



**Program:** B.S./B.A. in Physics

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**Department:** Physics

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### 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 modifications detailed below and on the following pages, was discussed and approved by unanimous vote of the full-time Physics faculty on February 21, 2006.

**How and when were the goals developed?** The goals were developed in 1995 by the Department of Physics faculty. They were modified slightly in consultation with the Physics faculty in 2003 and were re-approved by the Physics faculty in 2005. Goal #2 (computational skills) was modified in 2006 by deleting an obsolete programming language. This change was discussed and approved by unanimous vote of the full-time Physics faculty on February 21, 2006.

**How and when were the outcomes developed?** The outcomes were developed in AY 1995-96 and 1996-97 by the Department of Physics faculty. They were modified slightly in consultation with the Physics faculty in 2003 and were re-approved by the Physics faculty in 2005. The outcomes were reviewed and approved by unanimous vote of the full-time Physics faculty on February 21, 2006.

#### **Assessment modifications in AY 2005-2006 (details on following pages):**

- Data collection has been revised to reduce the chance of “missing” students and to make testing instruments more uniform. The Subject Knowledge test will now be given during class time in PHY 330 – a required course for all B.S. and B.A. majors. Most of the Computer Project data and Laboratory data will now come from the lab portion of PHY 474 – also required for all B.S. and B.A. majors - increasing uniformity of assessment.
- The department chair will discuss Subject Knowledge Test data once per year with the department faculty and also with the professor who teaches most of the Introductory Physics courses for the majors.
- The Laboratory Skills data now come from approximately three experiments done in PHY 474 – required for all B.S. and B.A. majors – rather than from a single experiment performed out-of-class-time by individual students.

#### **Curriculum and services modifications in AY 2005-2006 (details on following pages):**

- A new Modern Physics laboratory course – PHY 335 - was developed and approved. It will be an elective for the B.S. and B.A. degrees and will increase the students’ hands-on laboratory skills and report-writing skills, as required for many industrial R&D positions. (The course has been approved for Writing Across the Curriculum).
- Free tutoring by graduate students is now available to all students in PHY 241-244 (University Physics I and II).



**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. (The written analysis portion will be reviewed in AY 2006-7).**

Outcomes	Research Methods	Findings	Review	Actions
1). 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.	Nobody took the test in AY 2005-2006. It has become too difficult to contact each student and get them to appear for the test. This will be corrected effective Fall 2006 by giving the test on class time in PHY 330 (required course for all B.S. and B.A. Physics majors).	The testing problem was reviewed at a faculty meeting on February 21, 2006 and corrective action taken as shown at right. Beginning in AY 2006-2007, the department chair will discuss the data once per year with the department faculty and also with the professor(s) who do most of the PHY 241-244 teaching.	Effective Fall 2006 the Subject Knowledge test will be given during class time in PHY 330, which is required for all B.S. and B.A. Physics majors. PHY 330 is offered once per year, in the Fall semester. This decision was approved by unanimous vote of the full-time Physics faculty on February 21, 2006. Free tutoring by graduate students is now available to all students of PHY 241/243 and 242/244.
2). 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 2005-2006, all data came from the new computer exercises done by all students in PHY 474 – Thermal Physics.  Results (maximum possible = 100): Number of students: 8 Lab 1: Avg=83 ± 7, Range 80-100 Lab 4: Avg=85 ±8, Range 80-100 Lab 5: Avg=76 ±21, Range 50-100  Rubrics in Appendix B, Lab Manual in Appendix D.	Since the new computer exercises have been given only once, we do not yet have comparative data over time. The average score on Labs 1 and 2 (84 out of 100) appears to be very good/excellent given the complexity of the physics and mathematics involved. The lower average score on Lab 5 (76 out of 100) is reasonable since this exercise also included paper derivation of formulae. Formal faculty review will begin in AY 2006-2007, when more data will be available.	An additional source of computer projects – exercises given in PHY 474 – was initiated. Since all B.S. and B.A. majors take this course, these exercises should provide a more uniform assessment than our other measures.  Since the new exercises have been performed only once (by eight students), we do not have sufficient evidence to make curricular changes at this time. Formal review, and possible corrective actions, will begin in AY 2006-2007.



