LEBANESE UNIVERSITY
Faculty of Sciences II

SCIENTIFIC REPORT

Optics/Thermo Lab P3303

Experiment 2 B: DETERMINATION OF THE SPECIFIC HEAT RATIO

By

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I- Abstract

This experiment will go over a mechanical analogy in order to determine the specific heat ratio γ. Experimental measurements include: measuring the mass of a ball, the diameter of the ball to find the cross-section of the tube where the ball is placed in to oscillate, and different times at which the ball completes 5 oscillations to eventually find γ. This experiment also includes the measurement of uncertainties to eventually find a range where the true value of the specific heat ratio lies in. At the end, results of the experiment will be studied in order to see whether the the final goal of the experiment was achieved and what can be concluded from these results

Key words: *error*, *specific heat*, *pressure*, *volume*

II- Introduction

In part **B** of *experiment 2*, also know as **Rüchardt's method**, the aim is to find the specific heat ratio, symbolized by γ:

$$\gamma = \frac{C_p}{C_v} \tag{1}$$

Where C_p is the specific heat at **constant pressure** and C_v is the specific heat at **constant volume**, which both represent the amount of heat required ber unit mass to raise the temperature by $1K$(or $1°C$). The values of the specific heat at constant pressure and volume changes with temperature as well as how many atoms a molecule is made of, that is if it's a monoatomic or polyatomic gas for example. Theoretically, in this case, *newton's second law* and knowing the fact that the transformation is adiabatic and reversible, a second-order ODE is found to be:

$$\frac{d^2x}{dt^2} = -\frac{\gamma P A^2}{mV} x \tag{2}$$

Where m is the mass of the ball, P is the pressure, A is the cross-section of the tube, V is the volume of the ball and x is the distance traveled by the ball. This is just the equation of simple harmonic motion so:

$$T = 2\pi\sqrt{\frac{mV}{PA^2}} = \frac{2\pi}{\omega} \tag{3}$$

Where $\omega^2 = \frac{\gamma P A^2}{mV}$ so:

$$\boxed{\gamma = \frac{4\pi^2 mV}{A^2 P T^2}} \tag{4}$$

The following diagram emphasizes the objective of this experiment:

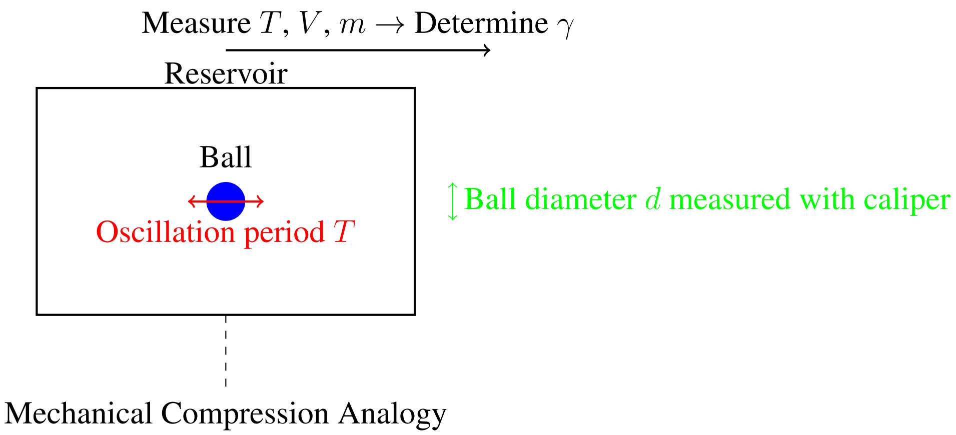

Diagram I: Diagram of Rüchardt's experiment

III- Procedure

The steps of the experiment are as follows

1. Measure the mass of the ball, using a balance, as precisely as possible to maximize the precision of the results.

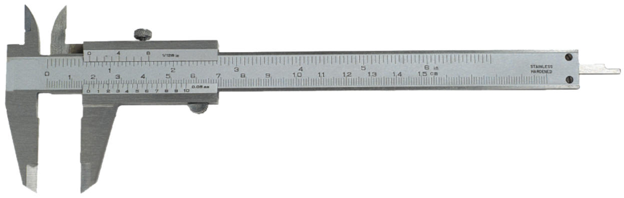

Photo I: Vernier caliper [1]

2. Clean the tube thoroughly.
3. Open the tap of the reservoir and introduce the blocked tube(with a finger) with the ball into it.
4. Close the tap and start the experiment and measure the number of oscillations of the ball while using a timer to record the time needed for 5 oscillation(in this experiment's case).
5. Repeat the experiment 9 more times times while recording its mean value in order to be used in the calculations.

