Cleveland State University

2008 Assessment Report

Program:	B.S./B.A. in Physics	**Completed By:**	Paul D. Hambourger, Assoc. Professor of Physics
Department:	Physics	**Date:**	May 28, 2008

hG5k#)II hw v hG5k#)II#d7d hw v hG5YY)IY#dGd

Introduction/Context

Programs: The department is authorized to combine the assessment efforts for the Bachelor of Science and Bachelor of Arts majors in Physics, herein referred to as "B.S./B.A. in Physics."

Faculty involvement in assessment design: The entire full-time Physics faculty was involved in the development and modification of this assessment plan as detailed below. The entire plan, with modi hG5Y(#Gk4dGd hwnv hG5YYkG)4d#IIYkdGd hwdv hG5YY)Gd

Goal 1: Know the basic physical concepts and laws of Mechanics, Electromagnetism and Optics, Thermal and Statistical Physics, and Quantum Physics. Be able to apply those concepts and laws to the description of concrete problems. Be able to present, in a coherent manner in written format, an analysis of a scientific topic.				
Outcomes	**Data Collection**	**Data Analysis & Findings**	**Review of Findings**	**Follow-up Actions**
a) Subject knowledge	1). After completing Introductory Physics courses (PHY 241/243, 242/244), each student takes 1-hr written test of one basic and major area (Mechanics). The same test and scoring rubrics have been used since 1995 (Appendix A). 2). Chair and faculty solicit feedback from alumni and re their success in jobs and/or graduate school.	Test was given in Fall 2007 on class time in PHY 330 (required course for all B.A. and B.A. Physics majors),ensuring that most or all majors take the test). Results: Number of students: 12 Mean score: 54% (C/D).	Fall 2007 results are essentially the same as those of Fall 2006 (12 students, mean score 55%). Review of Fall 2007 data by the Physics faculty was postponed to Fall 2008 because Department Chairperson was on sabbatical.	In the future, test results will be reviewed by the Physics Faculty in the same academic year that the test was given. Free tutoring by graduate students continues to be available to all students of PHY 241/243 and 242/244.
b) Ability to apply subject knowledge to concrete problems	1). During junior or senior year, each student does a Computer Project that demonstrates subject knowledge and ability to apply it to concrete problems. A set of new computer exercises in PHY 474 – Thermal Physics were added to the Project list by unanimous vote of full-time Physics faculty on Feb. 21, 2006. Course is required for all B.S. and B.A. majors. Projects and rubrics are described in Appendix B. 2). Chair and faculty solicit feedback from alumni and re their success in jobs and/or graduate school.	In AY 2007-2008, all data came from the new computer exercises done by all students in PHY 474 – Thermal Physics – Fall 2007. Results (maximum possible = 100): Lab 1 (8 student reports): Avg=92 $\pm$ 5, Range 80-90 Lab 4 (4 student reports): Avg=66 $\pm$31, Range 20-90 Rubrics in Appendix B, Lab Manual in Appendix D.	The Lab 1 average (92) is considerably better than those in AY 2005-2006 (83) and 2006-2007 (80). We consider the 2007-08 score to be excellent and the 2005-2006 and 2006-2007 scores to be very good/excellent, given the complexity of the material. Lab 4 is new and was only finished by four students, so its scores cannot be compared with previous years' data. Formal review will begin in AY 2008-2009, when we have more data	Due to the small number of student reports – particularly on the new Lab 4 – we do not have sufficient evidence to make curricular changes at this time. Formal review, and corrective actions if needed, will begin in AY 2008-2009.

Goal 2: Have logical, analytical and computational skills to mathematically model physical problems. Logical skills refer for example to discerning cause from effect. Analytical skills are algebra, geometry, trigonometry, and calculus. Computational skills include programming in at least one language (e.g. FORTRAN, C, C++) and use of at least one mathematical package (e.g. MathCad, Maple).

Outcomes	Data Collection	Data Analysis & Findings	Review of Findings	Follow-up Actions
a) Logical, analytical and co putational skills	1). During junior or senior year, each student does a Co puter Project as part of a ajor Physics course. A ong other things, this tests the student's logical, analytical and co putational skills listed in Goal 2. The projects are graded by the professor teaching the course. Projects and rubrics are described in Appendices B and D. 2). Chair and faculty solicit feedback fro alu ni and re their success in jobs and/or graduate school.	In AY 2007-2008, all data ca e fro the new co puter exercises done by all students in PHY 474 – Ther al Physics – Fall 2007. Results (axi u possible = 100): Lab 1 (8 student reports): Avg= 92 ± 5, Range 80- 90 Lab 4 (4 student reports): Avg=66 ±31, Range 20- 90 Rubrics in Appendix B, Lab Manual in Appendix D.	The average scores on Lab 1 (92, 80, and 83 in the past three acade ic years) de onstrate high effectiveness of progra 's training in logical, analytical and co putational skills. Lab 4 is new (and was only finished by four students), so its scores cannot be co pared with previous years' data. The rather low score on Lab 4 is of concern, but cannot be considered until we have ore data. For al faculty review was postponed to Fall 2008 because Depart ent Chairperson was on sabbatical.	This goal was revised by the Physics faculty in AY 2005-2006 to update the list of relevant co puter languages and athe atical packages; thus it was not necessary to revise it again in 2007-2008. For al Physics faculty review, and corrective actions if needed, will begin in AY 2008-2009, when one ore set of student reports will be available.
b) Ability to apply subject knowledge to concrete proble s	1). The Co puter Project described in the cell above also tests the student's ability to apply subject knowledge to concrete proble s relevant to the course in which it is done. 2). Chair and faculty solicit feedback fro alu ni and re their success in jobs and/or graduate school.	Described in the cell above.	Described in the cell above. Results de onstrate high progra effectiveness in teaching students to apply their subject knowledge to specific co putational analyses.	Described in the cell above.