**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	Research Methods	Findings	Review	Actions
1). Logical, analytical and computational skills	<p>1). During junior or senior year, each student does a Computer Project as part of a major Physics course. Among other things, this tests the student's logical, analytical and computational skills listed in Goal 2. The projects are graded by the professor teaching the course. Projects and rubrics are described on previous page and in Appendix B (page 5).</p> <p>2). Chair and faculty solicit feedback from alumni and re their success in jobs and/or graduate school.</p>	<p>In AY 2005-2006, all data came from the new computer exercises done by all students in PHY 474 – Thermal Physics. Use of these for assessment was approved by unanimous vote of the full-time Physics faculty on Feb 21, 2006.</p> <p>Results (maximum possible = 100):</p> <p>Number of students: 8</p> <p>Lab 1: Avg=83 ± 7, Range 80-100</p> <p>Lab 4: Avg=85 ±8, Range 80-100</p> <p>Lab 5: Avg=76 ±21, Range 50-100</p> <p>Details and rubrics in Appendix B.</p>	<p>Since the new computer exercises have been given only once, we do not yet have comparative data over time.</p> <p>The average scores demonstrate high effectiveness of program's training in logical, analytical, and computational skills.</p> <p>Formal faculty review will begin in AY 2006-2007, when more data will be available.</p>	<p>This Goal was reviewed by the department faculty. Pascal was deleted from the list of programming languages. The others are still heavily used by practicing physical scientists and engineers. (FORTRAN programs are now run on personal computers and modern supercomputers). Revised Goal 2 was approved by unanimous vote of full-time Physics faculty on Feb 21, 2006.</p> <p>Since the new computer exercises have been given only once, no curricular changes were made in AY 2005-2006.</p>
2). Ability to apply subject knowledge to concrete problems	<p>1). The Computer Project described in the cell above also tests the student's ability to apply subject knowledge to concrete problems relevant to the course in which it is done.</p> <p>2). Chair and faculty solicit feedback from alumni and re their success in jobs and/or graduate school.</p>	Described in the cell above.	<p>Described in the cell above.</p> <p>Results demonstrate high program effectiveness in teaching students to apply their subject knowledge to specific computational analyses.</p>	Described in the cell above.



**Goal 3: Have laboratory skills to set up an experiment and to acquire and analyze data.**

Outcomes	Research Methods	Findings	Review	Actions
<p>1). Ability to set up an experiment and to acquire and analyze data</p>	<p>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.</p> <p>This change of assessment tool was approved by unanimous vote of the full-time Physics faculty on Feb. 21, 2006.</p>	<p>Results (maximum possible = 100):            Number of students: 8            Lab 2:            Avg=85 ± 6, Range 80-95            Lab 3:            Avg=67 ±20, Range 45-90            Lab 6:            Avg=73 ±14, Range 60-98            Details and rubrics in Appendix C, Lab Manual in Appendix D.</p>	<p>Since the new lab experiments have been used only once, we do not yet have comparative data over time.</p> <p>The average scores are somewhat lower than those on the other formal outcome measures, possibly suggesting a need for additional lab experience.</p> <p>Formal faculty review will begin in AY 2006-2007, when more data will be available.</p>	<p>The lab skills assessment tool was changed from one experiment to three as described under "Research Methods" at left.</p> <p>Per Review at left, a lab course, PHY 335 – Modern Physics Laboratory (4 credit hours, with WAC credit) was developed and approved during AY 2005-2006 to increase hands-on lab and report-writing skills. It will be an elective for the Physics B.S. and B.A. degrees. Course description is in Appendix E.</p> <p>Both actions were approved by unanimous vote of the full-time Physics faculty on Feb. 21, 2006.</p>
<p>2). Ability to apply subject knowledge to concrete problems</p>	<p>The lab experiment described above also tests 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.</p>	<p>Described in the cell above.</p>	<p>Described in the cell above.</p>	<p>Described in the cell above.</p>



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**Appendix A**  
**General Physics Test**

(Goal #1, Outcome 1)

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%.



