Christopher Culbreath

Working Personnel Action File

Cal Poly Physics Department · January 2018

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Dr. Christopher Culbreath

Lecturer, Physics Department
California Polytechnic State University
San Luis Obispo, California
cculbrea@calpoly.edu

Educational Preparation

- *Ph.D. Chemical Physics* (2015)
  Liquid Crystal Institute. Kent State University. Kent, Ohio.
  Subject: Artificial Microscopic Structures in Nematic Liquid Crystals Created by Patterned Photoalignment and Controlled Confinement: Instrumentation, Fabrication and Characterization.
  Advisor: Hiroshi Yokoyama.
- *B.S. Physics* (2008)
  California Polytechnic State University. San Luis Obispo, California.

Employment

- *Lecturer* (August 2016–present)
  California Polytechnic State University Physics Department
  San Luis Obispo, California.
- *Lecturer* (January 2015–June 2016)
  Chico State University Department of Physics
  Chico, California.
- *Graduate Researcher* (2008-2015)
  Liquid Crystal Institute
  Kent, Ohio.
- *Partner, Photographer* (2009-2014)
  Iconic Photography *iconic-photo.com*
  Kent, Ohio.
- *Senior Service Technician* (2005-2007)
  MacSuperstore
  San Luis Obispo, California.

Teaching Related Activities

Cal Poly Courses

- Physics 132 General Physics II · F16, W17, S17, W18
- Physics 132 Lab General Physics II Laboratory · F16, W17, S17, W18
- Physics 133 General Physics II · F17, W18
- Physics 133 Lab General Physics II Laboratory · S17, F17, W18

Chico State Courses

- Physics 204A Physics for Students of Science and Engineering: Mechanics · Spring 2015, Fall 2015, Spring 2016
- Physics 204A Lab Physics for Students of Science and Engineering: Mechanics Laboratory · Spring 2015, Fall 2015, Spring 2016
- Physics 202A Lab General Physics Laboratory (Mechanics) · Fall 2015
- Physics 202B General Physics (Algebra-based) · Spring 2016
- Physics 202B Lab General Physics Laboratory (E/M and Optics) · Spring 2016

Curriculum Contributions

- *Uncertainty in Measurement* — Interactive and competitive laboratory exercise written to introduce the concepts of measurement uncertainty, error propagation and the statistics of repeated measurements to introductory laboratory students, piloted at Cal Poly, Winter 2017. (page 35)

Advising

- Eric Gomez (Chico State). Measurement of surface anchoring strength of nematic liquid crystals on photo-aligned substrates. One semester preparation and six-week summer research trip to the Liquid Crystal Institute, Kent, Ohio. Summer 2016.
- Ryan Lau (Cal Poly Physics). Frost Research Program, Summer 2017. We investigated the development and testing of a novel thermal actuator made from a single-crystal Cu-Al-Ni shape memory material. I advised Ryan on research and directly instructed him in the machine shop, where he developed the skills to produce experimental components on his own, from scratch.
- Lauren Smith (Cal Poly Physics). Frost Research Program, Summer 2017. We probed the origin and character of a previously uninvestigated spontaneous EMF observed in single-crystal Cu-Al-Ni during the martensitic transition. Lauren's work mainly focused

on the development and design of an apparatus for systematically inducing the martensitic transition with varying strain regimes.

Scholarship

Publications (Other Institutions)

- C. Culbreath, N. Glazar and H. Yokoyama. “Automated maskless micro-multidomain photoalignment" *Rev. Sci. Instrum.* **82**, 126107 (2011).
- N.Glazar, C. Culbreath, Y. Li, H. Yokoyama: “Switchable liquid crystal phase shift mask for super-resolution photolithography based on Pancharatnam-Berry phase" *Appl. Phys. Express.* **8** 116501 (2015)
- J. Angelo, C. Culbreath, and H. Yokoyama. “Breaking Planar Liquid Crystal Anchoring to Form Controllable Twist Disclination Loops.” Molecular Crystals and Liquid Crystals **646**, 1 (2017)

