Cleveland State University

2007 Assessment Report

Program:	B.S./B.A. in Physics	**Completed By:**	Paul D. Hambourger, Assoc. Professor of Physics
Department:	Physics	**Date:**	May 30, 2007

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.

Highlights of AY 2006-2007:

- The new Modern Physics laboratory course (PHY 335) developed in AY 2005-2006 was given experimentally in Spring 2007 as a 2 CH Independent Study course. Hereafter it will be given in alternate years as a 4 CH course with Writing Across the Curriculum credit (already 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.
- Free tutoring by graduate students for students in PHY 241-244 (University Physics I and II) continued as initiated in 2005-2006.
- CSU's Physics bachelor's degree production for the years 2002-2004 ranks 5th in the nation among M.S.-granting departments. (American Institute of Physics Report R-151.41 – see attached Appendix E).
- The Physics Department's increase in bachelor's degrees awarded per year (138% in 2003-05 vs 1997-99) ranks 4th in the nation among Ph.D.- and M.S.-granting departments. (*InterActions across physics and education*, March/April 2007 – see attached Appendix F).
- The National Task force on Undergraduate Physics compared bachelors degrees awarded in 2002-04 with those in 1997-99 and finds CSU's percentage increase to be in the top 30 in the US – see attached Appendix G.

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.	Test was given in Fall 2006 on class time in PHY 330 (required course for all B.A. and B.A. Physics majors. Results: Number of students: 12 Mean score: 55% (C/D).	Results will be reviewed by the Physics faculty in Fall 2007.	In the future, test results will be reviewed 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.
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 2006-2007, all data came from the new computer exercises done by all students in PHY 474 – Thermal Physics – Fall 2006. Results (maximum possible = 100): Number of students: 7 Lab 1: Avg=80 ± 14, Range 50-90 Lab 4: Avg=90 ±10, Range 65-100 Lab 5: Not done due to lack of time Rubrics in Appendix B, Lab Manual in Appendix D.	Since the new computer excercises have been given only twice, we have limited comparative data over time. The average scores on Labs 1 and 4 are in good agreement with those in 2005-2006 (83 and 85 respectively). These scores are very good/excellent given the complexity of the physics and mathematics involved. Formal faculty review will begin in AY 2007-2008, when more data will be available.	Since the new computer exercises have been performed only twice (by a total of 15 students), we do not have sufficient evidence to make curricular changes at this time. Formal review, and possible corrective actions, will begin in AY 2007-2008.

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	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 in Appendices B and D. 2). Chair and faculty solicit feedback from alumni and re their success in jobs and/or graduate school.	In AY 2006-2007, all data came from the new computer exercises done by all students in PHY 474 – Thermal Physics – Fall 2006. Results (maximum possible = 100): Number of students: 7 Lab 1: Avg=80 ± 14, Range 50-90 Lab 4: Avg=90 ±10, Range 65-100 Lab 5: Not done due to lack of time Rubrics in Appendix B, Lab Manual in Appendix D.	Since the new computer excercises have been given only twice, we have limited comparative data over time. The average scores demonstrate high effectiveness of program's training in logical, analytica, and computational skills. Formal faculty review will begin in AY 2007-2008, when more data will be available.	This goal was revised by the Physics faculty in AY 2005-2006; thus it was not necessary to revise it again in 2006-2007. Since the new computer exercises have been given only twice, no curricular changes were made in AY 2006-2007.
2). Ability to apply subject knowledge to concrete problems	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. 2). Chair and faculty solicit feedback from alumni and re their success in jobs and/or graduate school.	Described in the cell above.	Described in the cell above. Results demonstrate high program effectiveness in teaching students to apply their subject knowledge to specific computational analyses.	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
1). 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 2006-2007, all data came from the new hands-on lab experiments done by all students in PHY 474 – Thermal Physics – Fall 2006. Results (maximum possible = 100): Number of students: 7 Lab 2: Avg=66 ± 20, Range 50-80 Lab 3: Avg=70 ±24, Range 40-100 Lab 6: Avg=75 ±5, Range 70-80 Details and rubrics in Appendix C, Lab Manual in Appendix D.	Since the new lab experiments have been used only twice, we have limited comparative data over time. Average score for Lab 2 shows some decrease vs Fall 2005 (66 vs 85), while Labs 2 and 3 show small increases (70 vs 67, 75 vs 73). These scores are somewhat lower than those on the other formal outcome measures, possibly suggesting a need for additional lab experience. It should be noted that the first offering of PHY 335 – Modern Physics Laboratory – did not take place until *after* the data in cell to left were obtained. Formal faculty review will begin in AY 2007-2008, when more data will be available.	We anticipate that the new lab course, PHY 335 – Modern Physics Laboratory (4 credit hours, with WAC credit), first offered in Spring 2007, will 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 our 2006 Assessment Report. Establishment of PHY 335 was approved by unanimous vote of the full-time Physics faculty on Feb. 21, 2006.
2). 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.

