Experiment 4: Acoustical properties of Liquid Helium

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Class: Physics 180D
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Dated: June 12^{th}, 2019

I. INTRODUCTION

When trying to observe and test properties of materials in the many ways possible in life, one mechanic in all properties is the acoustical modes. Formations that materials try to form are tested and undergo different types of oscillations, and experience different effects in these oscillations, weather it be by differing frequencies or the method of oscillation, miraculous effects are attained. In our laboratory, we will be working with liquid super cooled Helium. When looking at materials undergoing second order phase transitions they typically show high attenuation as well as breakdown of acoustical effects, for quantum fluids this behavior is apparent in greater effect. Helium 3 the material we specifically work with, at low temperatures, below 2 Kelvin, and high frequencies exhibits not ordinary sound but a phenomenon known as zero sound which is the distortion of the Fermi Surface of this Fermi liquid. Helium 4 is a Bose liquid and displays super-fluid properties unlike any other material.

II. THEORY

The objective of the experiment was to measure the phase velocity of the 1st, 2nd, and 4th sound through the plane wave resonant mode of the cylindrical cavities. In our experiment we drive the super fluid helium in a cavity and setup explained more later.

In our experiment we observe the 1st sound, which is a simple plane wave propagating in the liquid and transports the changes in density pockets in the material. For the 2nd sound we observe the temperature wave, where the temperature of the material will have pockets of cooler and hotter liquid based on the deformation making the movement of the material more chaotic. The normal component flows toward cooler regions but the super fluid toward the hotter regions. The waves will flow in such a way where they experience counter flow known as the 2nd sound, we achieve this by making slits in the base of the chamber. For the 4th sound the interior of the cavity propagates normally but goes through a cavity filled with powder, this causes some super leak and has to be accounted for, we did this by comparing the theoretical expected value of the 4 wave speed and the measured one, we show the variables below, where n is the scattering.

$$n = \frac{c_{4theoretical}}{c_{4measured}} \qquad [1]$$

After measuring the scattering we are asked to measure the porosity of the 4th channel which is given by the following equation, and shows how we derive the Porosity, whose value will be expressed later, P is the Porosity of the channel.

$$n = \sqrt{2 - P} \qquad [2]$$

$$P = -n^2 + 2 \qquad [3]$$

After making measurements of the 4th channel correction, we wanted to observe Thermodynamic properties of the material such as the Specific Heat and the density relation of the super fluid and normal. To find the density relation we used a simple formula with the 4th and 1st channel wave speed which goes as follows

$$C_4^2 = \frac{p_s}{p} C_1^2 \qquad [4]$$

$$\frac{C_4^2}{C_2^2} = \frac{p_s}{p} \qquad [5]$$

Then for calculating the Specific heat, we use another set of equation, this time including Temperature and entropy, given by T and S respectively.

$$C_2^2 = \frac{p_s}{p} \frac{S^2 T}{C_p} \qquad [6]$$

$$C_P = \frac{\frac{p_s}{p}}{1 - \frac{p_s}{p}} \frac{S^2 T}{c_2^2} \qquad [7]$$

This concludes all major calculations made, all other results were gathered from the raw data.

III. APPARATUS AND PROCEDURE

To conduct the experiment, to simplify it we used a bucket filled with Helium that was cooled and monitored by us during the experiment, where we then drove waves in that bucket and observed at what frequencies anomalies occur. We also used a Aluminized Teflon foil to secure the whole of the Liquid Helium and capacitors inside of it to measure the overall experiment, we show the diagram of the setup below.

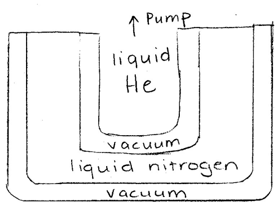

Figure 1: This Diagram shows Cryostat housing the liquid helium.

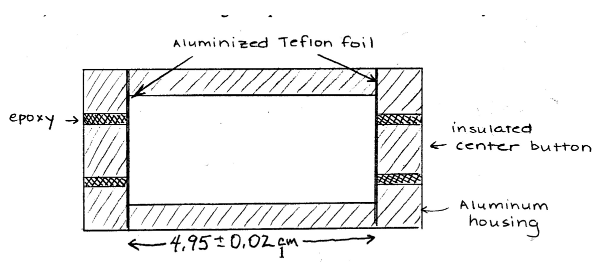

Figure 2: This Diagram shows the aluminum foil around the chamber.

We housed the chamber of liquid helium in another chamber of liquid nitrogen to make sure the experiment was fully cooled.