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Appendix B
Computer Project

(Goal #1, Outcome 2 and Goal #2, Outcomes 1 and 2)

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 05

Assessment – Spring 2006 (Computer exercises)

Number of Students: 8

Lab 1: Mass of Atmosphere [Computer]

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

Table with 2 columns: Question description and Points. Rows include 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 83 ± 7, range 80-100

Lab 4: Stability of Dry Air and Brunt-Vaisala Oscillations [Computer]

Objective: (1) Find analytic expression for temperature profile
(2) Derive expression for the frequency of oscillation
(3) Numerical integration of nonlinear equation using Runge-Kutta Method

Table with 2 columns: Question description and Points. Rows include Q1 (Find buoyant force for parcel of air) 10 pts, Q2 (Derive expression for temperature profile) 10 pts, Q3 (Find lapse rate for dry air) 10 pts, Q4 (Qualitative discussion of nonlinear differential equation) 20 pts, Q5 (Numerical integration of nonlinear differential equation) 25 pts, Q6 (Plot height of parcel of air vs time) 10 pts, Q7 (Discussion of two cases) 10 pts, Q8 (Find numerical values) 5 pts.

Total 100 pts

Statistics: Score 85 ± 8, range 80-100



**Lab 5: 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
<hr/>	
Total	100 pts

**Statistics: Score 76 ± 21, range 50-100**

**Statistical Physics, Monte Carlo Simulation of Complex Systems, Environmental Physics, and Computational Physics**

Each project contains approximately ten computing assignments. The assignments test students' application of theory to solving problems, use of mathematical models of the physical world, ability to use algebra, geometry, trigonometry and calculus, and mastery of computational software. For example, the assignments in Statistical Physics cover numerical simulations of magnetic cooling, negative temperatures, Einstein and Debye quantum models of solids, electromagnetic (blackbody) radiation, electron gas model of metals, Bose condensation, and the Ising model of ferromagnetism.

The assignments carry equal weight.

*Scoring rubrics for each assignment:* 90% or more of assignment satisfactorily completed – full credit. Less than 90% of assignment satisfactorily completed – no credit.



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Appendix C
Hands-on Laboratory Experiments

(Goal #3, Outcomes 1 and 2)

Thermal Physics Laboratories PHY474 – Fall 05

Assessment – Spring 2006 (Hands-on laboratory experiments)

Number of Students: 8

Lab 2: Constant Volume Gas Thermometer [Experiment]

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

Table with 2 columns: Question description and Points. Rows include Q1 (Find ambient pressure in kPa) 10 pts, Q2 (Record pressure for temperatures 0° C – 100° 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 85 ± 6, range 80-95

Lab 3: Mechanical Equivalent of Heat [Experiment]

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

Table with 2 columns: Question description and Points. Rows include 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 67 ± 20, range 45-90



**Lab 6: 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

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Total 100 pts

**Statistics: Score  $73 \pm 14$ , range 60-98**

**PHY 474 THERMAL PHYSICS**  
**Computational Projects and Laboratories**

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## Appendix D

### 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  $M = \rho Adz$  so that

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

[Is the density  $\rho$  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:

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

## Appendix D

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

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

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  $\kappa = 0.02$ ]:

$$P(n) := \left. \begin{array}{l} \kappa := 0.02 \\ P \leftarrow 1 \\ \text{for } x \in 1..n \\ P \leftarrow (1 - \kappa) \cdot P \end{array} \right\}$$

**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

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

Calculate the density at sea level.

The total mass is obtained by integrating the density:

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

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

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

where

$$\lambda = \frac{R_e}{L} = \frac{6.37 \times 10^6 \text{ m}}{8.04 \times 10^3 \text{ m}} \simeq 792.$$

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

$$\begin{aligned} M_{\text{atm}} &= \frac{4\pi P(0)R_e^3 m}{kT} \cdot 1.27 \times 10^{-3} \\ &= \frac{4\pi \cdot 1.27 \times 10^{-3} \cdot 1.013 \times 10^5 \text{ Nm}^{-2} \cdot 2.58 \times 10^{20} \text{ m}^3 \cdot 28.8 \times 1.661 \times 10^{-27} \text{ kg}}{1.38 \times 10^{-27} \text{ JK}^{-1} \cdot 300 \text{ K}} \\ &\simeq 5 \times 10^{18} \text{ kg.} \end{aligned}$$

We observe that the mass of the atmosphere is very small compared to the mass of the Earth  $M_e \simeq 6 \times 10^{24} \text{ kg}$ .

