

# Thermal Physics PHY474 Lab #4 Experiment

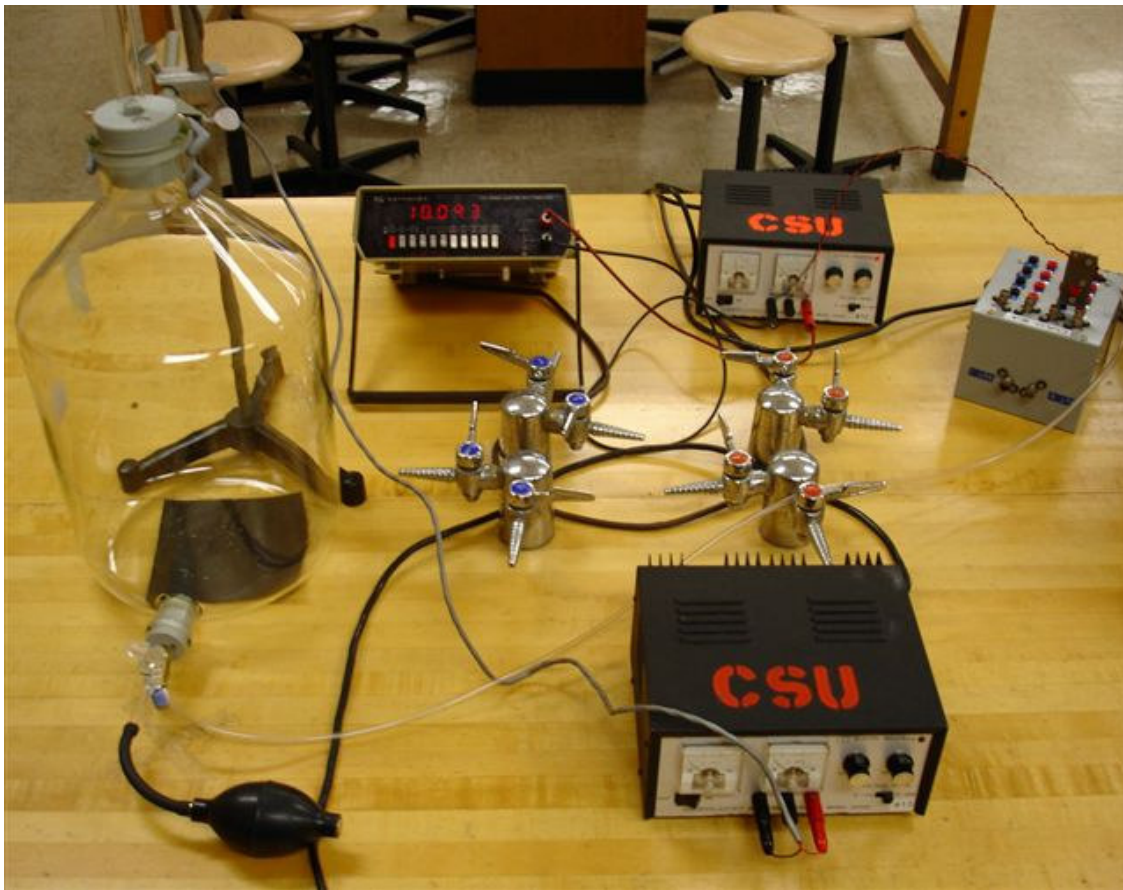
## Ruchardt Method for Measuring $C_p/C_V$

### I. OBJECTIVE

In this experiment we determine the ratio of specific heats  $C_p/C_V$  using the Ruchardt method. The ratio of the isobaric to isochoric heat capacity is solely determined by the type of gas molecule: monatomic, diatomic, or polyatomic. The Ruchardt method involves a mechanical measurement to determine  $C_p/C_V$  and implicitly the microscopic chemistry of the gas.

### II. MATERIALS

Absolute pressure sensor with 2 feet of thin rubber tubing, banana-banana plug wire (2qty), computer with “Waveforms” program and “474 Cp/Cv TEMPLATE” file, data acquisition system, digital multimeter, electromagnet with holding clamp, Electro Industries power supply (2qty), 10 Liter aspirator with small rubber mat at base, large rubber stopper with hole, small rubber stopper with hole and tap, rubber bulb air pump with thin rubber tubing, glass 1/4 turn valve, large rod and base with 3 cushioned holding 3 prong clamps, precision glass tube, triple beam balance, small steel ball that fits perfectly inside the glass tube, rubber bulb air pump, vernier calipers, glass cleaner, long thin bristle brush, and a tissue for cleaning.