For the Procedure, all we really did was add liquid Helium to the Dewar and measure the temperature to see it is in ranges we want. Then we used a spectrum analyzer and drove the acoustics to see what channels we were utilizing and witnessing throughout the experiment. Then we cooled the Dewar by slowly opening the pressure valve and observing the pressure change with corresponding temperature to slowly measure the temperature of the systems. We did this for all the different waves and temperatures.

IV. DATA AND ANALYSIS

We ran the experiment at around 49.5 $\pm .2$ mm for the propagating wavelength throughout the entire experiment because the length of the chamber was this value. In this experiment we wanted to see the wave speed with different propagation's against temperature, since we were looking for resonances for our frequencies. To start we look at the plots of resonant frequencies in figures 3-5.

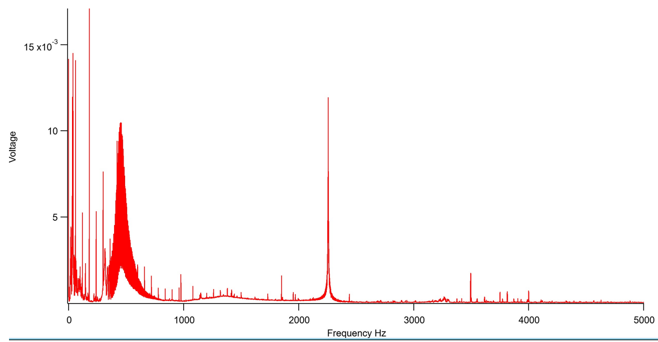

Figure 3: This is an example of Raw data of our first capture of first sound.

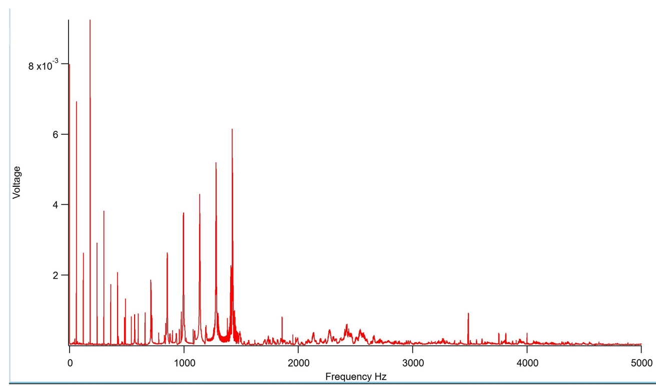

Figure 4: This is an example raw data for the second sound.

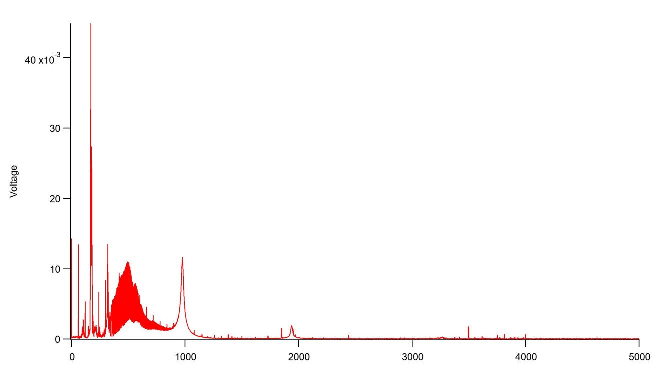

Figure 5: This is an example of raw data for the 4th sound.

After looking at examples of raw data, we analyzed them by looking at the strongest peaks in the graphs I will show the captured frequencies and wave speeds in a table in Table 1 and 2 which are found in the back of the laboratory as well as other thermodynamic relations. and then leading us to a graph of $C_{1,2,4}$ vs T but first with the correction of T being added as for C_4. To calculate the scattering n we simply used equation 2. We were yielded the values of $\frac{182.8}{229.4} = .79$ which we flip to 1.26 this a unit less ratio depicting the error in the 4th channel.Then now we show the actual measurement of the captured sounds through the liquid Helium showed in figures 6,7, and 8 where the color blue represent the 1st,2nd, and 4th sound respectively, and the red is the theoretical expected values.