## 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

$$P = b + mT, \quad (1)$$

where  $P$  is the absolute pressure,  $T$  is the temperature in degree Celsius,  $m$  is the slope 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

$$T_0 = -\frac{b}{m}. \quad (2)$$

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 is 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  $P_g$ :

$$P_g = V_G \frac{1250 \text{ KPa}}{\text{V}}. \quad (3)$$

The absolute pressure in the bulb is then

$$P = P_g + P_B, \quad (4)$$

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

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

## Appendix D

### 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  $0^\circ\text{C}$ .
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  $0^\circ\text{C}$ . 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  $10\text{--}15^\circ\text{C}$ . 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  $10^\circ\text{C}$ . 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  $100^\circ\text{C}$ , 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 rechecking each pressure sensor reading.

### D. Data Analysis

1. Using a sheet of graph paper, label the horizontal axis in units of  $^\circ\text{C}$ , with the scale extending from  $-300^\circ\text{C}$  to  $+100^\circ\text{C}$ . 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 mercury thermometer at boiling and freezing temperatures.

## Appendix D

### 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 absolute 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 position several inches above the floor. The work done on the cylinder is  $W = \tau\theta$ , where  $\tau$  is the torque exerted by the nylon cord and  $\theta$  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

$$W = RMg2\pi N. \quad (1)$$

The cylinder is made of aluminum with a specific heat

$$c \simeq 215 \frac{\text{calories}}{\text{kg } ^\circ\text{C}}. \quad (2)$$

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  $\Delta T$ :

$$Q = mc(T_f - T_i). \quad (3)$$

The mechanical equivalent of heat is defined

$$J = \frac{W}{Q}. \quad (4)$$

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

## Appendix D

### 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 transferred into the calorimeter from the room to help offset the heat transferred 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

$R$ [k $\Omega$ ]	$T$ [°C]	$R$ [k $\Omega$ ]	$T$ [°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
104.80	24	41.29	45
100.00	25	39.61	46

#### IV. STABILITY OF DRY AIR AND BRUNT-VAISALA OSCILLATIONS

##### A. Stability of Dry Air

We consider a volume  $V$  of dry air [‘parcel’] with density  $\rho$  surrounded by air with density  $\rho'$ . Archimedes principle then gives for the acceleration of the volume of dry air:  $\rho V \cdot a = \rho' V \cdot g - \rho V \cdot g$  so that the acceleration of the dry air parcel follows

$$a = g \frac{\rho' - \rho}{\rho} = g \left( \frac{\rho'}{\rho} - 1 \right). \quad (1)$$

We assume the ideal gas law to write  $\rho/\rho' = T'/T$ , where  $T$  is the temperature of dry air and  $T'$  is the temperature of atmosphere.

$$a = g \left( \frac{T}{T'} - 1 \right). \quad (2)$$

**Q1:** Use numerical examples to test this equation. Does it agree with your expectations?

##### B. Temperature Profile

As a result of this acceleration, a parcel of air initially at the height  $z_0$  moves to a height  $z$ . We assume that the parcel does not exchange heat with the surrounding so that the process is adiabatic. This means that dry moving up (down) will cool down (warm up). As a result, the temperature depends on the height: temperature profile  $T = T(z)$ . We apply the first law to one mole of gas:

$$C_p(T - T_0) = -Mg(z - z_0), \quad (3)$$

where  $M$  is the molar mass. We solve for  $T$ :

$$T = T_0 - \frac{Mg}{C_p}(z - z_0) = T_0 - \Gamma(z - z_0). \quad (4)$$

where we introduced the *lapse rate*  $\Gamma = Mg/C_p$ .