Goal 3: Have laboratory skills to set up an experiment and to acquire and analyze data.				
Outcomes	**Data Collection**	**Data Analysis & Findings**	**Review of Findings**	**Follow-up Actions**
a) Ability to set up an experiment and to acquire and analyze data	Effective Fall 2005, the lab skills assessment tool is a set of three hands-on lab experiments in thermodynamics done by students in PHY 474 – Thermal Physics (required course for all B.S. and B.A. Physics majors). This tests students' skills in experiment setup, data collections/analysis and presentation of results. The written lab reports are graded by the professor teaching the course. Projects and rubrics are described in Appendices C and D. This change of assessment tool was approved by unanimous vote of the full-time Physics faculty on Feb. 21, 2006.	In AY 2007-2008, all data came from hands-on lab experiments done by all students in PHY 474 – Thermal Physics – Fall 2007. Results (maximum possible = 100): Lab 2: (9 student reports) Avg=92 ± 4, Range 85-100 Lab 3: (7 student reports) Avg=94 ±8, Range 45-100 Lab 5 (called Lab 6 in 2005-2006 and 2006-2007): (4 student reports) Avg=83 ±2, Range 50-100 Rubrics in Appendix C, Lab Manual in Appendix D.	Average score for Lab 2 was 92 in 2007-2008 vs 66 in 2006-2007 and 85 in 2005-2006. Average score for Lab 3 was 94 in 2007-2008 vs 70 in 2006-2007 and 67 in 2005-2006. Average score for Lab 5 (formerly called Lab 6) was 83 in 2007-2008 vs 75 in 2006-2007 and 73 in 2005-2006. These represent a positive trend, though the small number of students makes precise measurement difficult. Formal faculty review was postponed to Fall 2008 because Department Chairperson was on sabbatical.	Formal Physics faculty review will begin in AY 2008-2009. However, the good-to-excellent lab scores reported in the cells to left do not suggest a need for major corrective action. We expect the new elective lab course, PHY 335 – Modern Physics Laboratory, first offered in Spring 2007, to improve hands-on lab and report-writing skills. The Physics Department is only permitted to offer it in alternate years, so it will not be given again until Spring 2009. Thus it will take some time to determine the effectiveness of this course.
b) Ability to apply subject knowledge to concrete problems	The lab experiments described above also test the student's ability to apply knowledge of physics, particularly thermodynamics, to the concrete problems of measuring the heat capacity of matter, the pressure-temperature relationship of gases, and the mechanical equivalent of heat.	Described in the cell above.	Described in the cell above.	Described in the cell above.

★ **Community Engagement Activities:**

Outcomes	Data Collection	Follow-up Actions		
a) Physics faculty collaboration with local science education activities.	The Physics Department is actively involved with the 9-16 Task Force, which enables interaction between Greater Cleveland high school teachers and CSU faculty. This provides teachers with expertise and resources to better prepare high school students. CSU Physics Prof. Petru Fodor worked with science teachers and students at Bedford High School to measure heat loss from the school's building, using a sophisticated infrared camera. Extramural funding was obtained to support this project. CSU Physics Prof. Jearl Walker's web site at www.flyingcircusofphysics.com received over 100,000 visits in 2007. Updated monthly as a public service to teachers, students and the general public, it includes hundreds of physics news items and over 10,000 journal references. (See Appendix E).	Will consider involving undergraduate Physics majors in some of these activities as appropriate opportunities arise.		
b) PHY 400/500 – Conceptual Physics for Middle School Teachers, offered each Spring, provides scientific content and inquiry skills necessary for teaching physics in middle school. Students are senior Education majors and in-service teachers. Learning objectives are based on national standards for 4^{th}-8^{th} grade science.	Spring 2008 enrollments: PHY 400: 19 PHY 500: 4 Data source: CSU Course Schedule web page, May 26, 2008			
c) Annual CSU Physics Day brings local middle school and high school science students and teachers to campus for faculty physics lab demonstrations and talks, tour of CSU Physics research labs, and lunch.	April 18, 2008: 38 students from Horizon Science Academy, John Hay HS Early College, N. Royalton HS, Lakewood Catholic Academy, Harding School, St. Bernadette School, Lee Middle School, John Paul II Academy, and Waverly School; 12 teachers; 5 CSU students from PHY 400/500. Two CSU Physics majors acted as tour guides. Data source: Attendance taken at door. Program reproduced in Appendix F.			
d) Several CSU Physics professors (Fodor, Kaufman, Streletzky, Zurcher) supervise science competition research projects by high school students from Horizon Science Academy.				

