Lab 1 - Temperature and Gas

Simen Løken
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In this article, we aim to answer questions regarding temperature, gasses and frequencies and their relation with each other. In addition to this, we dabble a bit in Modular Dynamics and find results relating to our experiments to better gauge gas on a micro-level as opposed to the macro we're doing in the lab. We'll see that oxygen is an ideal gas and behaves similarly with the noble gases at higher temperature and the relation between resonant frequencies and speeds of sound.

I. INTRODUCTION

In thermodynamics, one of the most important facets are gas. It's all around us, we can't see it, but it's there. In this exercise we're going to be looking at gas in isolated environments to better study how they interact with central concepts of thermodynamics like heat and movement. Additionally we're going to be looking at molecules on the microscopic level to better understand what's happening "behind the scenes A central equation in this lab will be the relation between a length of tubing and it's resonant frequency, given by:

$$\lambda_n = \frac{c}{2L} \tag{1}$$

In addition, we'll need this equation for our certainty-evaluation:

$$\Delta Z = Z\sqrt{(\frac{\Delta Z_1}{Z_1})^2 + ... + (\frac{\Delta Z_n}{Z_n})^2} \tag{2}$$

where λ is a resonant frequency, c is the speed of sound and L is the length of the tubing.
To measure the temperature of the tubes we used the following equations

$$T_C(r) = 25 - 24lnr \tag{3}$$

where r = $\frac{R_t}{10^5\Omega}$ and R_t is the resistance of the resistor in the tube.

II. RESULTS AND DISCUSSION

First of all we had four tubes, K1 through K4, with the measurements:

Tube	L [mm]	$\delta L [mm]$
K1	1243	±1.5
K2	1243	±1.5
K3	1244	±1.5
K4	1244	±1.5

TABLE I. Lengths of the tubes K1 through K4

The temperatures are 25°in K1 and K2, while K4 and K3 have 50°and 70°respectively, all Celsius.

We measured the resonant frequencies to be:

	K2	K4	K3	K1 Argon	K1 CO_2
Res.freq [Hz]	285.5	314.1	311.2	269.8	233.8
	417.8	451.3	465.8	389.2	336.9
	561.4	594.0	616.9	524.6	442.3
	682.7	738.6	769.4	650.0	561.1
	836.9	883.3	921.9	777.8	670.2
	975.6	1028.5	1074.9	904.7	780.9
	1114.8	1174.1	1229.1	1033.1	891.7
	1254.0	1320.7	1382.8	1161.1	1002.4
	1393.3	1466.7	1536.5	1292.0	1113.4
	1532.2	1612.9	1690.0	1420.3	1225.4
	1671.5	1759.2	1843.6	1548.4	1336.4
	1810.4	1905.7	1998.3	1667.8	1447.6
	1949.9	2051.8		1806.9	1559.0
				1935.8	1670.7
					1782.3
					1894.7
					2006.2

TABLE II. Resonant Frequencies in tube K1 through K4

We assume an uncertainty of $\pm 0.5 Hz$ for each frequency Now we're going to derive a way to convert these frequencies into speed of sound. Let's take a look at Eq [1]. We know that a resonant frequency is equal to the speed of sound divided by the length of the tubing, for accuracy's sake, we find the difference between each measurement and create a best fit line. This line will be the slope of the resonant frequencies, which we can use to find the speed of sound.

We run our data through our script and find the following slopes.

unit=Hz	K2	K4	K3	K1 Argon	K1 CO_2
a	139.17	145.28	153.3	128.20	111.13
Δa	0.36	0.26	0.11	0.23	0.14

TABLE III. Slope for fit resonant frequencies line

We can now insert these into Eq.[1] and find the speeds of sound given a gas and temperature, but first we need to calculate our new uncertainty using Eq.[2]. We estimate

unit=m/s	K2	K4	K3	K1 Argon	K1 CO_2
v	345.98	361.46	381.40	318.71	276.26
Δv	0.98	0.78	0.53	0.69	0.48