Appendices

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%.

Appendix B
<u>Computer Project</u>

(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 06

Assessment – Computer exercises

Number of Students: 7

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 8- ± 14, range 50-90

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

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 90 ± 10, range 65-100

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
Total	100 pts

Statistics: Not done in Fall 2006

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.

Appendix C
<u>Hands-on Laboratory Experiments</u>

(Goal #3, Outcomes 1 and 2)

Thermal Physics Laboratories PHY474 – Fall 06

Assessment – Hands-on laboratory experiments

Number of Students: 7

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 66 ± 20, range 50-80

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 70 ± 24, range 40-100

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
Total	100 pts

Statistics: Score 75 ± 5, range 70-80

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 $M = \rho A dz$ 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

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

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* $\kappa = 0.02$]:

```
                κ := 0.02
P(n) := | P ← 1
        | for x ∈ 1..n
        | P ← (1 − κ) · P
```

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:

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

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

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

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 [$m = 28.8\,\text{u}$]

$$\begin{aligned} M_{\text{atm}} &= \frac{4\pi P(0)R_e^3m}{kT}\cdot1.27\times10^{-3} \\ &= \frac{4\pi\cdot1.27\times10^{-3}\cdot1.013\times10^5\,\text{Nm}^{-2}\cdot2.58\times10^{20}\,\text{m}^3\cdot28.8\times1.661\times10^{-27}\,\text{kg}}{1.38\times10^{-27}\text{JK}^{-1}\cdot300\text{K}} \\ &\simeq 5\times10^{18}\,\text{kg}. \end{aligned}$$

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:

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

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:

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

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 $10-15^\circ$ 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 $^\circ$ C, with the scale extending from -300° C to $+100^\circ$ 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.

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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
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 ρ surrounded by air with density ρ'. 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 accelaration of the dry air parcel follows

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

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.

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

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:

$$C_p(T - T_0) = -Mg(z - z_0), \tag{3}$$

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

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

where we introduced the *lapse rate* $\Gamma = Mg/C_p$.
Q2: Derive Eq. (3).
Q3: Find the lapse rate fro 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:

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

Inserted into Eq. (2), we get

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

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

Appendix D

Numerical solution using MathCad: Define the temperature profiles:

$$\begin{aligned} T(z) &:= T_0 - \Gamma \cdot (z - z_0), \quad \text{(dry air)} \qquad (7)\\ Te(z) &:= T_0 - \gamma \cdot (z - z_0). \quad \text{(ambient air).} \qquad (8) \end{aligned}$$

We define

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

The second-order differential equation can then be written:

$$\begin{aligned} \frac{dz_0}{dt} &= z_1 \qquad (10)\\ \frac{dz_1}{dt} &= g \cdot \left(\frac{T(z_0)}{Te(z_0)} - 1 \right). \qquad (11) \end{aligned}$$

This is implemented in MAthCad as:

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

The initial conditions are written

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

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

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

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:

$$\begin{aligned} t &:= \text{solut\_dfq}^{<0>}, \qquad (15)\\ z &:= \text{solut\_dfq}^{<1>}, \qquad (16)\\ v &:= \text{solut\_dfq}^{<2>}. \qquad (17) \end{aligned}$$

Q5: Use $\Gamma \simeq 1 \times 10^{-2}\,\mathrm{Km}^{-1}$ and $\gamma = 0.6 \times 10^{-2}\,\mathrm{Km}^{-1}$. 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 $\Gamma \simeq 1 \times 10^{-2}\,\mathrm{Km}^{-1}$, find the lapse rate γ that corresponds to a period of 3 minutes.

V. RUCHARDT METHOD FOR MEASURING C_p/C_v

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. 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 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. 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 attched 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.

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.