Engaged Learning activities for CSU students:

Outcomes	Data Collection	Follow-up Actions		
a) Physics research experiences for CSU undergraduates.	Research projects in the period May 2007 – August 2008 include Protein Crystallography (with Prof. Vitali), Microfluids (Prof. Fodor), Thin Films Coated Materials (Prof. Hambourger), Light Scattering from Polymeric Nanoparticles (Prof. Streletzky), and Entropy Analysis of EMG data from subjects with muscular pain (Prof. Zurcher). Typically 5-10 students are involved at any one time. Arrangements include Independent Study courses and paid jobs funded by research grants and the Provost's Summer Undergraduate Research Program.	In Summer 2008, we will hold informal gatherings for the Undergraduate Physics Research students to present and discuss their projects.		
b) Society of Physics Students – CSU Chapter.	The Chapter hosted regular seminars where students, faculty and outside speakers presented and discussed their research. Typical student attendance at these was 10-12.			
c) Student participation at professional meetings.	A few Physics majors participated in professional national and state meetings of the American Physical Society and presented their research.	We anticipate that some of the 2008 Summer Undergraduate Physics Research students will present papers at the October 2008 meeting of the American Physical society – Ohio Section in Dayton.		

Appendices

Appendix A
General Physics Test

Goal #1, Outcome a)

Test has 15 questions – 4 informational (not graded) and 11 on basic knowledge of Mechanics (graded with equal weight).

Scoring rubrics for each graded question: Correct equations and numerical output – 100%. Correct equations, incorrect numerical output – 50%. Incorrect equations – 0%.

Appendix B
Computer Exercises

Goal #1, Outcome b) and Goal #2, Outcomes a) and b)

Each student does a project as part of a junior-senior level Physics course. Currently, the course titles are Thermal Physics, Statistical Physics, Monte Carlo Simulation of Complex Systems, Environmental Physics, and Computational Physics. Project details depend somewhat on the course, as shown below:

Thermal Physics Laboratories PHY474 – Fall 07

Assessment – Spring 2008

Number of Students: 9

Lab 1: Mass of Atmosphere [Computer]

Objective: (1) Familiarize with MathCad
(2) Numerical Solution of ordinary differential equation

Q1: (Find characteristic length scale)	20 pts
Q2: (Graph pressure vs height from iteration)	20 pts
Q3: (Find exact solution)	20 pts
Q4: (Use MathCad to find value of definite integral)	20 pts
Total	100 pts

Statistics: Score 92 ± 5, range 80-90 (number of reports: 8)

Lab 4: Ruchardt Method for Measuring C_P/C_V –Simulation

Q1: (Derive nonlinear differential equation for height of ball)	25 pts
Q2: (Characterization of small oscillations))	20 pts
Q3: (Derive linearized equation of motion)	15 pts
Q4: (Integration of differential equation using Runge-Kutta)	20 pts
Q5: (Plot height of ball as a function of time)	20 pts
Total	100 pts

Statistics: Score 66 ± 31, range 20-90 (number of reports 4)

Appendix C
Hands-on Laboratory Experiments

Goal #3, Outcomes a) and b)

Thermal Physics Laboratories PHY474 – Fall 07

Assessment – Spring 2008

Number of Students: 9

Lab 2: Constant Volume Gas Thermometer [Experiment]

Objective: (1) Ideal gas law
(2) Find estimate of absolute zero temperature

Q1: (Find ambient pressure in kPa)	10 pts
Q2: (Record pressure for temperatures 0^o C – 100^o C	20 pts
Q3: (Plot data)	20 pts
Q4: (Extrapolation to zero pressure)	20 pts
Q5: (Error for absolute zero temperature)	20 pts
Q6: (Discuss error)	10 pts
Total	100 pts

Statistics: Score 92 ± 4, range 85-100 (number of reports 9)

Lab 3: Mechanical Equivalent of Heat [Experiment]

Objective: (1) Comparison of mechanical and thermal energy
(2) Determine mechanical equivalent of heat

Q1: (Determine mass of aluminum cylinder)	10 pts
Q2: (Measurement of resistance vs number of “cranks”)	20 pts
Q3: (Convert resistance to temperature using table)	20 pts
Q4: (Determine mechanical equivalent)	20 pts
Q5: (identify errors)	10 pts
Q6: (Error analysis)	20 pts
Total	100 pts

Statistics: Score 94 ± 8, range 45-100 (number of reports 7)

