to create these temperature waves, a porous metal capacitor plate was oscillated with an AC electrical signal inside an experimental cell. Temperature

was then measured in the middle of the cell. At resonant frequencies in the cell, resonant peaks should be observed at the measuring end of the cell. The second purpose of the setup was to collect data for use in calibrating the thermistor, which would in turn be used in later experiments. My part in the project was designing a Labview program to interface with the control device, an HP 3225A.

## **2.1 Setup**

The experiment itself used a dipstick, as shown in Figure 1, a device designed to be lowered into a dewar of liquid helium for low temperature experiments. In addition, it has connections run down its length to allow for connecting to the experimental devices. In this case, the dipstick held our experimental second sound cell. The experimental cell was attached at the bottom of the dipstick and connected to coaxial connections running along the length of the device. This device was then lowered into a Dewar of liquid helium 4. The dipstick was then pumped on using a rotary vane pump to reduce the helium cell pressure to below the lambda point. Varying AC signals were then applied to the metal plate in the cell and the results observed.

## **2.2 Labview Interfacing**

In order to conduct the frequency varying scans, a HP 3225 A synthesizer was used. The HP device itself could be programmed from the front panel; however, it was only capable of running up to 99 second scans. This was a weakness of the device's design. In order to overcome this limitation, I developed a Labview program that took in the overall scan one desired and then fed it to the device in 60 second scans bits. I chose 60 seconds as a value so the operator could simply choose how many minutes the scan was to run. The program accomplished this by breaking down the desired frequency scan and duration—say 1 Hz to 1 kHz over 20 minutes—and internally calculating 20 separate one minute scans. These would then be fed one at a time, with a preset one minute delay in the program, so that as soon as the HP device finished one data scan, it would receive and



Figure 1: Dipstick in helium dewar: The long tube is the dipstick, which is shown inserted into the helium dewar at the bottom. When experiments are underway, the tube is fully inserted. All experimental devices are contained inside the metal sheath of the dipstick.

start another.

### 2.3 Result

The Labview program allowed the HP 3225 to be run over long periods scanning wide frequency bandwidths; however, no sound sound resonance was detected. Regardless, calibration data were obtained for the thermistor, and the Labview program was a complete success in overcoming the HP 3225 A device's firmware limitations.

### 3 Project: Cell Design

The primary experimental goal of the lab was hinged on the creation of an experimental cell for the turbulence experiments. My particular task within this project was to develop a way to attach the experimental cell and solenoids to the mixing chamber of the cryostat, and to redesign the holder for the quadrupole magnetics in the setup.

In order to perform the experiment, a method of moving the grid was needed. To accomplish this, an armature of stycast (special epoxy), which is partially coated with niobium, is attached to the grid. At the temperatures used, niobium is a superconductor. A driving solenoid is positioned such that the armature runs through the center. When a current is applied to the solenoid, a magnetic field is induced, and by the Meissner effect, the superconducting coated portion of the armature is repulsed out of the field. This causes the armature to move based on the generated magnetic field, and hence the applied current. In order to hold the armature in the center of the cell, two groups of quadrupole magnetics are used. These create a magnetic field that centers the armature while moving. The complete setup is shown in Figure 2.

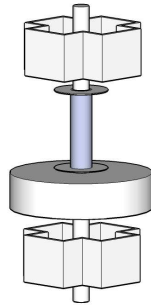


Figure 2: Cell Setup Without Holding Attachments: This shows the entirety of the experimental cell setup. At the top and bottom, the quadrupole magnetic holders are shown. The wide cylinder in the middle is the experimental volume. The solenoid atop the experimental volume is the driving solenoid—which is the motor for the experiments.

### 3.1 Design of Cell Setup

The primary concern of holding the entire setup together is stability and preventing thermal contact between the cell and solenoids. This thermal isolation is necessary to avoid noise, which may overwhelm the turbulence sensors. To this end, the lab approved of an interim design that used long metal strips to separately attach the solenoids and the cell to the mixing chamber of the cryostat. In order to provide increased thermal isolation during experiments, superconducting heat switches are used in contact between the cell and the holder. Since superconductors in the superconducting state are very poor conductors of heat, they can be used as a way to control the flow of thermal energy. In order to allow for thermal contact during the cool down process, a strong magnetic field (above the superconductor's critical field) is applied to the superconductor to disrupt the superconducting state. This field is turned off when thermal isolation is desired.

My tasks revolved around the redesign of the quadrupole holder and the design of the holding system itself. The previous quadrupole holder was unnecessarily bulky—this added to the strain on the holding system. In addition, extra bulk or material added to the difficulty of cooling down the system. The new design involved far less material to address these concerns.

I also designed the holding system. In order to keep the quadrupoles and solenoid isolated from the cell, two separate sets of four metal strips are used: one set holds up the magnet assemblies; the other holds up the cell. In addition, these two sets of strips are attached to the mixing plate of the cryostat rotated with respect to each other, so that any thermal noise from the magnetics has to travel through the entire length of the strips twice. This setup is in addition to the lab's superconducting heat switch. This is shown in Figure 3.

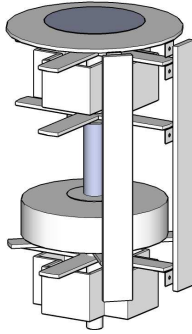


Figure 3: Cell Setup With Holding Attachments: The additional parts in this Figure are designed to hold the cell setup. The top disk attached directly to the cryostat and provides thermal contact for cooling. The strips shown (only two of the eight are shown) attach to the quadrupoles and solenoid, and separately to the cell itself. Four attach to each. Not shown is the heat switches on the underside of the cell.