(a) Main Experimental Set-up



**(b) Precision Tube with Electromagnet**

### III EXPERIMENTAL PROCEDURE

**1. Preparation:** The apparatus has already been cleaned and assembled for you. Be careful not to alter anything. If you encounter any problems such as: (1) the ball does not oscillate freely inside the glass tube or if it bounces off the bottom staple during oscillations (2) you do not obtain a smooth sinusoidal waveform even though it looks like it is oscillating properly, please ask your instructor for help and follow the steps below.

**a.** Make sure that the precision glass tube is perfectly vertical and free of dust. You can determine this by observation of the tube and, after running the experiment, observation of the waveform. You can clean the tube using the long bottle brush with a glass cleaner and a tissue wrapped around the bristles. Run the brush through the tube until clean and dry.

**b.** Make sure that you do not have any air leakage. Leakage is apparent when the metal ball does not oscillate freely in the center of the glass tube but falls quickly and bounces off the staple at the bottom of the glass tube. (1) First, make sure that the electromagnet is set to release the ball from the point where the center of mass of the ball is centered at the tip of the glass tube. If you are too high, you will not have a proper seal. (2) Secondly, ensure that the large rubber stopper at the top and the small rubber stopper at the bottom of the aspirator are fully seated and sealed by carefully pushing the rubber stoppers firmly in place. Be careful not to alter the alignment or damage the precision glass tube. If this does not work and you still have leakage, remove the rubber stoppers and clean both the rubber and glass surfaces with a glass cleaner to ensure a smooth tight seal.

**2. Measurements:**

**a.** Measure and record the mass of the steel ball using the balance. Make sure the ball is clean before re-inserting it into the glass tube.

**b.** Measure and record the volume of the aspirator.

**c.** Measure and record the volume of the precision glass tube. The inside diameter of the tube should be the same as the diameter of the steel ball.

**3. Settings:**

**a.** Begin with standard air which is mostly composed of diatomic Nitrogen, N<sub>2</sub>.

**b.** Connect the pressure sensor to channel 0 or channel 1 of the data acquisition system (DAS). Make sure your polarity is correct or you will end up with negative pressure readings.

**c.** Open the "Waveforms" program located on the desktop of your computer. Select the channel you are using and set the number of points to 200. Set the sample period to 0.05 seconds and the sample averaging to 5000. You do not need to enter a value for the scan interval since we are only using one channel.

**d.** Set the power supply for the sensor to 10.0 Volts and keep it here for the duration of the experiment. Use the digital multimeter to measure this voltage since this is more accurate than the scale on the power supply. Do not exceed 10 Volts or you will damage the sensor.

**e.** Turn on the power supply for the electromagnet. Set it to 15 Volts and 0.5 Amps. Open the air valve. Use the plastic bulb to pump air into the aspirator and **gently** raise the metal ball to the electromagnet which will catch and hold the ball. Once the ball is raised close the valve.

**f.** Open the Mathcad file "474 CpCv TEMPLATE" located on the desktop of your computer.

**4. Run the experiment:**

- a. Release the ball from the electromagnet by turning off the power supply. Once the ball drops immediately select “Run” from the “Waveforms” program.
- b. The run should take 10 seconds. The DAS is finished collecting data when the “Run” statement returns to bold.
- c. Select the statement “data:= READPRN(“c:\Documents and Settings\temp.prn”)” on the template and then select “Calculate” which can be found at the top of the Mathcad worksheet with the symbol “=” in order to retrieve the data you just collected.
- d. You should observe a waveform consisting of smooth damped oscillations. Damping is due to the unavoidable losses of energy by friction. If you do not, check your set-up and run the experiment again. Once you have obtained a suitable waveform, embed your data following the steps given on the template.

**IV. DATA ANALYSIS**

- 1. Follow the analysis on the template to obtain the ratio Cp/Cv.
- 2. Repeat the experiment and data analysis 3-5 times. Record all the values of  $\gamma$ . Get a mean and standard deviation.
- 3. Compare your value of Cp/Cv with the theoretical value for air.