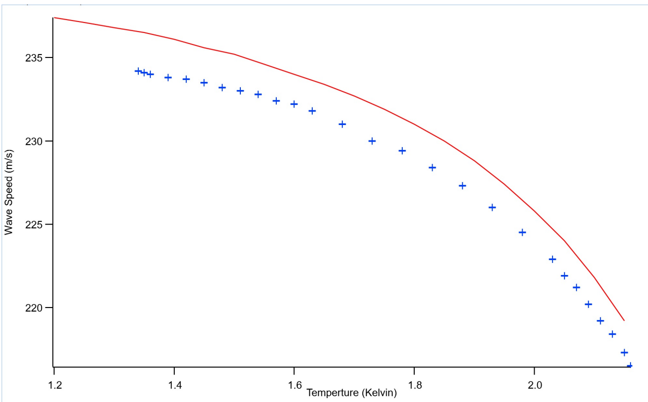

Figure 6: This is the sounds of the liquid helium versus temperature, blue dots are the calculated value the red line is the Theoretical value.

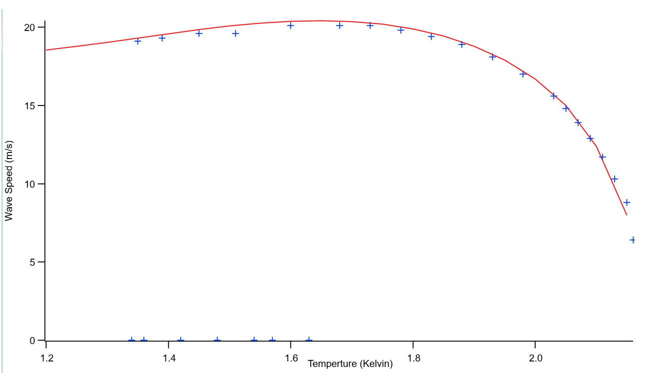

Figure 7: This is the sounds of the liquid helium versus temperature,Blue is 2nd sound, red is the Theoretical.

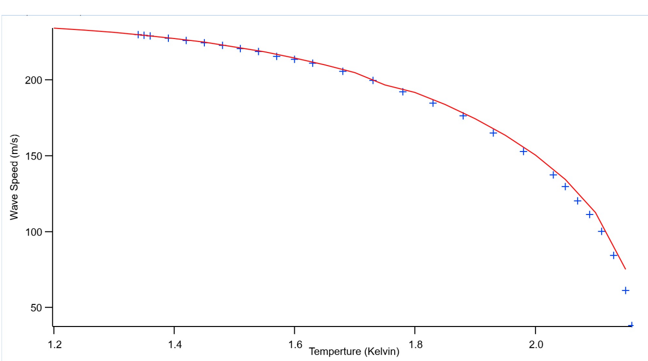

Figure 8: This is the sounds of the liquid helium versus temperature,Blue is 4th sound, red is the Theoretical.

Lastly after capturing the sound modes we make measurements of the Scattering and Porosity of the 4th channel. The relation was simple the scattering was found using the numbers $\frac{229.4}{182.8} = 1.26$ which came from the measured and expected 4th wave speed. To find the Porosity we again use the equations from the theory which then yielded an result of $P = -n^2 + 2 = .41$.After measuring the Porosity, we then moved onto to compute $\frac{p_s}{p}$ using equations 4 and 5, and we plotted it as a function of temperature below in figure 7.

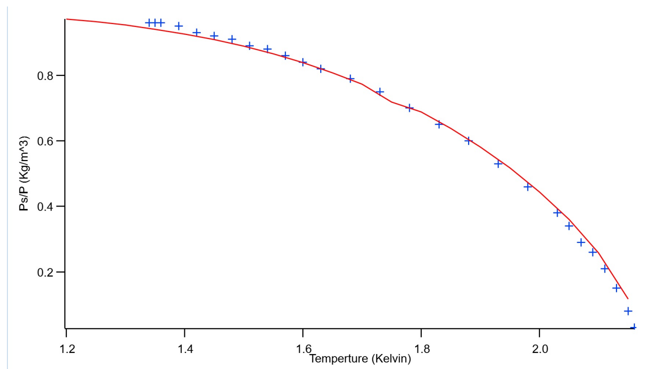

Figure 9: The figure shows the density relationship versus temperature .

The last effect we sought to capture in this experiment was the thermodynamic property of specific heat. The way we were able to achieve this was by using equations 6 and 7 which shows the 2nd sound having a relation to the entropy and temperature as well as the relation of $\frac{p_s}{p}$ we found in the previous graph. We show the specific heat against temperature in figure 9.