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By Patrick J. Mulvey
Starr Nicholson

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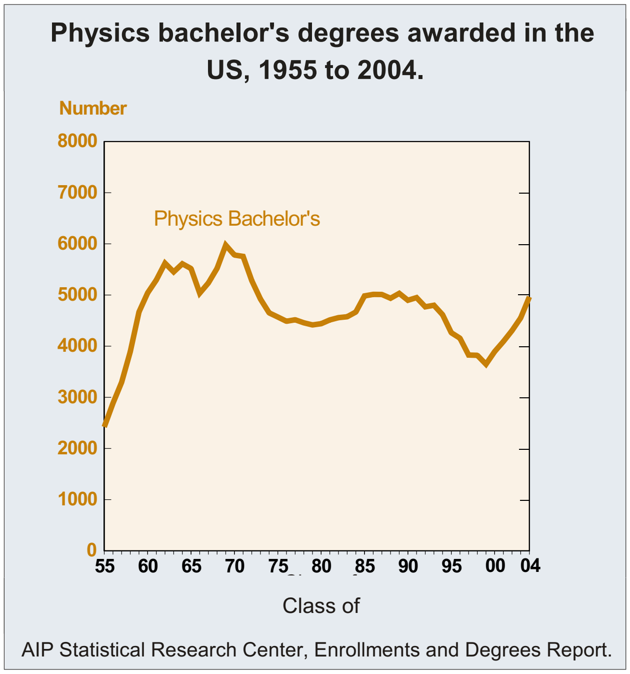
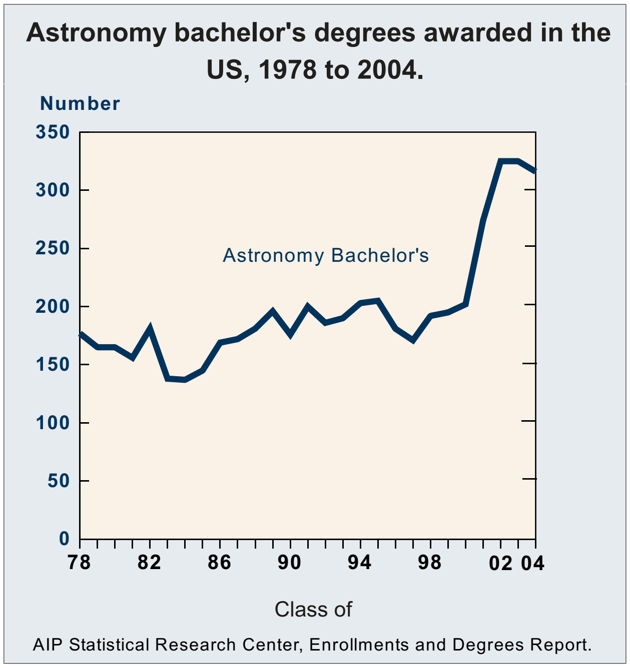
ENROLLMENTS AND DEGREES REPORT, 2004.



Physics bachelor's degrees awarded in the US, 1955 to 2004.

AIP Statistical Research Center, Enrollments and Degrees Report.



Astronomy bachelor's degrees awarded in the US, 1978 to 2004.

AIP Statistical Research Center, Enrollments and Degrees Report.

Highlights

- Physics bachelor's degree production continued to increase in 2004, up 36% over the recent low in 1999 **(Cover)**.

- In part due to the rise in physics bachelor's, the number of US citizens enrolling as first-year physics graduate students in the fall of 2004 increased 2% from the previous year, and is up 50% from their recent low in the fall of 1998 **(Figure 4)**.

- In contrast, the number of foreign students enrolling in US graduate physics departments declined 11% from the previous year. This decline is responsible for the overall decline of 4% in total first-year student enrollments, the first such decline in six years **(Figure 4)**.

- Steady increases are anticipated in PhD production, a result of the number of first-year students entering graduate school over the previous five years **(Figure 9)**.

Appendix E

Table 6. Master's-granting departments averaging 7 or more physics bachelor's degrees per year, classes of 2002, 2003 and 2004.

	Annual Average		Annual Average
Miami U (OH)	13	CA State U-Fullerton	8
Appalachian State U (NC)	11	SUNY-Binghamton U (NY)	8
CA State U-Northridge	11	U of CO, Colorado Springs	8
Northern Arizona U	11	Virginia Commonwealth U	8
Cleveland State U (OH)	10	Creighton U (NE)	7
Texas State U-San Marcos	10	San Diego State U (CA)	7
San Jose State U (CA)	9	San Francisco State U (CA)	7
Southwest Missouri St U	9	U of Memphis (TN)	7

Note: List includes only those departments who contributed degree data for all 3 years.
AIP Statistical Research Center, Enrollments and Degrees Report.