Lab 5: Ruchardt Method for Measuring C_P/C_V -Experiment

Q1: (Measure pressure inside jug)	10 pts
Q2: (Derive equation for damped harmonic oscillator)	20 pts
Q3: (Measure pressure vs time using data acquisition)	20 pts
Q4: (Plot data using MathCad)	10 pts
Q5: (Use nonlinear regression fit for data)	20 pts
Q6: (Find value for adiabatic constant)	10 pts
Q7: Error analysis	10 pts
Total	100 pts

Statistics: Score 83 ± 2, range 50-100 (number of reports 4)

PHY 474 THERMAL PHYSICS
Computational Projects and Laboratories

Ulrich Zürcher*
Physics Department, Cleveland State University, Cleveland, OH 44115

(Dated: May 10, 2006)

PACS numbers:

*Electronic address: u.zurcher@csuohio.edu

Laboratory Schedule (tentative)

Date	Experiment
9/4	Mass of Atmosphere [Simulation]
9/11	Gas Thermometer
9/25	Equivalence of Heat and Work
10/9	Stability of Dry Air [Simulation]
10/23	C_P/C_V Ruchardt Oscillations [Simulation]
11/6	C_P/C_V Ruchardt Oscillations
11/20	Vapor Pressure

I. MASS OF THE ATMOSPHERE

A. Objectives

1. To familiarize with MathCad.

2. To find a numerical solution of an ordinary differential equation

B. Theory

We consider a horizontal slab of air whose thickness [height] is dz. If this slab is at rest, the pressure holding it up from below must balance both the pressure holding it up from below must balance both the pressure from above and the weight of the slab:

$$P(z+dz)\cdot A + Mg = P(z)\cdot A, \quad \text{or} \quad P(z+dz)-P(z) = -\frac{Mg}{A},$$

where A is the area of the slab and M is its total mass. The mass is given by $M=\rho A dz$ so that

$$\frac{P(z+dz)-P(z)}{dz} = -\rho g, \quad \text{or} \quad \frac{dP}{dz} = -\rho g.$$

[Is the density ρ constant over the entire atmosphere? *Explain!*]
The density of the gas is $\rho = M/V = Nm/V = Pm/kT$, where m is the average molecular mass and in the last step, we used the ideal gas law. Inserted above, we find

$$\frac{dP}{dz} = -\frac{mg}{kT}P.$$

Q1: Show that a *characteristic length scale* for the problem is given by

$$L = \frac{kT}{mg}$$

Air is about 80% N_2 and 20% O_2. Find the numerical value of the characteristic length scale for air.

Some of you may now the solution of the differential equation for the pressure. Here, we first want to find a *numerical* solution. To this end, we write $P = P_0\hat{P}$, where P_0 is the pressure at sea level:

$$\frac{d(P_0\hat{P})}{dz} = P_0\frac{d\hat{P}}{dz} = -\frac{P_0\hat{P}}{L}, \quad \text{or} \quad \frac{d\hat{P}}{dz} = -\frac{\hat{P}}{L}.$$

Note that $\hat{P}(0)=1$. We re-write the differential equation as a difference equation:

$$\frac{\hat{P}(z+\Delta z)-\hat{P}(z)}{\Delta z} = -\frac{\hat{P}(z)}{L}, \quad \text{or} \quad \hat{P}(z+\Delta z) = \hat{P}(z) - \hat{P}(z)\frac{\Delta z}{L}.$$

That is, once we know $\hat{P}(z)$, we can compute $\hat{P}(z+\Delta z)$. Using this result, we then find $\hat{P}(z+2\Delta z)$. This is called an *iterative* solution. We define

$$\hat{P}(n) = \hat{P}(n \cdot \Delta z), \quad \hat{P}(z+\Delta z) = \hat{P}(n+1), \ \text{etc.}$$

with the initial condition $\hat{P}(0) = 1$. We observe that the ratio $\kappa = \Delta z/L$ is dimensionless. We find

$$\hat{P}(n+1) = (1-\kappa)\,\hat{P}(n).$$

In MathCad, the iterative scheme is implemented in the following way [we *choose* $\kappa = 0.02$]:

$$\kappa := 0.02$$

$$P(n) := \left| \begin{array}{l} P \leftarrow 1 \\ \text{for } i \in 1..n \\ \quad P \leftarrow (1-\kappa)\cdot P \end{array} \right.$$

Q2: Graph P as a function n. Find an estimate for the pressure at Mt. Whitney [14,500 feet] and Mt. Everest [29,000 feet].

Q3: Show that the (exact) solution of the differential equation is given by

$$P(z) = P(0)e^{-z/L},$$

where $P(0)$ is the pressure at sea-level [$z = 0$]. Compare the exact and numerical solutions.