**Q2:** Derive Eq. (3).

**Q3:** Find the lapse rate for dry air [i.e., an ideal, diatomic gas].

##### C. Brunt-Vaisala Oscillations

We assume that the lapse rate of the ambient air is different from the lapse rate for dry air:

$$T'(z) = T_0 - \gamma(z - z_0), \quad \gamma \neq \Gamma. \quad (5)$$

Inserted into Eq. (2), we get

$$\frac{d^2 z}{dt^2} = g \left( \frac{T(z)}{T'(z)} - 1 \right). \quad (6)$$

**Q4:** Discuss *qualitatively* the cases  $\gamma < \Gamma$  and  $\gamma > \Gamma$ .

## Appendix D

Numerical solution using MathCad: Define the temperature profiles:

$$T(z) := T_0 - \Gamma \cdot (z - z_0), \quad (\text{dry air}) \quad (7)$$

$$Te(z) := T_0 - \gamma \cdot (z - z_0). \quad (\text{ambient air}). \quad (8)$$

We define

$$z_0 = z, \quad z_1 = v = \frac{dz}{dt}. \quad (9)$$

The second-order differential equation can then be written:

$$\frac{dz_0}{dt} = z_1 \quad (10)$$

$$\frac{dz_1}{dt} = g \cdot \left( \frac{T(z_0)}{Te(z_0)} - 1 \right). \quad (11)$$

This is implemented in MATHCad as:

$$D(t, z) := \begin{pmatrix} z_1 \\ g \cdot \left( \frac{T(z_0)}{Te(z_0)} - 1 \right) \end{pmatrix}. \quad (12)$$

The initial conditions are written

$$\text{init\_cond} = \begin{pmatrix} z_0 \\ v_0 \end{pmatrix}. \quad (13)$$

We use the Runge-Kutta method to integrate the coupled differential equations:

$$\text{solut\_dfq} = \text{rkfixed}(\text{init\_cond}, 0.2000, 2000, D). \quad (14)$$

Note that rkfixed returns a matrix in which the first column contains time, the second column contains position, and the third column contains the velocity:

$$t := \text{solut\_dfq}^{\langle 0 \rangle}, \quad (15)$$

$$z := \text{solut\_dfq}^{\langle 1 \rangle}, \quad (16)$$

$$v := \text{solut\_dfq}^{\langle 2 \rangle}. \quad (17)$$

**Q5:** Use  $\Gamma \simeq 1 \times 10^{-2} \text{ Km}^{-1}$  and  $\gamma = 0.6 \times 10^{-2} \text{ Km}^{-1}$ . Plot the graph  $z$  vs.  $t$ .

**Q6:** We found a periodic motion of the parcel of dry air. Derive an expression for the period and compare with your numerical results.

**Q7:** Discuss the cases  $\Gamma > \gamma$  and  $\Gamma < \gamma$ .

**Q8:** The ambient lapse rate can become negative [in what atmospheric condition?]. For  $\Gamma \simeq 1 \times 10^{-2} \text{ Km}^{-1}$ , find the lapse rate  $\gamma$  that corresponds to a period of 3 minutes.

## Appendix D

### V. RUCHARDT METHOD FOR MEASURING $C_p/C_v$

A precision 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

$$mg + AP_{\text{atm}} = AP_0. \quad (1)$$

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,

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

We assume that the compression and expansion of the air inside the vessel is “fast,” and thus ignore heat exchange with the environment. 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

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

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

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

**Q2:** How are “small” oscillations characterized?

**Q3:** Find the “linearized” equation of motion.

Since  $AP_{\text{atm}} + mg = AP_0$  this can be simplified:

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

For  $z/l \ll 1$ , we have

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

Inserted above we have

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

This is the equation for a harmonic oscillator. The (angular) frequency  $\omega$  follows

$$\omega^2 = \frac{\gamma A^2 P_0}{m V_0} \quad (8)$$

## Appendix D

### A. MathCad Implementation

We define

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

and

$$N := 800, \quad T_{\text{tot}} := \frac{N}{200} T_{\text{approx}}, \quad n := 0..N. \quad (10)$$

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

$$\zeta := \begin{pmatrix} 10 \\ 0 \end{pmatrix}. \quad (11)$$

The equations of motion read

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

The integration is done using the Runge-Kutta method:

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

MathCad gives the result in matrix form:

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

**Q4:** What happens if the initial displacement is large?

## VI. RUCHARDT 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 preceding lab we have derived an equation for the displacement of the ball in the tube:

$$\frac{d^2 z}{dt^2} = -\frac{\gamma A^2 P_0}{m V_0} z, \quad (1)$$

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

$$z = -\frac{V}{\gamma P A} \Delta P. \quad (2)$$

Show that the pressure change obeys the same differential equation:

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

where  $\omega^2 = \gamma A^2 P_0 / m V_0$ .