**V. REPORT**

You report should include: theory, data collection and analysis, explanation of discrepancy between theory and experiment, literature search using authoritative, current, and reliable information sources.

data := READPRN("c:\Documents and Settings\temp.prn")

**Embed Your Data Here----->**

NP := data<sub>1</sub> = 200

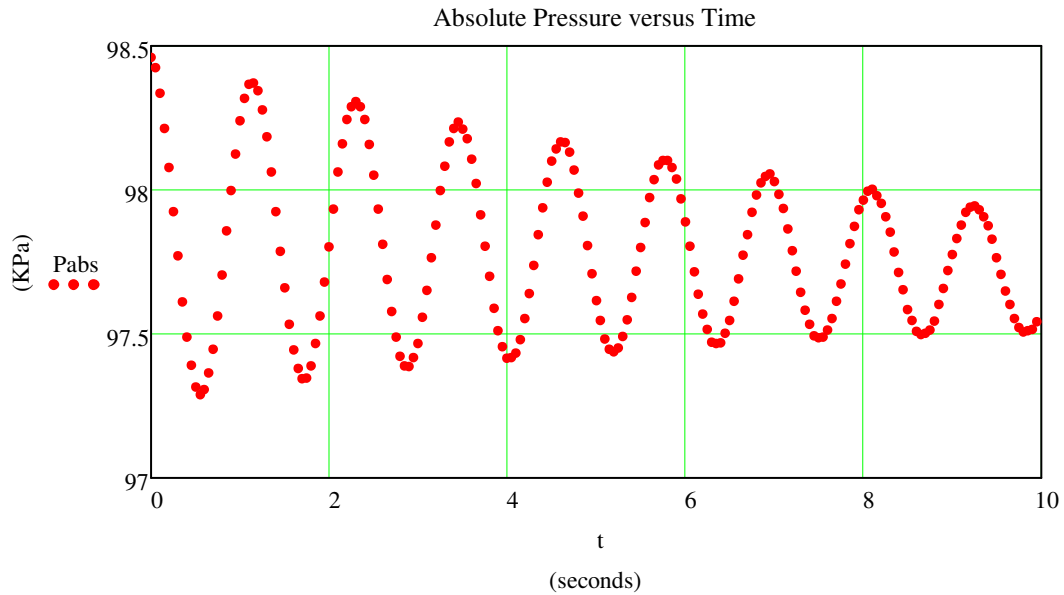
data :=

	0
0	1
1	200
2	5·10 <sup>-6</sup>
3	0.05
4	0
5	0.05
6	0.1
7	0.15

t := submatrix(data, 4, NP + 3, 0, 0)

Pabs := submatrix(data, NP + 4, 2·NP + 3, 0, 0)·2500

$\overrightarrow{Pabs} := |Pabs|$



Your waveform data should have the appearance of a damped sinusoidal oscillation. You can characterize your data with the following parameters.

- $a := 0.6$  Initial amplitude of damped pressure oscillation in KPa.
- $\tau := 10$  Time in seconds for amplitude of damped pressure oscillation to fall by the factor  $1/e = 0.37$ .
- $T := 1.15$  Period of damped oscillation in seconds.
- $\theta := 0$  Phase constant of sinusoid oscillation in radians.
- $b := 97.9$  The final equilibrium gauge pressure after the oscillation decays.
- $c := -0.01$  Slope of average absolute pressure

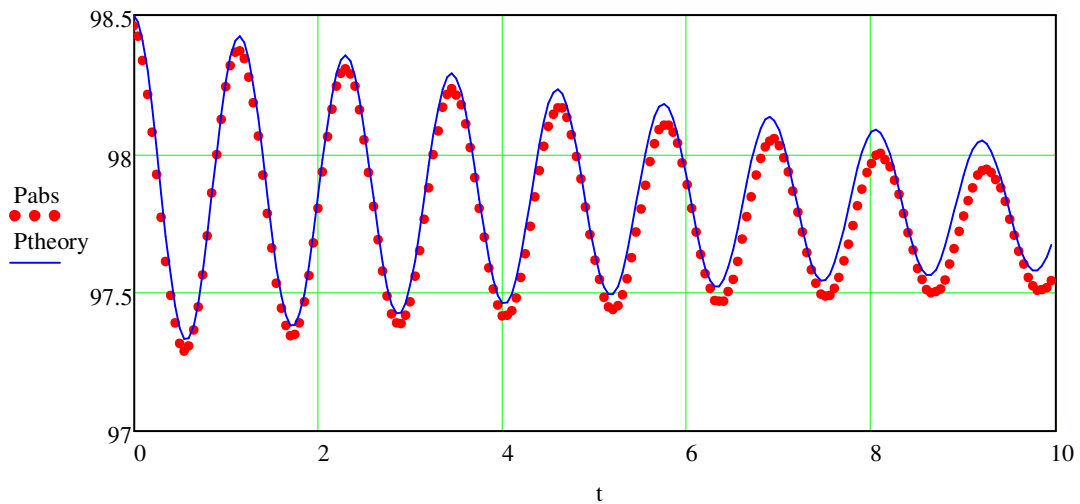
With these parameters the following function can be used to fit your data

$$P(t, a, \tau, T, \theta, b, c) := a \cdot e^{\frac{-t}{\tau}} \cdot \cos\left(\frac{2 \cdot \pi}{T} \cdot t + \theta\right) + b + c \cdot t$$

What is the physical significance of the  $c \cdot t$  term in the fitting formula for pressure?

$$\text{guess} := \begin{pmatrix} a \\ \tau \\ T \\ \theta \\ b \\ c \end{pmatrix}$$

$\xrightarrow{\hspace{2cm}}$   
 $P_{\text{theory}} := P(t, a, \tau, T, \theta, b, c)$  <---- Vectorize to make Ptheory a vector at the times of the vector t.