The density follows

$$\rho(z) = \frac{P(0)m}{k_B T}e^{-z/L}.$$

Calculate the density at sea level.
The total mass is obtained by integrating the density:

$$M_{\text{atm}} = 4\pi \int_0^\infty \rho(z)\cdot(z+R_e)^2 dz = \frac{4\pi P(0)m}{k_B T}\int_0^\infty z^2 e^{-z/L}dz.$$

Now use the substitution $z = R_e \cdot \hat{z}$ so that

$$M_{\text{atm}} = \frac{4\pi P(0) R_e^3 m}{k_B T}\int_0^\infty (1+\hat{z})^2 e^{-\lambda\hat{z}}d\hat{z},$$

where

$$\lambda = \frac{R_e}{L} = \frac{6.37\times10^6\,\text{m}}{8.04\times10^3\,\text{m}} \simeq 792.$$

Q4: Now use MathCad to find the numerical value of the (definite) integral: we find 1.27×10^{-3}.For the mass of the atmosphere, we thus find [$m = 28.8\,\text{u}$]

$$\begin{aligned} M_{\text{atm}} &= \frac{4\pi P(0) R_e^3 m}{k_B T}\cdot 1.27\times10^{-3} \\ &= \frac{4\pi\cdot 1.27\times10^{-3}\cdot 1.013\times10^5\,\text{Nm}^{-2}\cdot 2.58\times10^{20}\,\text{m}^3\cdot 28.8\times1.661\times10^{-27}\,\text{kg}}{1.38\times10^{-27}\text{JK}^{-1}\cdot 300\text{K}} \\ &\simeq 5\times10^{18}\,\text{kg}. \end{aligned}$$

We observe that the mass of the atmosphere is very small compared to the mass of the Earth $M_e \simeq 6\times10^{24}\,\text{kg}$.

II. CONSTANT VOLUME GAS THERMOMETER

A. Objectives

1. To check a mercury-in-glass thermometer against an air thermometer.
2. To obtain an experimental graph of the pressure-temperature relationship for a real gas.
3. To use an extrapolation method to estimate "absolute zero."

B. Theory

At low densities, the (absolute) pressure of a real gas held at constant volume is proportional to its absolute temperature. This relationship can be expressed as

$$P = b + mT, \tag{1}$$

where P is the absolute pressure, T is the temperature in degree Celsius, m is the slop in the $P - T$ diagram and b is the intercept with the pressure axis at $T = 0$.

Absolute zero is the temperature T_0 that brings the absolute pressure in the constant volume thermometer to zero. From Eq. (1), we have $0 = b + mT_0$, or

$$T_0 = -\frac{b}{m}. \tag{2}$$

The usual way to do this experiment is to use the mercury manometer (Fig. 1) to measure the gauge pressure in the bulb. Calibration is no problem with this gauge since the readings in mm Hg also serve as standard pressure units. In our apparatus, however, we use a modern silicon pressure device (Fig. 2). Its electrical output us a voltage proportional to the pressure difference between its 'positive' and 'negative' ports. To measure positive gauge pressures we will leave the negative port open to the atmosphere and connect the bulb to the positive port. To use this gauge we must depend on the formula provided by the manufacturer for converting the voltage reading V_G from the pressure sensor to the gauge pressure P_g:

$$P_G = V_G \frac{1250\,\text{KPa}}{\text{V}}. \tag{3}$$

The absolute pressure in the bulb is then

$$P = P_G + P_B, \tag{4}$$

where the barometric pressure P_B is measured with a mercury barometer:

$$P_B = (\text{barometer reading in mm Hg})\,\frac{101.13\,\text{KPa}}{760\,\text{mm Hg}}. \tag{5}$$

C. Procedure

1. Read the wall barometer and record P_B. Be sure the screw at the bottom of the barometer has been adjusted so that the ivory peg just makes contact with the surface of the mercury in the cup. Convert the reading to KPa. In the handbook, look up the corresponding boiling temperature of water. The freezing temperature of water is much less temperature dependent and can be taken to be exactly $0°$ C.

2. Leave the thin tube connected to the bulb but disconnect it from the pressure sensor at the other end. Place the weighted bulb in the can and fill the can with a mixture of ice and water. The open thin tube prevents any water from getting inside the bulb but allows air in the bulb to come to equilibrium at ice temperature and atmospheric pressure. Stir the mixture with the glass rod until the mercury-in-glass thermometer indicates equilibrium is established.

3. Connect the thin tube to the positive port [marked red]. Record the temperature and pressure sensor reading. The temperature may not be exactly $0°$ C. The gauge pressure reading will be a very small positive or negative voltage.

4. Remove the surplus ice and replace with water. Heat the can with the *Bunsen burner*, removing when the temperature reaches $10-15°$ C. Stir thoroughly to obtain a uniform temperature, allowing time for the heat to flow into the air in the flask, and take readings as before. This time the sensor output will be a positive voltage. To avoid wasting time, begin with the data analysis [see part D].

5. Continue heating the can, removing the flame and taking readings of the thermometer and pressure sensor roughly every $10°$ C. As higher temperatures are reached, the flame should be only partially removed each time so that you can maintain a constant temperature for each reading.

6. Take your last reading with the water boiling vigorously. Do not expect to reach $100°$ C, since that figure holds only for a room pressure of exactly 760 mm Hg.

7. As the water cools, recheck several of your previous high temperature readings. You may have to supply heat to keep the temperature constant for a sufficient length of time before reacording each pressure sensor reading.