Presentations

External Presentations (Other Institutions)

- N. Glazar, C. Culbreath and H. Yokoyama. “Switchable phase mask for super-resolution photolithography” Chirality at the Nanoscale Conference, Poster Presentation. June 4 - June 5, 2015. Kent, Ohio
- C. Culbreath, N. Glazar and H. Yokoyama.“Controlled Generation of Disclination Lines: A Quantitative Study of Defect Energetics”. International Liquid Crystal Conference. Poster Presentation. June 29 - July 4, 2014. Dublin, Ireland
- N. Glazar, C. Culbreath and H. Yokoyama.“Real Time Imaging Polarimeter using Pancharatnam Retarder”. International Liquid Crystal Conference. Refereed Talk. N. Glazar, presenter. June 29 - July 4, 2014. Dublin, Ireland
- C.Cheng, C. Culbreath, N. Glazar, P. Palffy-Muhoray and H. Yokoyama.“Observation of Angular Momentum in Liquid Crystals Using a Torsion Pendulum”. International Liquid Crystal Conference. Poster Presentation. June 29 - July 4, 2014. Dublin, Ireland
- C. Culbreath, N. Glazar and H. Yokoyama: “Maskless Automated Photoalignment”. Symposium on Flexible Liquid Crystal Devices. Poster Presentation. Sep 2012. Kent, Ohio
- C. Culbreath, N. Glazar and H. Yokoyama: “Maskless Automated Photoalignment”. Liquid Crystal Day. Poster Presentation. Nov 8, 2012. Kent, Ohio.
- Christopher Culbreath.“Nanoparticles in Electrospun Liquid Crystal Celluloses”. Christopher Culbreath, presenter. Invited Talk. NSF-OTKA Symposium for Complex Fluids. July 8 and 10, 2009. Eger, Hungary.

- C. Culbreath and P. Palffy-Muhoray. “Falling Magnets and Electromagnetic Braking”. APS March Meeting. Pittsburgh, Pennsylvania. Christopher Culbreath, presenter. Refereed talk. March 2009.

Service and University Citizenship

Departmental Committees

- Lower Division Curriculum Committee Fall 2016, Winter 2017
- Demonstration Committee (ad-hoc) Fall 2016, Winter 2017
- Assessment Committee Fall 2017, Winter 2018

Student Service

- Society of Physics Students. Faculty participant. Fall 2016, Winter 2017.

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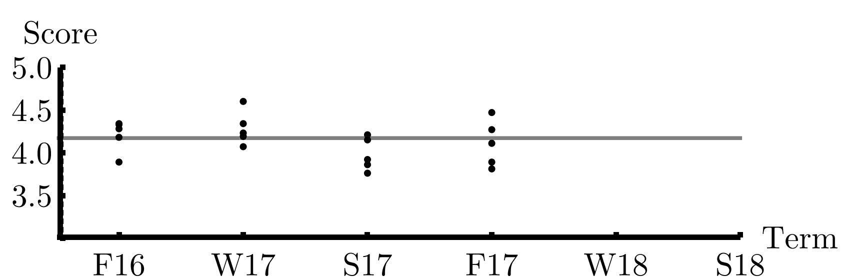
Student Evaluations

Evaluation Summary

Year	Quarter	Prefix	Course №	Type	Instructor Score*	№ of Responses
2017	Fall	PHYS	133	Lecture	4.15	23
2017	Fall	PHYS	133	Lab	3.93	7
2017	Fall	PHYS	133	Lab	3.85	10
2017	Fall	PHYS	133	Lab	4.50	5
2017	Fall	PHYS	133	Lab	4.31	13
2017	Winter	PHYS	132	Lecture	4.27	47
2017	Winter	PHYS	132	Lab	4.64	14
2017	Winter	PHYS	132	Lab	4.11	14
2017	Winter	PHYS	132	Lab	4.23	13
2017	Winter	PHYS	132	Lab	4.38	16
2017	Spring	PHYS	132	Lecture	4.19	27
2017	Spring	PHYS	132	Lecture	3.90	29
2017	Spring	PHYS	133	Lab	3.80	15
2017	Spring	PHYS	132	Lab	3.96	14
2017	Spring	PHYS	132	Lab	4.25	12
2016	Fall	PHYS	132	Lecture	4.32	34
2016	Fall	PHYS	132	Lecture	3.93	29
2016	Fall	PHYS	132	Lab	4.38	12
2016	Fall	PHYS	132	Lab	4.37	15
2016	Fall	PHYS	132	Lab	4.22	9
				Weighted Average	4.17	363 (total)