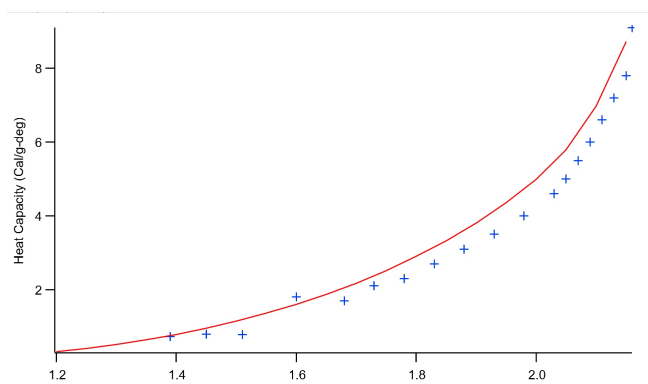

Figure 10: This is the specific heat against temperature, the blue dots are calculated values, the red is theoretical values.

V. ERROR ANALYSIS

Since we did no calculations major calculations in this experiment, and all our measurement came from the experiment itself and already known values, we are littered with error in all our measurements but only a single type of measurement. All our frequency measurements in our tables should have an error associated with them, this ranges is typically found with the points around it, and with our measuring devices we find that the error depending on the graph was either $\pm.5Hz$ or $\pm1Hz$, though we use 1 Hz since it will maximize our range of error. This then translates into our error in measuring the Sounds in the experiment, though the calculation is simple. All the sounds were typically calculated in the same way except sound 4 which has a ratio multiply it but has no error added so I will present the error following from equation 8 below. In equation 8 λ is the wavelength of the box given by 49.5 mm with an error of $\pm.2mm$, the other value f is the resonant frequency, which varies depending on the temperature and sound we measure, but had an error maximized of $\pm1Hz$. The error then translates to equation 9 where we take the derivative with respect to λ and f, which just yields the f or λ respectively. We then calculate following formula 9, an example given below equation 9 shows the result of .181.

$$C = \lambda * frequency \qquad [8]$$

$$\delta F = \sqrt{(\frac{dF}{dx})^2(\delta x)^2 + (\frac{dF}{dy})^2(\delta y)^2} \qquad [9]$$

$$\delta C = \sqrt{(\frac{dC}{df})^2(\delta f)^2 + (\frac{dC}{d\lambda})^2(\delta\lambda)^2}$$

$$\delta C = \sqrt{(655Hz)^2(.0005m)^2 + (.01m)^2(1Hz)^2} = .181\frac{m}{s}$$

This concludes the calculated error in the experiment, while there were other calculations they did not propagate error because they either utilized values we received from a book or just constants that are natural in the math.

VI. CONCLUSION

In this experiment we were faced with many challenges though we moved past them all by careful analysis and checking our results thoroughly. In our experiment we sought to observe the generation, of many different types of waves in super cooled helium. This meant we had to take into account all physical factors, which in this case, meant we had to make sure the helium was in a isolated and super cooled chamber and was working properly with its pressure measurements. We mainly interacted with the channels so which type of wave was inputted and the temperature, we sweep ed through a large range of frequencies to capture all the points of excitation and then analyzed them for the true modes. In the end what we can conclude is that acoustical waves in a chamber filled with liquid helium can show us the Thermodynamic properties of Liquid Helium, in our case we calculated the Super fluid density, which goes down as the temperature increases. Another property we could measure from the sound waves we generated was the heat capacity of the Super Fluid Helium which we show has an anomalous massive increase at a the 2.16 K point, not only does this show us how to interact with quantum properties using macroscopic properties. The data we observed followed theory and sources of error can come from the fact no system is perfect and the miscommunication by technologies values could have impacted our data. In the end our results were highly accurate and provide a thorough analysis of how Liquid Helium's properties can be accessed through acoustical methods.

Point	Pressure	Temp__k_	'1st_freq'	'Error Frequency'	'4th_freq'	'Error 4thFrequenc	'2nd_freq_at_n_4'	'Error 2ndFrequen	X2nd_freq_at_n_5	'Error 2ndFrequen
0	1.65	1.35	2389	±1	1865	±1	780	±1	975	±1
1	1.54	1.34	2390	±1	1868	±1		±1		±1
2	1.72	1.36	2388	±1	1861	±1		±1		±1
3	2.02	1.39	2386	±1	1849	±1	789	±1	980	±1
4	2.4	1.42	2385	±1	1837	±1		±1		±1
5	2.81	1.45	2383	±1	1824	±1	801	±1	1002	±1
6	3.26	1.48	2380	±1	1810	±1		±1		±1
7	3.78	1.51	2378	±1	1793	±1	801	±1	1014	±1
8	4.35	1.54	2375	±1	1776	±1		±1		±1
9	4.99	1.57	2371	±1	1751	±1		±1		±1
10	5.69	1.6	2369	±1	1735	±1	821	±1	1026	±1
11	6.47	1.63	2365	±1	1714	±1		±1		±1
12	7.93	1.68	2357	±1	1671	±1	822	±1	1028	±1
13	9.64	1.73	2350	±1	1623	±1	819	±1	1012	±1
14	11.6	1.78	2341	±1	1562	±1	809	±1	1001	±1
15	13.84	1.83	2331	±1	1501	±1	793	±1	991	±1
16	16.38	1.88	2319	±1	1433	±1	771	±1	963	±1
17	19.22	1.93	2306	±1	1341	±1	740	±1	925	±1
18	22.4	1.98	2291	±1	1242	±1	695	±1	869	±1
19	25.92	2.03	2274	±1	1117	±1	638	±1	796	±1
20	27.42	2.05	2265	±1	1054	±1	604	±1	756	±1
21	28.98	2.07	2257	±1	978	±1	571	±1	712	±1
22	30.6	2.09	2247	±1	905	±1	528	±1	655	±1
23	32.27	2.11	2237	±1	815	±1	479	±1	599	±1
24	34	2.13	2229	±1	685	±1	419	±1	516	±1
25	35.78	2.15	2217	±1	497	±1	360	±1	410	±1
26	36.69	2.16	2209	±1	310	±1	260	±1	326	±1