TABLE IV. Slope for fit resonant frequencies line

the uncertainties of the temperature to be around 0.5°C Let's now compare some ideal gases to our oxygen gas. We know that since noble gases are ideal, they have a adiabatic constant $\gamma = \frac{5}{3}$ which means we can calculate their speeds easily with:

$$v_s = \sqrt{\frac{\gamma RT}{M}} \tag{4}$$

We then get the following plot:

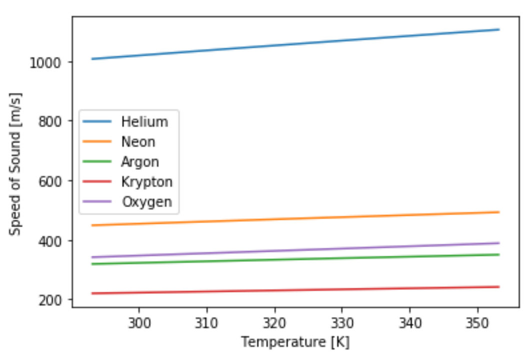

FIG. 1. Noble gases vs. oxygen

We can conclude that oxygen does behave like an ideal gas at higher temperatures.

III. METHODS

For equipment, we've used four tubes of about $1.25m$. Tube 2 through 4 contains oxygen while tube 1 contained both Argon and Carbon Dioxide. The oxygen tubes had different temperatures while the Argon/Carbon tube had room temperature. Through these tubes we transmitted a frequency which, at the right frequency (see Eq.[1]), had resonance. Using this we could use an oscilloscope and record our data which we could later run though a script to get the velocity of the sound transmitting through the gas, which was the goal of the exercise.
We've also used the MD-program LAMMPS and OVITO for viewing.

IV. CONCLUSION

In conclusion, we've shown the tightly knit relationship between speeds, sound and temperature, and have worked extensively on gases as part of this. In the work we've done we've shown that oxygen behaves like an ideal gas (on a macroscopic level, at least), and that can it can be used to model the relationship between temperature and speeds of sound.

Appendix A: Requested problems

1. Problems in the lab text

- 3.1
  One-atomic gases have three degrees of freedom
  Two-atomic gases have five or seven degrees of freedom
  Tri-atomic gases have six or seven degrees of freedom
- 3.2
  Oxygen has 5 degrees of freedom
  Hydrogen has 5 degrees of freedom
  Water has 7 degrees of freedom at lower temperatures
  Carbon Dioxide has 6 degrees of freedom
  Ammonia has 6 degrees of freedom
  The noble gasses all have 3 degrees of freedom

2. Problems in the molecular dynamics text

- 1
  We know that

  $$C_p - C_v = \frac{\delta(U + nRT)}{\delta T} - \frac{\delta U}{\delta T} = nR$$

  for an ideal gas.
- 2
  We know that

  $$C_V = \frac{\delta E}{\delta T}$$

  where E is total energy and T is temperature
  From there we can calculate the mean value of E over T with uncertanties and we find that

  $$C_V = 0.67 \pm 0.00093$$
- 4
  We find from a script that a small part of the velocity array has an RMS of:

  $$v_{rms} = 1.22m/s$$

  From there we can use the equation

  $$v_{rms} = \sqrt{\frac{3RT}{M}}$$

  where M is the molar mass and R is the gas constant
  Solve for T and we find that $T = 417.72K$ or 24 °C. This is pretty far off from what our program tells us, but we get a pretty large standard deviation (and error) when calculating the RMS of v from the data, $\Delta v = 0.44$ which means $\Delta T = 54.33K$, although still not correct, even with the certainty taken into account, we're atleast closer. We can then derive that since the volume is constant the pressure must be directly proportional to the temperature we just found, and we solve as such:

  $$P = \frac{nRT}{V}$$

  and find that $P = 4.3 \times 10^{-18}$
- 5
  Yes, C_V changes with temperature
- 6
  I'm going to assume yes but I can't check because I don't have the time.
- 7
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- 8
  –
- 9
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