**Overall evaluation score with a 5-point basis*



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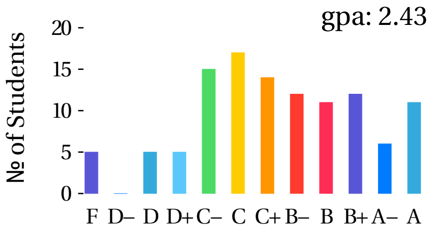
Grading Patterns

PHYS 132



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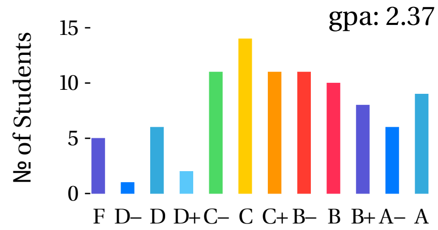
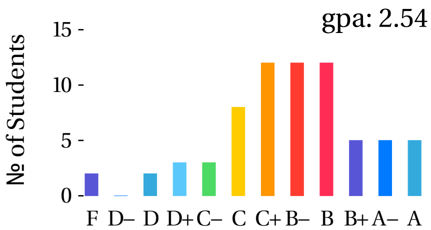
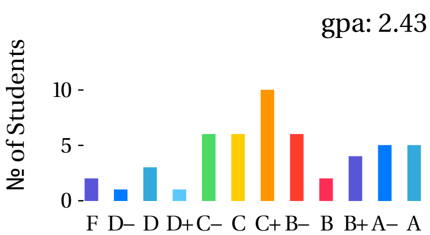


Spring 2017



Winter 2017

PHYS 133



Fall 2017

Term	**Course**	**№ of Students**	**A**	**B**	**C**	**D**	**F/WU**	**W/I**	**GPA**
Fall 2016	PHYS 132	47	12.8%	31.9%	44.7%	4.3%	6.4%	0.0%	2.39
Fall 2016	PHYS 132	66	16.7%	30.3%	37.9%	12.1%	3.0%	0.0%	2.46
Spring 2017	PHYS 132	48	14.6%	27.1%	41.7%	10.4%	6.2%	0.0%	2.34
Spring 2017	PHYS 132	47	17.0%	34.0%	34.0%	8.5%	4.3%	2.1%	2.41
Winter 2017	PHYS 132	70	14.3%	41.4%	32.9%	7.1%	2.9%	1.4%	2.54
Fall 2017	PHYS 133	51	19.6%	23.5%	43.1%	9.8%	3.9%	0.0%	2.43

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Statement of Teaching Philosophy and Approach

Great teaching is unmistakable. The best teachers make learning easy, enjoyable and long-lasting. I am a student of great teaching. I have always hungered to understand the secret sauce that makes a great class, great. I have long expected to be a teacher myself, so for the excellent courses I have taken, and there have been many, I have made an effort to analyze and discuss what choices made the class successful. Behind every class, there is as a teacher and a process. I have been inspired by the talents of famous teachers—Bill Nye's enthusiasm, Neil DeGrasse-Tyson's profundity, and Richard Feynman's clarity. And, I've been guided by the greats in my own life—the creativity of Mr. Wallace, the big-picture view of Dr. Palffy and impeccable presentation by Dr. Sungar. Yet, I have observed that the talent of the instructor does not strictly determine the quality of the course (although talent sure helps). Universally, my observations have lead me to a single conclusion that forms the core of my teaching philosophy: great teaching is built on a foundation of hard work, preparation and careful execution. Everything else is extra. Conversely, complacency, weak preparation, and sloppy mistakes are ruinous. As an instructor, I have built my own courses on this core philosophy and leveraged my enthusiasm to make the class entertaining and fun.

