Computer based laboratory: Ruchhardt's method for measuring the ratio of specific heats for air

Laboratorio basado en computador: el método Ruchhardt para medir la proporción de calores específicos para el aire

D. Amrani

Physics Laboratory, Service des Enseignements Généraux, École de Technologie Supérieure, University of Quebec; 1111, Rue Notre-Dame Ouest, Montreal (QC) H3C 1K3, Canada.
Tel.: (514) 396 8583, Fax: (514) 396 8513, damrani@seg.etsmtl.ca, Djilali.Amrani@etsmtl.ca

Abstract

A Microcomputer Based Laboratory (MBL) experiment is presented which measures the ratio of specific heats of air, $\gamma = C_p/C_v$, using Ruchhardt's method and low pressure sensor to record the oscillations of damped pressure. The obtained experimental value of γ was 1.41±0.03. The error between the experimental and accepted value of γ was approximately 1%. The details of the experimental procedure are described and the results are reported.

Key words*: microcomputer based laboratory, Ruchhardt's method, ratio of specific heats for air, oscillations*

Resumen

Se presenta un experimento de laboratorio computarizado que mide el cociente del calor específico del aire, $\gamma = C_p/C_v$, usando el método de Ruchhardt y el sensor de la presión baja para registrar las oscilaciones. El valor experimental obtenido de γ era 1.41±0.03. El error entre el valor experimental y aceptado de γ era aproximadamente 1%. Los detalles del procedimiento experimental se describen y se divulgan los resultados.

Palabras clave: *laboratorio computarizado de física, método de Ruchhardt, cociente del calor específico para el aire, oscilaciones.*

INTRODUCTION

The amelioration of the experimental results in science education and technology are due to the increasing development and research in computer interfaces, data logging software and accessories designed for undergraduate teaching experiments. Students are able to perform hands-on experiments easily in reasonably short time compared to traditional experiments which are not using data acquisition system analysis.

Several experimental investigations of measuring the ratio of specific heats (γ) of gases have been reported in literature using Ruchhardt's method

(GIACOMO TORZA, *et al*., 2001; G. MILLER, 1986). In this paper, we describe a commercially available setup which illustrates the Rucchardt's and can easily be used by teachers and students to perform data measurements of pressure oscillations as a function of time, for different heights of the cylinder, in order to determine the average oscillating periods.

A graduated cylinder is filled with air and a pressure sensor (Pasco Scientific, 2003) is attached. The piston is plucked by hand and allowed to oscillate. The oscillating pressure is recorded as a function of time and the period is determined. The ratio of specific heat capacities is calculated using the period of oscillations.

This experiment is implemented in our physics laboratory and the details of the procedures are described in the section Experimental Setup. The simplicity of performing this MBL activity and the good results compared to the accepted value of the gamma of air lead us to recommend it also for other student laboratories.

THEORY

In Ruchhardt's method (ANN HANKS, 2004), a cylinder of gas is compressed adiabatically by plucking the piston. The piston will then oscillate about equilibrium position. The ratio of specific heats can be determined by measuring the period of oscillation. If the piston is displaced downward a distance x, there will be a restoring force which forces the piston back toward the equilibrium position.

Just like a mass on a spring, the piston will oscillate. The piston acts as the mass and the air acts as the spring. The period of oscillation of a mass on a spring (or for the piston and air) is

$$T = 2\pi\sqrt{\frac{m}{K}} \tag{1}$$

To determine the spring constant, **k**, for air, calculate the force between the piston is displaced a distance x. When the piston is displaced downward a distance x, the volume decreases by a very small amount compared to the total volume: dV = xA, where A is the cross-sectional area of the piston.

The resulting force on the piston is given by F = (dP) A, where dP is the small change in pressure. To find a relationship between dP and dV, we assume that if the oscillations are small and rapid, no heat is gained or lost by the gas. Thus the process is adiabatic and PV^{γ} = constant (2)

Where

$$\gamma = \frac{C_P}{C_V} = \text{ Ratio of Molar Specific Heats} \tag{3}$$

For a diatomic gas, C_V = 5/2 R and C_p = 7/2 R, so γ = 7/5.

Taking a derivative of equation (2) gives

$$P\gamma V^{\gamma-1}dV + V^{\gamma}dP = 0 \tag{4}$$

Solving for dP, $$dP = -\frac{P\gamma V^{\gamma-1}}{V^{\gamma}}dV \tag{5}$$

Since dV = xA, $$dP = -\frac{\gamma PxA}{V} \tag{6}$$

Plugging into F = (dP) A gives

$$F = -\left(\frac{\gamma PA^2}{V}\right)x \tag{7}$$

Comparing this to F = - kx shows that

$$k = \left(\frac{\gamma PA^2}{V}\right) \tag{8}$$

Substituting into the period equation for k gives

$$T = 2\pi\sqrt{\frac{mV}{\gamma PA^2}} \tag{9}$$

Solving for the volume gives. $V = \frac{\gamma A^2 PT^2}{4\pi^2 m}$ The total volume is A(h +h_0), where h is the height measured on the labelled scale and h_0 is the unknown height below zero on the label. Substituting in for the volume and solving for the height of the piston, h, gives

$$h = \left(\frac{\gamma AP}{4\pi^2 m}\right)T^2 - h_0 \; 4 \tag{10}$$

Thus, if the piston height is plotted versus the square of the period, the resulting graph will be a straight line with *slope* = $\left(\frac{\gamma AP}{4\pi^2 m}\right)$ and y-intercept h_0.