Table 7. PhD-granting departments averaging 20 or more physics bachelor's degrees per year, classes of 2002, 2003 and 2004.

	Annual Average		Annual Average
U of California-Berkeley	74	Ohio St U	26
U of Washington	64	U of Utah	26
Harvard U (MA)	58	Cornell U (NY)	25
MA Inst of Technology	58	Cornell U-Applied (NY)	25
Brigham Young U (UT)	52	U of California-Davis	25
U of IL-Urbana/Champaign	41	U of Florida	24
U of Texas-Austin	36	U of MN-Minneapolis	24
CA Inst of Technology	33	Georgia Inst of Tech	23
Rutgers U-New Brunswick (NJ)	33	Portland State U (OR)	23
U of California-Santa Cruz	33	U of Michigan-Ann Arbor	23
U of CA-Los Angeles	32	U of Wisconsin, Madison	23
U of Maryland-College Park	31	Carnegie Mellon U (PA)	22
U of California-San Diego	31	Oregon State U	21
U of California-Santa Barbara	31	Pennsylvania St U	21
U of Arizona	30	Purdue U-W. Lafayette (IN)	21
U of Virginia	29	Case Western Reserve U (OH)	20
Colorado School of Mines	28	North Carolina State U	20
U of Chicago (IL)	28	Stanford U (CA)	20

Note: List includes only those departments who contributed degree data for all 3 years.
AIP Statistical Research Center, Enrollments and Degrees Report.