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:

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

The solution reads:

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

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

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

**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. Therefore, we use a method that makes it possible to lift the ball to the top of the tube without handling it. First the ball is prevented from falling into the jug by a wire stop attached to the rubber stopper at the top of the jug. Secondly a pressure bulb air pump connected to the stopcock at the bottom of the jug is used to levitate the ball to where it can be held just above the tube by an electromagnet.

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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 when 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 low 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  $\omega'$  and the time constant  $\beta$ . Use this result to determine the undamped angular frequency  $\omega$ . Now determine the adiabatic exponent  $\gamma$ , and do an error analysis. Compare with known result  $\gamma = 1.4$ . Discuss any discrepancy.

## Appendix E

Proposal  
Kiril Streletzky  
Modern Physics Laboratory (PHY335) – 4 credit hours

### **Background:**

The physics department currently faces a growing number of students in the medical physics program. We also have an increased student interest in optical and material physics programs, stimulated by the research activity of physics faculty in these areas. Indeed, Dr. Hambourger, Dr. Vitali, and Dr. Streletzky have students working in their research labs. (Dr. Zurcher and Dr. Lock also have students working with them). In this environment of the increased number of higher level physics students, the addition of a new intermediate level laboratory course should be well received. We also starting to get exceptionally good students interested in physics from the Honors Program.

In addition, the feedback from our physics majors indicates three most common complaints. First is the limited choice of lab courses in our program beyond our superb introductory laboratory. Indeed, we have only one intermediate laboratory course (Electronics Lab, PHY 360) and only one advanced laboratory course (Advanced Optics Lab, PHY 455/555). Second is the lack of any modern physics experiments (such as e/m, photoelectric effect, atomic spectra, or radioactivity) in a typical curriculum of any physics major. Third is the gaping absence of basic knowledge of error analysis and experiment design. Our exceptional but fast-paced university physics laboratory curriculum does not allow physics majors to learn the basic principles of measurement theory and experiment design.

I believe these complaints give us a glimpse of some of the shortcomings of our upper level physics program. In order to increase the competitiveness of our program we need to address these issues.

### **Goals of the course:**

- 1) To expose students to real physics experiments beyond Optics and Electronics (the topics of two existent upper level laboratory courses).
- 2) To create a laboratory course that would complement our popular Introduction to Modern Physics course (PHY330). The proposed lab will be a logical extension to PHY330 offering students the opportunity to do the experiments discussed in PHY330.
- 3) To eliminate the gap in education of our physics majors who by taking university physics, PHY 241/242 (instead of college physics, PHY 221/222) skip the important modern physics experiments (e/m, photoelectric effect, atomic spectra, etc).
- 4) To introduce our physics majors to the basic of Experiment Design and Measurement Theory.
- 5) To support our expanding medical and material physics programs by introducing students to modern material characterization techniques: X-ray structural analysis and NMR.
- 6) To insure broad experimental training of the physics majors for research environments of hospitals, industrial labs, and academia.
- 7) To prepare our physics majors for real lab/research experience in one of the Physics Department labs and/or theoretical groups.

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### Schedule:

The course will be offered in alternative years to the Advanced Optics Laboratory. Most of the experimental equipment (1 set up of each) for an initial run of the course has already been purchased using funds from Housebill-2004 and Housebill-2005. The only exception is the black body radiation set up, which is planned to be purchased under Housebill-2006.

### Content:

This course will begin by a brief introduction to Measurement Theory and Experiment Design and will be followed by several important experiments from the curriculum of university physics, modern physics, optics, and medical physics.