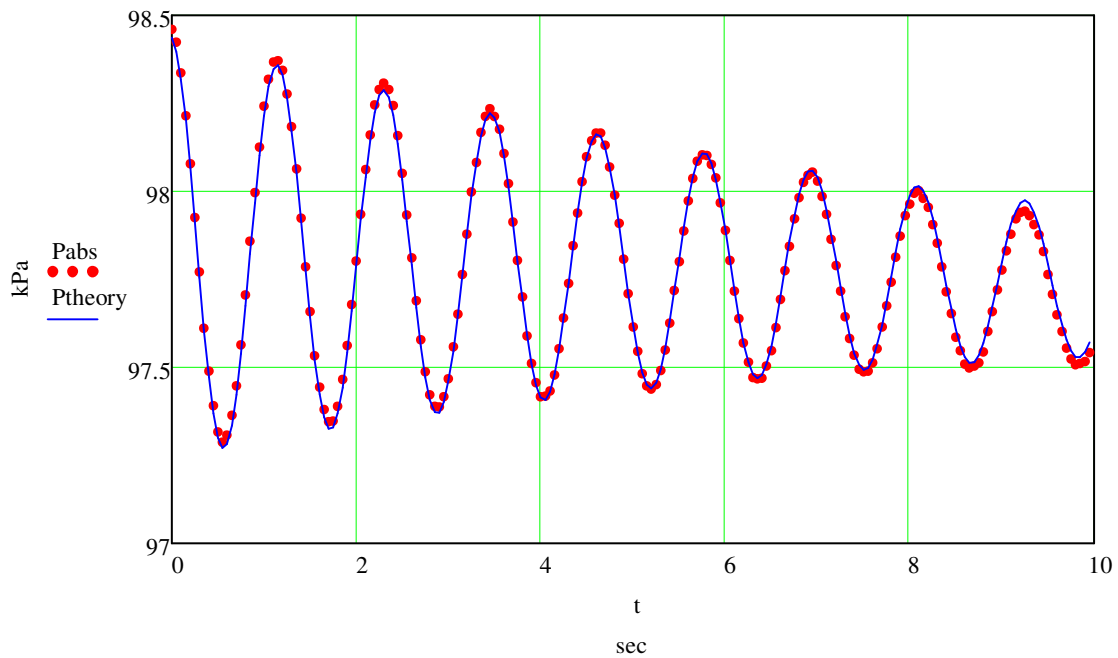


Use the nonlinear fitting program: genfit. You need to have a set of guesses for the six parameters.

$$\begin{pmatrix} a \\ \tau \\ T \\ \theta \\ b \\ c \end{pmatrix} := \text{genfit}(t, \text{Pabs}, \text{guess}, P)$$

$$\begin{pmatrix} a \\ \tau \\ T \\ \theta \\ b \\ c \end{pmatrix} = \begin{pmatrix} 0.598 \\ 9.567 \\ 1.158 \\ 0.084 \\ 97.84 \\ -0.01 \end{pmatrix}$$

$$\text{Ptheory} := P(t, a, \tau, T, \theta, b, c)$$



$$m := 0.0167 \text{ kg} \quad d := 0.016 \text{ m} \quad A := \frac{\pi}{4} \cdot d^2 \quad A = 2.011 \times 10^{-4} \text{ m}^2$$

$$V := 10.9 \cdot 10^{-3} + 0.3 \cdot A \quad V = 0.011 \text{ m}^3$$

$$P_{eq} := b \cdot 1000 \quad P_{eq} = 9.784 \times 10^4 \text{ Pa} \quad \text{Compare this to the atmospheric pressure reading from a barometer.}$$

$$\omega d := \frac{2 \cdot \pi}{T} \quad \omega d = 5.4 \frac{r}{s}$$

$$\beta := \frac{1}{\tau} \quad \beta = 0.1 \frac{r}{s}$$

$$\omega := \sqrt{\omega d^2 + \beta^2} \quad \omega = 5.425 \quad \frac{r}{s}$$

$$\gamma := \frac{m \cdot V \cdot \omega^2}{P_{eq} \cdot A^2} \quad \gamma = 1.362$$