Appendix F

InterActions

across physics and education

March/April 2007

Focal Point

Undergraduate Physics

reinventing the classroom

remaking the curriculum

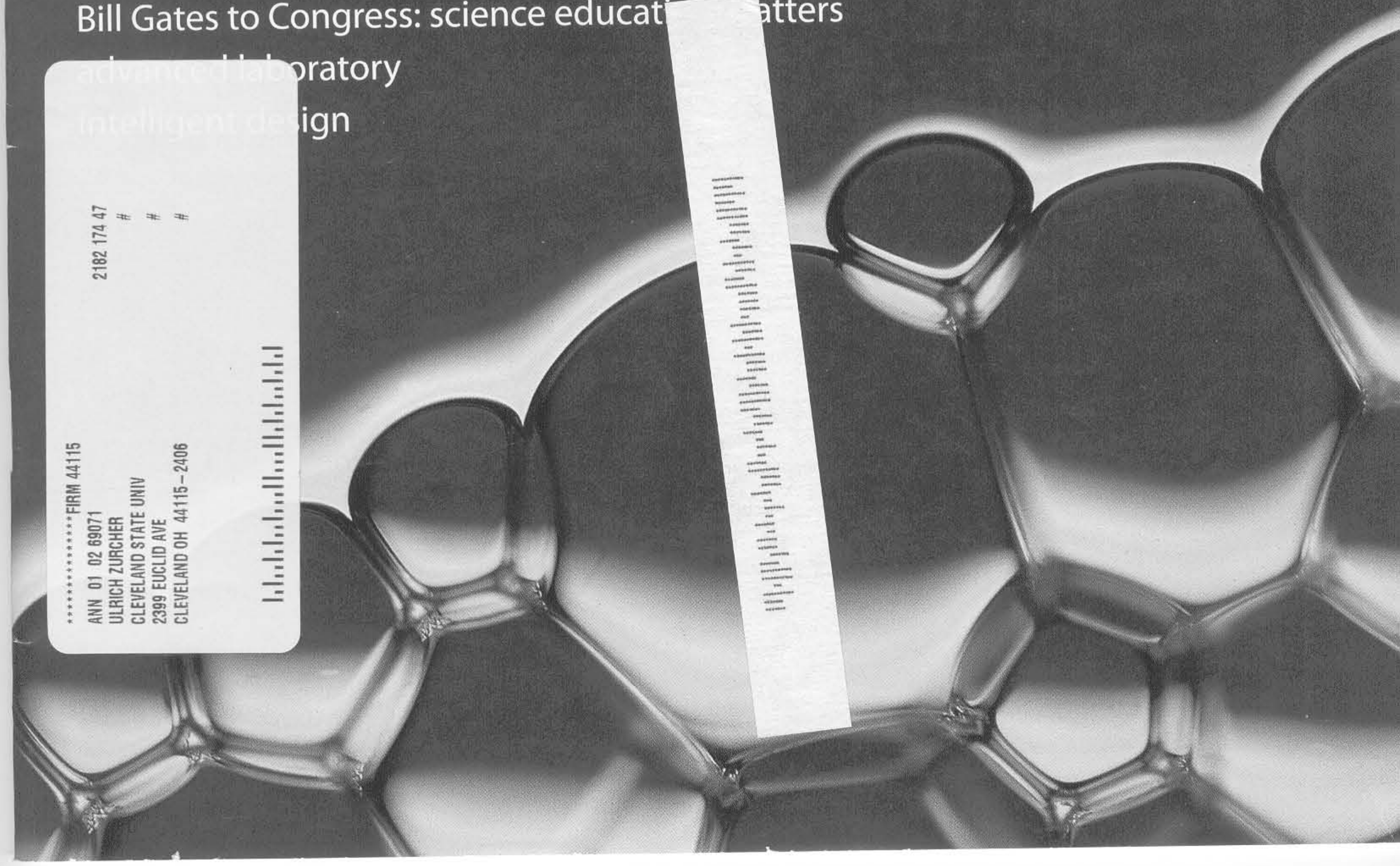
regenerating the physics major

plus:

Bill Gates to Congress: science educati atters

advanced laboratory

intelligent design



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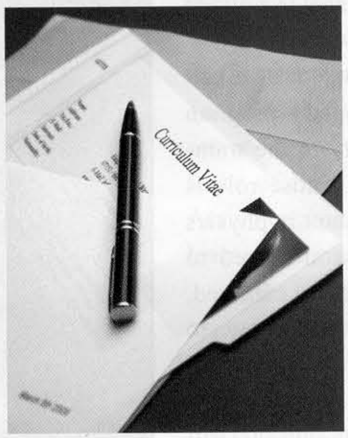
Appendix F

Help Wanted

What physics departments have done, can do, and should do to increase student enrollment and better prepare physics majors for the workforce.

BY KENNETH S. KRANE



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The 1960s were in many ways a golden age for undergraduate physics education in the United States. Perhaps in response to the growing interest in space exploration, undergraduate physics enrollment grew so that an average of 5,500 bachelor's degrees were awarded each year during the 1960s, peaking at 6,000 by the end of the decade. This growth in undergraduate enrollment produced a corresponding growth in graduate programs—the number of doctorates awarded each year tripled during the 1960s, totaling 1,500 in 1970. However, in the ensuing decades, the growth rate in physics majors has fallen, despite the explosive growth in technology.

In fact, undergraduate enrollment fell 25 percent before stabilizing at about 4,500 bachelor's degrees per year through the late 1970s. This decline occurred primarily at institutions that awarded master's or doctorates in physics. Curiously, during this same period there was nearly a 20 percent increase in the total number of STEM (science, technology, engineering, mathematics) bachelor's awarded; though more undergraduates majored in science and engineering, fewer majored in physics.

The '90s proved to be an even more critical period for undergraduate physics enrollment. Bachelor's degree production in physics declined by 25 percent, while STEM-related bachelor's rose by 15 percent. The number of physics bachelor's degrees fell to fewer than 4,000 each year between 1997 and 2000, which had previously occurred only prior to 1958. As a share of total STEM bachelor's degrees, physics fell from 5 percent in the late 1960s to 2 percent by 2000.

In response to what was clearly a crisis for the physics community, the National Task Force on Undergraduate Physics was formed in 1999 to stimulate the revitalization of undergraduate physics education in the United States. Rather than identify the causes for the decline in physics enrollment, the Task Force set out to identify and assess departments where enrollment had thrived despite the national declines.

One of the key elements characterizing thriving programs was the presence of flexible and diverse degree curricula. In the 1960s and 1970s, most physics departments offered only a single bachelor's degree curriculum, whose purpose was primarily to provide the rigorous background necessary for success in graduate school. Today many successful departments offer a range of degree alternatives: applied or engineering physics (including joint 3-2 engineering programs); specialized programs within physics (such as optics or materials science); joint degree programs with other academic disciplines (chemistry, computer science, business); and general programs for pre-service teachers, pre-law, and pre-medical training. These programs encourage students to think of physics more broadly as preparation for the workforce, rather than more narrowly as preparation for graduate school.