Here is the tentative schedule:

#### Lab Module 1

- 1) **Introduction to Error Analysis & Experiment Design** (*1.5 weeks*) - lectures
- 2) **Millikan Oil Drop Experiment - Nobel Prize-Quality Physics in the Student Lab** (*1.5 weeks*)  
**{in parallel with e/m Lab}**
- 3) **Measurement of the Speed of Light** (*1 week*) Foucault Method  
**{in parallel with Polarization of light Lab}**
- 4) **Microwave Radiation – Wave Optics in Centimeter Range** (*1.5 weeks*)  
Standing waves - nodes – antinodes, reflection, refraction, polarization, double slit, Michelson & Fabry-Perot interferometers, Brewster angle, Bragg Diffraction

#### Lab Module 2

- 5) **Black Body Radiation** (*1 week*)  
**{in parallel with Photoelectric effect Lab }**
- 6) **Two slit Interference, One Photon at a time**  
in parallel with  
**Earth's Field NMR, Conceptual Introduction to NMR** (*4 weeks total*)  
Curie Law, Proton spin-lattice relaxation time in water

The last Lab Module will be focused on X-ray Physics and will offer a multitude of experiments in atomic, nuclear, and solid state physics. Given the attractiveness of X-ray physics experiments to medical physics, biomedical, chemistry, and pre-med students, I would propose to have the entire block of 3 experiments on the same X-ray set up:

#### Lab Module 3

- 7) **X-ray Detection, X-ray photography, and X-ray attenuation** (*1.5 weeks*)  
fluorescence of a luminous screen and fogging of film pack in light-tight bag at different exposure dose, effect of absorber thickness, attenuation dependence on wavelength, attenuation dependence on the atomic number  
**{in parallel with Radioactivity Lab}**

## Appendix E

### 8) The Physics of the Atomic Shell (*1 week*)

examples: Bragg reflection at monocrystal, determination of Planck's constant, measurement of Rydberg constant, Compton effect

**{in parallel with Hydrogen Spectrum Lab}**

### 9) X-ray Structural Analysis (*2 weeks*)

Laue Diagrams – lattice structure of monocrystals; Debye-Scherrer photography/scan -lattice plane spacing of polycrystalline powder samples

Class meeting frequency: twice a week/ 4 hours per meeting.  
Prerequisites: University Physics 1 and 2 (PHY241/242)  
Introduction to Modern Physics (PHY330)  
Tentative textbook: "An Introduction to Error Analysis" by John R. Taylor  
or "Experimentation: An Introduction to Measurement Theory and Experiment Design" by D. C. Baird

#### **Note:**

In parallel to experiments 2, 3, 5, 7, and 8, students will be assigned the corresponding introductory physics labs from PHY 221/222. This will fulfill two goals:

- a) Students will get exposed to such important experiments as photoelectric effect, e/m measurement, atomic spectra, and polarization effect. These quintessential experiments are currently left out beyond lab curriculum of the physics majors.
- b) The scheduling issue of dealing with limited number of advanced physics experimental set ups will be partially solved by dividing students into two groups and assigning them separate experiments during corresponding weeks.

Also item #6 consists of two complicated experiments that will be done in parallel for a period of 4 weeks total.

#### **Conclusion:**

The addition of the modern physics laboratory should undoubtedly increase the visibility of our program, promote interdisciplinary student education, and better prepare our graduates for research hospitals, industrial labs, and academia.

## Appendix E

PHY 335

Spring, 200X

### Syllabus

#### **Lecturer**

Lecturer and lab coordinator for PHY355 is Dr. Kiril A. Streletzky.

Office: SI 124; email address: [k.streletzky@csuohio.edu](mailto:k.streletzky@csuohio.edu); phone: 687-2433.