The most important aspect to teaching a successful course is a strong foundation. The foundational elements are blackboard lecture, homework and office hours. I write lectures to concisely introduce topics and I work examples from beginning to end. It is most important to have a thorough preparation that develops a sound, sequential narrative, anticipates student misconceptions and is easy to understand. My lecture notes are detailed and understandable, and I design them to be useful to students who are forced to miss class. I assign homework problems that directly reinforce the skills demonstrated in lecture as well as problems that require an extension of the ideas presented.

While my own observations have determined the core of my teaching philosophy, I also systematically utilize findings of Physics Education Research (PER) to make changes to my teaching. I use student performance on the standardized Force Concept Inventory (FCI)[1] or Mechanics Baseline Test (MBT)[2] to quantify the effectiveness of my course and course modifications. It may sound trite, but it is certainly true: I want to be the best physics teacher that I can be—an expert practitioner of the craft.

I think that the metaphor most fitting to teaching physics is that of a toolbox. Throughout the term I work hard to build tools and store them, ready for use, in a toolbox. Some of the tools are used often and must be constructed with a rugged durability and handled with a deft understanding of their function and use, while others are for special purposes and need only to be of sufficient quality for occasional use. I often speak in terms of tools, and I like to remind students of their purpose when we encounter them, almost as manta: "A free body diagram is a tool we use to solve problems involving forces" and "The electric field is a tool we can use to find the force on a charge." This repetition guides the memorization of each tool's use, and students more readily apply the methods learned in lecture to solving problems I use a combination of homework problems from an online homework platform *(Mastering Physics)* and hand-worked problems. Grading calculations is essential to catching mistakes and building good habits.

Office hours are also an essential element of a successful course. I have no qualms about offering direct help with assigned homework during office hours. This individual attention offers some of the best learning available to students, and it provides an opportunity for dialog. In my experience, the best instructor office hours are bustling with students; this inevitably leads to discussion and collaboration among students who work together to solve their homework problems. By design, I hope to have a popular and inclusive office hour that promotes learning and student collaboration.

Beyond a strong foundation, a course is elevated through enthusiasm, demonstrations and creativity. I strive to deliver an enthusiastic and engaging presentation of physics. In evaluations[†] students overwhelmingly rate my teaching as *Very Good* or *Superior*. And their comments consistently mention my passion, excitement and enthusiasm. I guess I can't help myself: *I really do love physics!* When students see my appreciation for the subject, it makes the material more relevant, interesting and engaging. And while students may not share my interest, at the very least it raises curiosity on a personal level—why does this guy like physics so much? *General Physics* is a course full of opportunities for demonstrations that connect theory to application, and link lecture ideas to something real. I utilize demonstrations whenever possible, and never underestimate the value of fun. Often, the most memorable lessons from class are remembered not because of a clever explanation, but because of an inside joke, personal connection or fun had during class! While these experience can't be forced, a physics-is-fun attitude opens the door to life-long learning opportunities. It is these components added on top of a strong foundation that elevate a course to a higher level of entertainment, understanding and retention.

In order to improve the efficacy of my teaching methods, I systematically incorporate findings of physics education research into my classes. In order to protect the core integrity of the course, I take a measured approach to changes, and implement only one or two changes at a time. Student performance on the FCI or MBT allows a quantitative assessment of course changes from term-to-term. A considerable volume of PER suggests that real-time polling devices (clickers), not only improve student performance, but students like them too[3]. So, I have been giving clickers a try this semester. I've added detailed self-produced video solutions to my course website, and have been encouraging peer-instruction through group problem solving. Other PER concepts that I am focused on implementing are inquiry driven laboratory exercises, and integrated-lecture-and-lab "studio-physics" courses[4].