D. Data Analysis

1. Using a sheet of graph paper, label the horizontal axis in units of $°$ C, with the scale extending from $-300°$ C to $+100°$ C. Label the vertical axis in units of the absolute pressure P [in KPa], extending from 0 to the largest absolute pressure calculated from your observations of P_G.

2. Plot the absolute pressure as a function of the temperature. Draw in the straight line for the best fit for your points. The value obtained for the temperature intercept is "absolute zero." Find an estimate for the error of the absolute zero.

3. From the results of part D.7 determine the error (including sign) of your emercury thermometer at boiling and freezing temperatures.

E. Discussion

1. The error caused by the gas in the connecting tubes differing in temperature from the gas in the bulb becomes greater as the water bath temperature increasing differs from that of the surrounding air. From the fact that a confined gas tends to increase in pressure when heated, deduce the sign of this error in the recorded P_G when the water is (a) above room temperature and (b) below room temperature.

2. What effect does the answer to part 6a have on (a) the slope of your graph and (b) the temperature used to obtain your value of the aboslute zero?

3. List any other possible sources of systematic error you may have observed or become aware of in carrying out this experiment.

4. List any possible sources of random error.

III. MECHANICAL EQUIVALENT OF HEAT

A. Objective

1. Experimentally measure and compare the mechanical energy of work done to the produced thermal energy [friction].

2. Determine the mechanical equivalent of heat, i.e., the conversion between *joules* and *calories*.

B. Theory

Heat is defined as a transfer of energy due to a temperature difference while no work is done. One calorie [1 cal] is the amount of heat needed to raise the temperature of a gram of water by 1° C. [Note that *one calorie* in everyday life - "this can of soup has only 250 calories!" - is actually 1 Kcal. In the experimental set-up, mechanical work done on the system is used to overcome frictional loss; that is, it is transferred into heat. We measure both the mechanical work and the heat and thus obtain the desired conversion factor.

A nylon cord is wrapped around an aluminum cylinder several times with one end of the cord attached to a heavy weight. The cylinder is then rotated in a direction such that the frictional force of the cylinder on the cord will lift the heavy weight, ideally keeping the weight in equilibrium posoition several inches above the floor. The work done on the cylinder is $W = \tau\theta$, where τ is the torque exerted by the nylon cord and θ is the angle through which the cylinder is rotated. In mechanical equilibrium, with the mass above the floor, the tension is equal to the weight of the hanging mass. The torque is then given by $\tau = RMg$, where R is the radius of the cylinder and Mg is the weight of the mass. If the cylinder rotates a total of N times, then the angle is given by $\theta = 2\pi N$ [in radians!]. The total amount of mechanical work done on the cylinder is

$$W = RMg2\pi N. \tag{1}$$

The cylinder is made of aluminum with a specific heat

$$c \simeq 215\,\frac{\text{calories}}{\text{kg }^\circ\text{C}}. \tag{2}$$

If the temperature of the cylinder raises from T_i to T_f, the necessary amount of heat follows from the mass of the cylinder m, the specific heat of aluminum $c \simeq 215\,\text{cal/kg }^\circ\text{C}$, and the temperature increase ΔT:

$$Q = mc(T_f - T_i). \tag{3}$$

The mechanical equivalent of heat is defined

$$J = \frac{W}{Q}. \tag{4}$$

Note that J has units $[J] = \text{J/cal}$.

C. Procedure

1. Determine the weight of the aluminum cylinder and cool it to about 10°C below room temperature by placing it in the freezer. The calorimeter is cooled below room temperature to allow ambient heat transfered into the calorimeter from the room to help offset the heat transfered out of the calorimeter when it gets to temperatures above room temperatures. The starting and stopping temperatures should equally straddle room temperature.

2. Replace calorimeter onto rotating shaft and monitor its temperature.

3. Make sure that surface is dry and apply a thin film of graphite. item Wrap four (4) turns of rope around the calorimeter.

4. Turn the crank handle and observe temperature to raise. Note that the temperature is measured by a thermistor [see below].

5. Record the number of turns and measure the radius of the cylinder.

.

Thermistor

R [kΩ]	T [°C]	R [kΩ]	T [°C]
269.08	5	95.45	26
255.38	6	91.13	27
242.46	7	87.02	28
230.26	8	83.12	29
218.73	9	79.42	30
207.85	10	75.90	31
197.56	11	72.56	32
187.84	12	69.39	33
178.65	13	66.36	34
169.95	14	63.48	35
161.73	15	60.74	36
153.95	16	58.14	37
146.58	17	55.66	38
139.61	18	53.30	39
133.00	19	51.05	40
126.74	20	48.91	41
120.81	21	46.86	42
115.19	22	44.92	43
109.85	23	43.06	44

IV. RUCHARDT METHOD FOR MEASURING Cp/Cv - SIMULATION

A precison tube of cross section A is attached large vessel of volume $\mathcal{V}_0$. A stainless steel ball fits perfectly inside the tube. You take the ball and lower it slowly down the tube until the increased air pressure supports it.
Q1: Determine the distance below the tube's top at which the sphere is supported.