#### **Meeting Times**

Lecture/Lab: M, W 6:00-10:00 pm, SI 140

Office Hours: Tu and Th 10-11am; M and F 2:00-3:00pm, SI 124

#### **Academic Calendar Related to This Class**

First day of the class:	Jan
Last day to add:	Jan
Last day to drop:	Jan
Last day to withdraw:	Mar
Spring Break:	Mar – Mar (No classes)
Last day of the class:	May
Final Presentation:	May

#### **Course evaluation**

Your grade will be calculated as follows:

Regular Lab Reports (9)	(Each 8%)	72%
Quizzes (8)	(Each Quiz – 1.5%)	12%
Regular lab Presentations (2)	(Each – 4%)	8%
X-ray Lab Presentation	(1)	8%

#### **Lectures**

First week and half of the semester we will spend outside the lab, studying the error analysis and experiment design. Every week after that you will spend most of the class time in the lab, working on your experiments. Once a week, however, we are going to meet for a short lecture (1 hour – 1.5 hours) covering theoretical background and basics of experimental procedure. Attending these lectures is **essential** for the proper understanding of the material. The students are responsible for all the material discussed in class. Attendance requirements are stated in the CSU Undergraduate Bulletin.

#### **Regular Lab Reports**

The laboratory reports are to be kept in a hardbound notebook for all closed experiments. These reports need not be very elaborate. However, the reports should contain:

- 1) A statement of the object of the experiment
- 2) A brief description of the method, including a schematic optical diagram of the essential apparatus.
- 3) Tables of all the data taken, not just the best data.
- 4) The results, with typical calculations, and any derivations required.
- 5) A discussion of the accuracy of the experiment.
- 6) Any additional observations made during the experiment.

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The report should be prepared almost entirely in the laboratory. The goal is to learn taking the data directly in the notebook and to writing up an experiment neatly and adequately while it is being done. The ideal notebook is a clear, legible, working notebook, containing all pertinent and little superfluous information. The report should be understood by anyone reasonably informed on the subject without any additional explanation. Approach the experiment and the writing of the report as if you were doing publishable research.

In discussing the accuracy of the results, list the factors that might limit the accuracy. For as many of those factors as possible, make a numerical estimate of the uncertainty and its effect on the result. Single out those factors, which are most important and base an estimate of the accuracy of the final result on them. While doing an experiment, it is important to take repeated readings of each measured quantity in order to estimate the uncertainty in the measurement.

### Three Lab Presentations

The important component of the course curriculum is lab presentations. After completing each of the lab modules (Lab Module 1: Millikan, Speed of Light, Microwave; Lab Module 2: Black Body, Two Slit, NMR; Lab Module 3: X-ray) you will have to present your findings to the class and lecturer and be able to answer questions that arise during presentation. In addition to your experimental findings, you should present the theoretical basis of the experiment at least in the scope given to you in the Lab Manual. Make sure you can explain the formulas that you have been using as well answer simple questions on the subject. Since you are going to work on the experiments in pairs I expect from both partners to actively participate in presentation. Each student should present some theory and some of the results which are not presented by his partner. Usage of Power Point is encouraged. However, you can also present your results on overhead transparencies. More detailed guidelines on the length and content of each presentation will be given to at later point in time.

Note: each of your first two presentations will cost 4% of your final grade. You will get comments from after each presentation. The final presentation (on X-rays) will cost 8% your grade and will take place on the date of your final exam.

### Quizzes

As means of encouraging you to think about physics of the experiments you do in the lab you will be given 8 quizzes on the subject of regular lab experiments. Approximately, half of the quizzes will be take-home, the rest – in class quizzes. The in-class quizzes will take place during the scheduled lectures (see Schedule). I will be announcing the quiz dates and details on quiz taking as we proceed.

### Writing Requirement

PHY355 has **writing** requirement. You will prepare three essays outside of class in a form of polished lab reports with detailed outline of physical principles of the experiment, the experimental procedure, your analysis of the obtained data and experimental errors, and finally your conclusions about the lab. The detailed instructions

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about all three write-ups are going to be given to you during the corresponding lab experiment.

**ESSAY #1:** about 700 words about any Lab from Module 1. I will return this essay to you with my comments.

**ESSAY #2:** about 700 words about any Lab from Module 2, I will return this essay to you with my comments.

**ESSAY #3:** about 700 words about any Lab from Module 3. I will not return this essay.

You need a total of at least 2100 words. The writing is graded as pass or fail. In order to receive a C or better in this course, the student must write at a satisfactory level (C or better). If the student's writing is weak, but shows understanding of the course material, the student may be assigned a D, in which case WAC credit will not be received for the course. If you pass the writing component of the course then your grade is determined by exams, quizzes, homework, labs, computer project as explained above.