At the lower-division undergraduate level, it is my observation that Mechanics Laboratory is an area ripe for pedagogical improvement. The traditional three-hour block is often underutilized, with students finishing early or toiling over repetitive cookbook-style exercises. Further, the physical interpretation of nearly all observed motion in the lab requires a sophisticated and nuanced interpretation—we observe the motion of a basketball in freefall, but ignore the behavior of the bounces; we track the motion of a cart, but neglect friction; projectiles fly through the air without drag. Strings pass over "massless" pulleys, we observe "elastic" collisions, and motion is "conserved." Clearly, not many experiments can be cleanly idealized,

[†]A full set of student evaluations from one section of calculus-based mechanics (Fall 2015) is attached to the end of this document—more are available by request

and even fewer make an accurate prediction.

A studio-physics approach addresses many of these issues by making better use of time. With studio, we can do fewer, small experiments that require less idealization. I have loosely emulated this route by tightly integrating my traditional lecture with my 3-hour lab sessions. I also start lab sessions with a 30-minute homework recitation. In lower-division courses, the dearth of experiments that make reliable quantitative predictions demand we must question what the best use of laboratory time is. It's not clear that the classic predict/test/conclude exercise provides meaningful educational benefit. Beyond the classic approach, the laboratory provides an excellent opportunity to develop think-like-a-scientist skills like designing experiments, pattern recognition and troubleshooting. Inquiry and investigation are a source of deep understanding. And lab can be fun. The labs that I've written leverage friendly competition between lab groups and take projectile motion outside (with simple numeric drag integrated in Mathematica). An effective laboratory curriculum breaks out of the traditional of unenlightening cook-book routines to engage students and build useful skills.

I am a team player—If a course needs to be taught, I'll teach it. I enjoy teaching *General Physics* and *College Physics*, and I look forward to teaching courses for both majors and non-majors. I am interested in teaching *Physics on the Computer*, and *Electronics*. Upper division courses that interest me are *Electricity and Magnetism*, *Optics*, *Statistical Mechanics* and *Q-Lab*. Topics in liquid crystal physics can be incorporated in an Optics or Statistical Mechanics course—or developed into an upper division course of its own.

I love teaching. With or without a Ph.D. in Physics, I would be a teacher. It defines so many aspects of my life, perhaps no more so than at home, where together with my wife, we teach the lessons of love, happiness, wisdom and personal responsibility to our three young children. The joy of learning resonates in all of us. I try to constantly refine, retool and improve my approach. I adapt, evolve and iterate. I solicit feedback and I'm open to criticisms. As with this experience comes wisdom. For the craft of teaching matters to me; it's part of who I am and who I want to be. I am thrilled to be pursuing such a satisfying career: the virtues of teaching are many and its rewards extend far beyond the classroom.

References

[1] Hestenes, David, Malcolm Wells, and Gregg Swackhamer. "Force Concept Inventory." *The Physics Teacher* **30.3** (1992): 141-158.

[2] Hestenes, David, and Malcolm Wells. "A Mechanics Baseline Test." *The Physics Teacher* **30.3** (1992): 159-166.

[3] Docktor, Jennifer L., and José P. Mestre. "Synthesis of discipline-based education research in physics." *Physical Review Special Topics-Physics Education Research* **10.2** (2014): 020119.

[4] Knight, Randall D. *Five Easy Lessons: Strategies for Successful Physics Teaching.* San Francisco, Calif: Addison Wesley, 2004.

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Materials for Examination

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Course Materials for Examination

Physics Courses

Physics 132 (Fall 2016, Winter 2017, Spring 2017, Winter 2018)

Physics 133 (Fall 2017, Winter 2018)

PHYSICS 132

Course Syllabus/Winter 2018

INSTRUCTOR: Dr. Christopher Culbreath **OFFICE**: Jesperson Hall (116) 108
OFFICE HOURS: M 11:10 AM—12 PM (Baker 180-272) • T/R 1:10 PM—3 PM (Baker 6th Floor Lobby)
EMAIL: cculbrea@calpoly.edu **WEB:** http://physicscloud.net/132
LECTURE: T/R 4:40-6:00 PM in Science North 53-206
LAB: 180-273

COURSE OBJECTIVES: Physics 132 is the second course in the series of calculus-based introductory physics classes. Unlike the other courses in the introductory physics series, Physics 132 covers three broad topics: Waves, Optics and Thermodynamics. An full outline of the course objectives is posted on the course website.