Remarkably, the decline in undergraduate physics enrollment abated in 1999, and bachelor's degree production grew to more than 5,100 in 2005, the highest total since the early '70s. Based on the sizes of currently enrolled junior and senior classes, these increases are expected to continue at approximately 5 percent per year for at least the next two years. The revival in physics enrollment was led by Ph.D.-granting institutions, which on average

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This article was adapted from Kenneth Krane's panel presentation at the first Symposium on Physics Education, organized by the American Association of Physics Teachers (Seattle, January 10, 2007).

Appendix F

These programs encourage students to think of physics more broadly as preparation for the workforce, rather than more narrowly as preparation for graduate school.

awarded about half of all the physics bachelor's conferred in the United States in 2005 (see "Endpoint," page 52).

Despite the rosy national picture, not all departments have shared in these increases. Among Ph.D.-granting departments, about one-third award no more than six bachelor's degrees per year; approximately 33 percent of both B.A./B.S.- and M.S.-granting institutions award only two or fewer bachelor's degrees per year.

Many departments have posted increases between 2003 and 2005 that are far above the national average for their category. Table 1 represents "honor roll" institutions with Ph.D.- and M.S.-granting physics departments that significantly exceeded the national average increases (respectively 43 percent and 17 percent) in their categories relative to the 1997 to 1999 base period. Table 2 indicates "honor roll" institutions whose highest physics degree is the B.A./B.S. (for which the national average increase was 19 percent).

This survey was restricted to Ph.D.-granting institutions that awarded a total of 20 or more physics degrees during the 1997 to 1999 base period and to M.S. and B.A./B.S. institutions that awarded a total of 10 or more. As a result, depart-

Highest Degree	Institution	Degrees/y 2003-05	Change from 1997-99
Ph.D.	Michigan State Univ.	19	+164%
Ph.D.	Univ. of California, Santa Barbara	36	+163%
Ph.D.	Univ. of Arkansas at Fayetteville	19	+148%
Ph.D.	Oregon State Univ.	19	+138%
Ph.D.	Univ. of California, Santa Cruz	31	+119%
Ph.D.	Univ. of Maryland, College Park	33	+118%
Ph.D.	Univ. of Massachusetts Amherst	19	+107%
Ph.D.	Univ. of Arizona	35	+100%
Ph.D.	Univ. of Minnesota, Twin Cities	27	+95%
Ph.D.	University of Florida	24	+92%
Ph.D.	Brown University	15	+92%
M.S.	Missouri State Univ.	9	+160%
M.S.	California State Univ., Northridge	11	+154%
M.S.	University of Memphis	8	+150%
M.S.	Cleveland State Univ.	10	+138%
M.S.	Ball State University	8	+130%

Table 1. Ph.D.- and M.S.-granting departments with the largest recent increases in physics degrees conferred.

Institution	Degrees/y 2003-05	Change from 1997-99
Cal Poly, San Luis Obispo	24	+243%
Univ. of Northern Colorado	12	+133%
Benedict College	10	+131%
Gettysburg College	8	+130%
College of New Jersey	12	+125%
University of Wisconsin – La Crosse	19	+124%
Shippensburg University	9	+117%
Whitworth College	9	+117%
North Georgia College & State University	7	+110%
Rowan University	7	+110%
Williams College	18	+104%
Jacksonville University	9	+100%
University of Wisconsin – River Falls	10	+94%
Murray State University	9	+93%
Humboldt State University	7	+91%
Trinity University	7	+91%
Dickinson College	13	+90%
College of Charleston	19	+87%
Lewis and Clark College	9	+86%

Table 2. B.A./B.S. institutions with the largest recent increases in physics degrees conferred.

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Appendix G

Date: Thu, 07 Dec 2006 17:24:27 -0800
To: m.kaufman@csuohio.edu
From: Ken Krane <KraneK@physics.oregonstate.edu>
Subject: Increase in physics majors
12/08/2006

Dear Miron,

Recently AIP has gathered statistics showing a steady increase in the number of physics bachelors degrees awarded in the US since the late 1990's. Based on a comparison of three-year averages of 2002-2004 degrees with those from 1997-99 as a baseline, your department shows substantial increases over that time period and ranks in the top 30 in the US in the percentage increase in the number of degrees awarded.

Bob Hilborn, Amherst College
Ken Krane, Oregon State University
National Task Force on Undergraduate Physics (co-sponsored by AAPT, APS, and AIP)

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