The ball is in (mechanical) equilibrium when

$$mg + AP_{\text{atm}} = AP_0. \tag{1}$$

We choose a coordinate system such that $z = 0$ at the equilibrium position. If the pressure inside the vessel is $p > 0$, the air pushes the ball upwards,

$$m\frac{d^2z}{dt^2} = -mg + A(P - P_{\text{atm}}). \tag{2}$$

We assume that the compression and expansion of the air inside the vessel is "fast," and thus ignore heat exchange with the environemnt. That is, we assume that the process is adiabatic, $PV^\gamma = P_0V_0^\gamma$, where V_0 is the volume of the vessel *plus* the volume of the tube when the ball is in equilibrium. If the ball is at a height z, we have $V = V_0 + Az$, and

$$P = P_0\left(\frac{V_0}{V_0 + Az}\right)^\gamma = P_0\left(1 + z/l\right)^{-\gamma}, \tag{3}$$

where $l = V_0/A$ is a characteristic length scale for the problem. Thus the equation of motion is

$$m\frac{d^2z}{dt^2} == -mg + A\left[P_0(1 + z/l)^{-\gamma} - P_{\text{atm}}\right] \tag{4}$$

Q2: How are "small" oscillations characterized?
Q3: Find the "linearized" equation of motion.
Since $AP_{\text{atm}} + mg = AP_0$ this can be simplified:

$$m\frac{d^2z}{dt^2} = AP_0\left[(1 + z/l)^{-\gamma} - 1\right]. \tag{5}$$

For $z/l << 1$, we have

$$\frac{1}{(1 + z/l)^\gamma} \simeq \frac{1}{1 + \gamma z/l} \simeq 1 - \gamma\frac{z}{l}. \tag{6}$$

Inserted above we have

$$m\frac{d^2z}{dt^2} = -\frac{\gamma AP_0}{l}z = -\frac{\gamma A^2P_0}{V_0}z. \tag{7}$$

This is the equation for a harmonic oscillator. The (angular) frequency ω follows

$$\omega^2 = \frac{\gamma A^2P_0}{mV_0} \tag{8}$$

A. MathCad Implementation

We define

$$T_{\text{approx}} := 2\pi\sqrt{\frac{V_0 m}{A^2 P_0 \gamma}} \tag{9}$$

and

$$N := 800, \;\; T_{\text{tot}} := \frac{N}{200} T_{\text{approx}}, \;\; n := 0..N. \tag{10}$$

Furthermore, we define a two-dimensional vector containg the position $z = \zeta_0$ and the velocity $dz/dt = \zeta_1$. The Initial conditions are

$$\zeta := \begin{pmatrix} 10 \\ 0 \end{pmatrix}. \tag{11}$$

The equations of motion read

$$Z(t,\zeta); = \begin{bmatrix} \zeta_1 \\ -g + (A/m) \cdot (P_0\{1 + A\zeta_0/V_0\}^{-\gamma} - P_{atm}) \end{bmatrix}. \tag{12}$$

The integration is done using the Runge-Kutta method:

$$z := \text{rkfixed}(\zeta, 0, T_{\text{tot}}, N, Z). \tag{13}$$

MathCad gives the result in matrix form:

$$\text{time} := z^{<0>}, \quad \text{position} := z^{<1>}, \quad \text{velocity} := z^{<2>}. \tag{14}$$

Q4: What happend if the initial displacement is large?

VI. RÜCHARDT METHOD FOR MEASURING C_p/C_v: EXPERIMENT

A. Objective

To measure the ratio of $\gamma = C_P/C_V$ of air at room temperature.

B. Theory

In the preceeding lab we have derived an equation for the displacement of the ball in the tube:

$$\frac{d^2z}{dt^2} = -\frac{\gamma A^2 P_0}{mV_0} z, \tag{1}$$

where V_0 is the volume of the jug *plus* the volume of the tube when the ball is in (mechanical) equilibrium, $P_0 = P_{\text{atm}} + mg/A$.

Q1: We measure the pressure inside the jug instead of the position of the ball. Show that

$$z = -\frac{V}{\gamma PA}\Delta P. \tag{2}$$

Show that the pressure change obeys the same differential equation:

$$\frac{d^2\Delta P}{dt^2} + \omega^2 \Delta P = 0, \tag{3}$$

where $\omega^2 = \gamma A^2 P_0/mV_0$.

We see that the ball stops moving after 10 or twelve oscillations. This shows that we have to include damping [HRW 16-8 p. 360ff]. The equation of motion reads:

$$\frac{d^2\Delta P}{dt^2} + \beta\frac{d\Delta P}{dt} + \omega^2 \Delta P = 0. \tag{4}$$

The solution reads:

$$\Delta P(t) = (\Delta P)_0\, e^{-\beta t/2} \cos(\omega' t + \phi). \tag{5}$$

Here $(\Delta P)_0$ is the maximum amplitude. The angular frequency is given by

$$\omega' = \sqrt{\omega_0^2 - \frac{\beta^2}{4}} \tag{6}$$

Q2: What are possible sources of damping?