Make sure to measure the diameter of the ball(which gives us the diameter of the tube in our case) using a vernier caliper(while accounting the reading error) in order to calculate the values of the cross-section and volume of the enclosed air. Some useful values will be placed in the following table:

Table I: Measured or Given Values

Area (mm^2)	**Volume (l)**	**Approximate Pressure (kPa)**	**Gravity (m/s^2)**	**Mass (g)**
203.58	10	100.8	9.81	16.6

Please note that the measured values(Area, mass and pressure from weight of the ball) are *approximate* values that were measured/derived from measure values. In addition, the values of time of 5 oscillations of the balls are as follows:

Table II: Measured Time for 5 Oscillations of a Ball (10 Trials)

Trial	1	2	3	4	5	6	7	8	9	10
Time for 5 Oscillations (s)	4.59	4.71	5.06	5.19	5.26	5.19	5.09	5.24	5.01	5.28

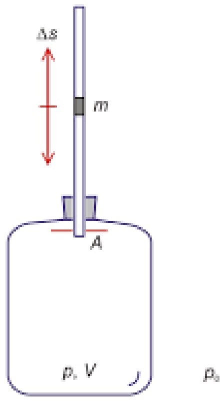

Photo II: Ball oscillating in the tube [2]

IV- Results and Analysis

In order to calculate the value of γ, the period of oscillations **T** must be found by using the **Mean** value of all the recorded times. While referring to the *appendix*, the mean value $\bar{t} = 5.06$s and n=5(number of oscillations) gives a period of oscillation of:

$$\bar{T} = \frac{\bar{t}}{n} = 1.01s \tag{5}$$

Now, as the all data is present, **Equation 4** can be used to get a value of $\gamma = 1.54$. Despite

getting the fianl value, this is not enough as the uncertainties must found in order to account for the errors. The following table includes these uncertainties:

Table III: Measured Mass, Radius, and Area with Uncertainties

Δm	**Mass (g)**	Δr	**Radius (mm)**	ΔA	**Area (mm^2)**
0.05	16.60 ± 0.05	0.01	8.05 ± 0.01	0.51	203.58 ± 0.51

Table IV: Measured Pressure and Period with Uncertainties

ΔP	**Pressure (kPa)**	$\Delta\bar{T}$	σ	**Period (s)**
0.004	100.8 ± 0.004	0.07	0.22	1.01 ± 0.07

$$\Delta P = \frac{g\Delta m}{A} + \frac{mg\Delta A}{A^2} \tag{6}$$

Equation 6 is from the absolute error formula(or just using natural logarithm, deriving and taking absolute values). σ is the standard deviation and $\Delta\bar{T}$ is the *standard error*. One can also take the square root of **Equation 6** and squaring each term alone to get the **Propagation error** to be 3.12 **Pa**(not kPa)(Refer to APPENDIX).

Now to compute $\Delta\gamma$:

$$\Delta\gamma = \gamma\left(\frac{\Delta m}{m} + \frac{\Delta P}{P} + 2\frac{\Delta A}{A} + 2\frac{\Delta\bar{T}}{\bar{T}}\right) \tag{7}$$

After computing $\Delta\gamma$ to be 0.22, the final result of the experiment is

$$\boxed{\gamma = 1.53 \pm 0.22}$$

(which is dimensionless because it is a ratio of two specific heats). Furthermore, as shown in **Equation 6**, the propagation error is 0.21, which is nearly the same as $\Delta\gamma$.

V- Conclusion

This experiment successfully helped determine the *specific heat* ratio along with its appropriate error analysis. Although, it was impossible to get an exact value of γ because of **random**

errors like environmental temperature fluctuations, slight damping of oscillations in the tube and friction inside the tube. In addition, **reading errors** from the caliper(specified on it) and the balance which will also affect the values of the area and pressure. Another obscure detail, is the timer used to give the time which will also be a bit different from the actual value due to human error and device itself.

VI- Appendix

$$P = P_0 + \frac{mg}{A} \tag{8}$$

Pressure Equation.

$$A = \pi r^2 \tag{9}$$

Area of the cross-section(same as the ball).

$$\bar{t} = \frac{1}{N}\sum_{i=1}^{N} t_i \tag{10}$$

Mean value where N is the total number of trials.

$$\Delta X = \sqrt{(\frac{\partial X}{\partial x}\Delta x)^2 + (\frac{\partial X}{\partial y}\Delta y)^2 + (\frac{\partial X}{\partial z}\Delta z)^2} \tag{11}$$

Where ΔX is the propagation error.

$$\Delta \bar{T} = \frac{\sigma}{\sqrt{N}} \tag{12}$$

Standard Error formula

$$\Delta A = 2\pi r \Delta r \tag{13}$$

Uncertainty of the Area

VII- References

[1] analog-vernier-calipers-depth-vernier-calipers-micrometers-marking-devices.html
[2] https://www.3bscientific.com/product-manual/UE2040200_EN.pdf