## 4 Project: Velocity Control Program

In order to control velocity of the armature in the test, there are two requirements: First, position information on the armature is needed; second, a program to interpret the position data and provide current feedback to control the velocity of the armature is necessary. Designing and calibrating this program was the final significant task of the summer. In order to provide the position data, a capacitive position sensor will be used.

### 4.1 Labview Interface

The Labview program I created to handle this is a very complicated design. It is necessary for the program to take in capacitance values from the position sensor, use calibration data to convert that to position data, and then calculate a velocity from this. This requires finding a time derivative of the position data. For this to occur, the program buffers a set number of data value, and does a linear fit of the data. The slope of the linear fit is used as the velocity. When the calculated velocity is compared to the desired velocity, the program provides



feedback in the form of a new current to the drive solenoid. The exact feedback calculation has not yet been determined; however, in principle it will involve the magnitude of the difference between the desired and current velocity, and the duration of the difference.

## **4.2 Circuit Test**

To test the concept of feedback from the program, the program was used to control the temperature of a heater-thermometer setup. The setup in question made use of two resistors and a Wheatstone bridge. The first resistor served as a heater and the second as a thermometer. In the latter case, a resistor with a strong heat dependence on resistance was used. In addition, a container of liquid nitrogen was set nearby to provide cooling. This cooling was necessary because of the slow heat up time of the resistor: with the cooling system, the resistor needed to always be on to maintain a stable temperature.

### **4.2.1 Result of Test**

The resistor circuit was fairly unstable and hard to control; however, the program was able to correctly provide feedback to the system. This test was a success in that the Labview program was proven capable of providing an ever changing feedback signal in an attempt to control a system. The non-responsiveness of the resistors aside, this was a success.

## **4.3 Dipstick Test**

To provide a better test, a more realistic system would be ideal. To this end, I designed an experiment on a dipstick that would test the program's feedback capability to power the actual drive solenoid and a test armature under superfluid helium conditions. This experiment is currently in progress.

### 4.3.1 Position Sensor Construction

I constructed the capacitive position sensor, as seen in Figure 4, out of two pieces of copper plate. These I folded into half cylinders and attached electric leads to each. These cylinders were then varnished in place to a metal plate, forming two halves of a cylinder. The sensor works by measuring capacitance with a Wheatstone bridge. Initially, with no material in between, the capacitance of the copper plates is near zero. As the armature is moved into the gap, two parallel capacitors are created—between the copper and the niobium coated armature. The capacitance increases as the distance the armature is inserted between the plates increases. This capacitance data can be then, with calibration data, converted to position data.

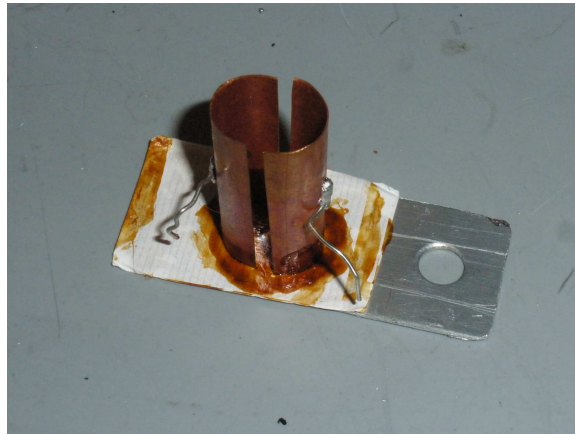


Figure 4: Capacitive Position Sensor: When the armature is inserted between the plates in the sensor, two parallel capacitors are formed. By measuring the resultant capacitance, one can obtain the depth that the armature has moved into the sensor.

## 5 Conclusion

Even as I finish the summer research program, the preparations for the experiment are not yet finished. The testing and configuration of the feedback program are currently in progress and will be completed by the lab after I leave.

Despite this, my programs and designs have been invaluable to the Ihas lab. The HP interface program allowed for the easy collection of calibration data on a thermistor. The cell holder designs will be sent to the machine shop for fabrication and implementation. Most importantly, the velocity control program will be modified and configured over the coming weeks to accurately control the velocity of the grid moving through the superfluid. This latter project is the most essential, as stable and known control of the grid is necessary to understanding the resulting turbulent behavior.

## 6 Acknowledgments

I would like to thank Dr. Ihas for my position in his lab and his guidance in this project. I would also like to thank Kyle Thompson for his invaluable assistance on the project and for his insight on 'binary theory'. Finally, I would like to thank the UF REU program, Dr. Selman Hershfield, Dr. Kevin Ingersent, and the UF Physics Department for providing me this opportunity to conduct undergraduate research this summer.

## References

- [1] Steven Van Sciever, *Helium Cryogenics*, Plenum Press, New York 1986.
- [2] Randall F. Barron, *Cryogenic Systems*, Second Edition, Oxford University Press, New York 1985.
- [3] J. Wilks and D. S. Betts, *An Introduction to Liquid Helium*, Second Edition, Oxford University Press, New York 1987.
- [4] R. J. Donnelly, *Quantized Vortices in Helium II*, Oxford University Press, New York 1991.