C. Procedure

1. The tube and ball have to be very clean. Otherwise there will be unwanted friction. Also the tube may become scratched or broken if excessive force is used to push the ball out past dirt on the inside of the tube

2. The mass of the ball is 16.7 g, the diameter of the tube is 16 mm, and the volume of the jug is 10.9 L.

3. The pressure gauge is connected to the jug through the rubber stopper at the bottom of the jug. The pressure gauge is powered by a power supply and has a calibration of 1250 KPa whne the power supply is set at 10V. Adjust and record the power supply voltage.

4. Set parameters on the control panel for the data acquisition system. If you ask for 500 points of data and make a sample period of 0.02 sec you will be able to follow several oscillations of the ball over a time interval of 10 sec. Select Channel and Ranges. The pressure gauge output requires the most sensitive range of 0.05 V. Because the pressure gauge puts out a lowe level signal of only about 1 mV in this experiment, electronic noise in this experiment is very noticeable. The data acquisition board is capable of taking accurate measurements at the rate of about 5,000 voltage samples per sec. Therefore, you may set the number of samples to be averaged to 500. Then each of the 500 data points reported will be an average of 500 measurements.

5. You are now ready to get the ball into position at the top of the tube. First, turn on the electromagnetic power supply and adjust its current to 200 mA so that the ball will stick to it when levitated. Use the pressure bulb attached to the stopcock to levitate the ball.

6. Turn off the power supply to the electromagnet to release the ball. The ball will typically hit the wire stop once or twice after this the ball oscillates in the tube. Now click RUN on the acquisition program to measure the pressure as a function of time. The data is saved on a floppy by the command WRTEPRN("a:FileData"):Vdata statement.

D. Analysis

Determine the frequency of the damped oscillation ω' and the time constant β. Use this result to determine the undamped angualr frequency ω. Now determine the adiabatic exponent γ, and do an error analysis. Compare with known result $\gamma = 1.4$. Discuss any discrepancy.

APPENDIX E

skip to content

- Home
- The Book
- Topics
- Store
- News/Updates
- Other Publications
- Flying Circus Blog
- About Jearl Walker
- Links
- Email Sign Up

- Site Map
- Privacy Statement
- Terms of Use
- Contact Us

***The Flying Circus of Physics* is a book of questions and answers about curious events and effects of the everyday world. The "Spotlight" lead story and samples from the book are given below. At the left, click on the menu for the following:**

Store: books, tee shirts, mug
News/Updates: more new stories added around the first of each month. Many archived stories, all free. Many hundreds of video links, including me on television.
Topics: Click on a chapter and then the PDF icon near the armadillo to find all the new stories, almost 2000 links to videos and photos, and over 10,000 references. View them on screen and save or print anything you want, all free. To print something, highlight it, copy it (control-C), and then paste it (control-V) into a word document. Also, under "Physics for...", catch the minor adventures of physics major Jay Waller, who shows that physics is *everywhere*.
Blog: Links to photos of me (bed of nails and fingers in molten lead), messages to/from me. I would love new ideas and references.
---- Jearl Walker
ps. If the biplane at the top of the page doesn't have sound and motion, download the free flash player from Adobe.com.

Flying Circus of Physics Spotlight

Indiana Jones and the Kingdom of the Crystal Skull

Thursday, May 01, 2008

As of May , de a s of h e new Ind ana ones o e (d e o on May 22) a e c ose y a ded, b spec a on based on h e e eased e s h a cen e s on h e c ys a s s h a f s appea ed n h e h ands of a h aeo o s s and w o d-be a h aeo o s s abo 0 yea s a o. S h a s . . .

Flying Circus of Physics Sample

Cocktail-party effect

In a s a pa y w h peop e s and n and a n n pa s, each e be of a pa s ands a a "soc a y accep ab e" d s ance f o h e o h e and h e w o can h ea each o h e w h o any o b e. How e e , as h e dens y of peop e n h e oo nc eases, w h y does h ea n beco e o e d ff c , and w h a does each e be of a pa do n esponse? h y can a o ces be d s n shed? o h no ce h ese sa e effec s n any o h e en on en s, s ch as a no sy es a an , o s b w ay ca . MORE

APPENDIX F

PHYSICS DAY 2008

Time	***Lecturer/Location/Group***		
9:00 9:20	Dr. Wood (SI 117) **I & II**		
9:40 10:00	Dr. Alla (SI 149) **I**	Dr. Streletzky (SI 140) **IIA** Dr. Streletzky (SI 140) **IIB**	Dr. Hambourger (SI 102) **IIB** Dr. Hambourger (SI 102) **IIA**
10:20 10:40	Dr. Alla (SI 149) **II**	Dr. Streletzky (SI 140) **IA** Dr. Streletzky (SI 140) **IB**	Dr. Hambourger (SI 102) **IB** Dr. Hambourger (SI 102) **IA**
11:00 11:30	Lunch (SI 117) **I & II**		

Group IA- Tara
Group IB- Nichole Harris
Group IIA- Jessica Schwan
Group IIB- Slava