Therefore the ratio of specific heats is given by

$$\gamma = \frac{4\pi^2 m(slope)}{AP} \tag{11}$$

Where m = mass of piston, A = cross-sectional area of piston, P = atmospheric pressure, and the slope is from the graph of h vs. T^2.

EXPERIMENTAL SETUP AND PROCEDURE

Setup

The experimental setup is using PASCO Scientific apparatus (PASCO, 2003) which are: (a) Heat Engine/Gas Law Apparatus made of a graduated cylinder, a moving piston, two ports and tubing, with a known diameter and mass, respectively; (b) Low Pressure sensor; (c) *Science Workshop* 750 Interface.

The low pressure sensor was attached to one of the ports on the heat engine/gas low apparatus. Both of the tube clamps were unclamped at the bottom of the apparatus. The piston was raised to the 9 cm mark and clamped at this position. The tube clamp was closed on the open port. The side thumb screw was loosened and the piston will stay at 9 cm. The low pressure was also plugged into channel A of the Science Workshop 750 Interface. This latter was connected to the microcomputer, as shown in figure1.

Readers could create their own file in Datastudio software (Datastudio 1.9, PASCO 2003); called "Specific heats.ds", or they can get a ready to use program file developed by PASCO Scientific. The parameter properties of the pressure sensor are well adjusted and the equation for the calculation of the cylinder height of air (i.e., the volume of air in cylinder) versus the squared period of the oscillating pressures is adequately interred into the calculator of Datastudio.

Figure 1. Experimental setup.

PROCEDURE

The file for data analysis was opened in the Datastudio program, and the following procedure was carried out:

Using the tip of the finger, the piston was plucked. The oscillating pressures as a function of time are plotted in real time and immediately available for the readers' analysis, figure 2. By using the *Smart Cursor*, the period of the oscillation was determined from the pressure versus time graph. The area of the graph that shows the oscillations was expanded, and the period was found by measuring the time of several peaks and dividing by the number of peaks. This period and the corresponding piston height were typed into the table in Datastudio.

The piston was lowered to 8 cm and the above procedure was repeated. Then the piston was lowered in steps of 1 cm, repeating the same procedure at each piston position down to 1 cm. From the slope of the resulting graph of height (h) versus the squared oscillating period (T^2), the calculated value of the ratio of specific heat for air, γ, was compared to the ideal value.

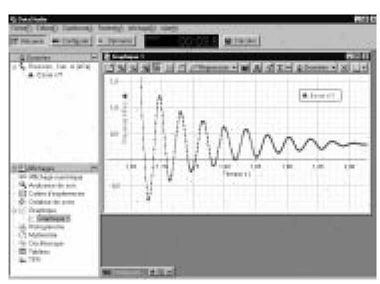

Figure 2. Piston oscillating pressure vs. time – The piston positioned at 9 cm.

RESULTS AND DISCUSSION

A sample of typical oscillating damped pressure of the piston, which was positioned at 9 cm of height, was illustrated in figure 3. Few peaks were taken to measure the average period. The average periods for heights from 9 to 1 cm were entered into the table of Datastudio program. The data of heights and periods were handled and performed within the spread-sheet that is built into the graphic calculator. The plot of the height (h) versus squared period (T^2) was shown in figure 4, where the best fitting line has a slope 86.2 ± 5.1, and correlation coefficient r = 0.988 was obtained for this case. The ratio of specific heat for air γ was calculated from Eq. (11). The recorded atmospheric pressure (P) was 1.018 x 10^5 Pa. The measured γ, 1.409, matched very well the accepted value, 1.4, where the observed difference between these two values was around 1%. We believe that the precision of the obtained experimental result compared to the theoretical value was partly due to the use of the Microcomputer-Based Laboratory in this activity.

Various laboratory protocols might be proposed to physical sciences students using this relatively inexpensive experimental setup.

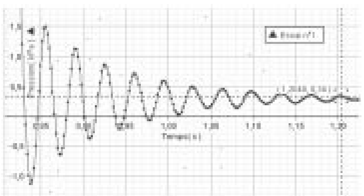

Figure 3. Oscillations of damped pressure – piston positioned at 9 cm.

Figure 4. Height (h) of vs. squared period (T^2)-Table of data.

CONCLUSION

The values of k obtained experimentally using Microcomputer Based Laboratory of water electrolysis as well as the theory of perfect gases, are found to be consistent with the accepted value. The observed difference between the experimental and accepted value was approximately 1%. The experiment serves as a didactical tool for college and university physical sciences students to do measurements on fundamental values, such as Boltzmann's constant and Avogadro's number. I believe it should be possible to use this experimental setup with other Datalogger programs with appropriate sensors, such as Vernier (Vernier Software & Technology 2004).

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