VII. TABLES

Table 1: This chart shows the frequencies captured in our experiment as well as the respective temperature and pressure of the system.

Table 2: This chart shows the frequencies captured in our experiment as well as the respective temperature and pressure of the system.

Point	Temp__k	C1	'Error C1'	C4	'Error C4'	C2__4th_	'Error C2 4th'	C2__5th_	'Error C2 5th'	Ps_P	Cp
0	1.35	234.1	±0.5	229.4	±0.4	19.1	±0.2	19.1	±0.2	0.96	
1	1.34	234.2	±0.5	229.8	±0.4	0		0		0.96	
2	1.36	234	±0.5	228.9	±0.4	0		0		0.96	
3	1.39	233.8	±0.5	227.4	±0.4	19.3	±0.2	19.2	±0.2	0.95	0.73
4	1.42	233.7	±0.5	225.9	±0.4	0		0		0.93	
5	1.45	233.5	±0.5	224.4	±0.4	19.6	±0.2	19.6	±0.2	0.92	0.79
6	1.48	233.2	±0.5	222.6	±0.4	0		0		0.91	
7	1.51	233	±0.5	220.5	±0.4	19.6	±0.2	19.9	±0.2	0.89	0.78
8	1.54	232.8	±0.5	218.5	±0.4	0		0		0.88	
9	1.57	232.4	±0.5	215.4	±0.4	0		0		0.86	
10	1.6	232.2	±0.5	213.4	±0.3	20.1	±0.2	20.1	±0.2	0.84	1.8
11	1.63	231.8	±0.5	210.8	±0.3	0		0		0.82	
12	1.68	231	±0.5	205.5	±0.3	20.1	±0.2	20.1	±0.2	0.79	1.7
13	1.73	230	±0.5	199.6	±0.3	20.1	±0.2	19.8	±0.2	0.75	2.1
14	1.78	229.4	±0.5	192.1	±0.3	19.8	±0.2	19.6	±0.2	0.7	2.3
15	1.83	228.4	±0.5	184.6	±0.3	19.4	±0.2	19.4	±0.2	0.65	2.7
16	1.88	227.3	±0.5	176.3	±0.3	18.9	±0.2	18.9	±0.2	0.6	3.1
17	1.93	226	±0.5	164.9	±0.3	18.1	±0.1	18.1	±0.2	0.53	3.5
18	1.98	224.5	±0.5	152.8	±0.2	17	±0.1	17	±0.2	0.46	4
19	2.03	222.9	±0.5	137.4	±0.2	15.6	±0.1	15.6	±0.2	0.38	5.9
20	2.05	221.9	±0.5	129.6	±0.2	14.8	±0.1	14.8	±0.2	0.34	5.7
21	2.07	221.2	±0.5	120.3	±0.2	13.9	±0.1	13.9	±0.1	0.29	5.2
22	2.09	220.2	±0.4	111.3	±0.2	12.9	±0.1	12.8	±0.1	0.26	6.5
23	2.11	219.2	±0.4	100.2	±0.2	11.7	±0.1	11.7	±0.1	0.21	6.4
24	2.13	218.4	±0.4	84.3	±0.1	10.3	±0.1	10.1	±0.1	0.15	6.5
25	2.15	217.3	±0.4	61.1	±0.1	8.8	±0.1	8	±0.1	0.08	8.5
26	2.16	216.5	±0.4	38.1	±0.1	6.4	±0.1	6.4	±0.1	0.03	9.1