TEXT: *Physics for Scientists and Engineers: A Strategic Approach with Modern Physics*, by Randall D. Knight, 4th Edition. Lab handouts are distributed digitally on the course website. Please read and print lab handouts ahead of time.

COURSE WEBSITE: The course website is **http://physicscloud.net/132/** ***The website is a source of essential information for this course.*** Assignments, solutions, the syllabus, course objectives, course schedule, lab handouts and exam solutions will all be posted to the site. Please check it regularly. I do not use the campus Poly Learn system.

PREREQUISITES: Prior completion of PHYS 141 (or equivalent) is a required prerequisite.

GRADING: Homework 10% • Quizzes, Other 10% • Two Exams 20% each • Final 30% • Lab 10%
No individual assignments will be curved, and no letter grades will be assigned until the end of the term. At the end of the quarter, every student's weighted point total will be ranked and the distribution curved such that C, C+ and C- grades indicate performance not far from the average. *A*s are reserved for exceptional performance and are typically awarded to 18%-or-less of the class.

CLICKER QUESTIONS: During lecture, real-time feedback, and attendance will be provided by multiple-choice conceptual and discussion questions. Answers are registered through multi-colored answer cards passed out on the first day of class, and are expected at each class meeting.

HOMEWORK: Homework will generally be collected Tuesday. Homework is due at the beginning of class. Late homework will receive a 33% deduction, and be graded on a credit/no-credit basis.

HOMEWORK PRESENTATION: Homework problems should be worked on blank, unruled, paper or quad-ruled, engineering-type graph paper. ***Do not use regular lined notebook paper.*** Blank printer paper is everywhere; use that instead. Clearly indicate the problem number on each page. Bind all pages of the homework set with a single staple in the upper-left corner. Number the pages in the upper right corner. Whenever possible, the solution should ***include a figure or sketch*** that illustrates the key parameters of the problem. Answers must be reported using a reasonable number of significant figures. Try to make your calculation as clear and tidy as possible; little effort will be made to decipher sloppy work. ***Work problems symbolically until the last step***, at which point you can plug-in actual numbers and recover a numeric answer. ***All numeric values must include units:*** if you write down a number, it must include appropriate units, even in intermediate calculation steps. If you don't want to include units, work symbolically until the last step.

HOMEWORK GRADING: As decided by class vote, homework will either be graded using a 1-2-3 or lottery grading scheme. Under the 1-2-3 scheme, each problem is worth three points. 1 point is awarded for submitting a reasonable solution *on time*, and the remaining 2 points are awarded with crude precision: 2 points for a correct, complete solution that fully adheres to the presentation guidelines above, 0 points for a solution obviously less than 50% complete/correct, and 1 point for any solution in between. With a lottery-type grading scheme, 0-3 problems per assignment are chosen at random to be graded rigorously with 10 points possible per problem.

PHYSICSCLOUD.NET At the beginning of the quarter you will receive email to signup for my course-management system at physicscloud.net. In addition to viewing your course grade and assignment statistics, physicscloud.net is used for scheduling review sessions, and for voting on important ***course options*** such as the total number of midterms and the homework grading scheme.

LAB: The three-hour lab meets weekly. Prepare for lab each week by reading the lab handout before coming to class. The lab schedule is attached to this syllabus. ***Attendance and participation for every lab exercise is required.*** If you miss a lab, your course performance will be considered Incomplete—and you must make up all missing lab assignments in a future quarter to receive a passing grade. If you must miss lab, you can make it up the same week in another section, but you must make arrangements with the appropriate lab instructor to participate in an alternate lab session. Exceptions to the lab attendance policy will only be made on a one-time basis, and only for a compelling reason. Quizzes will be regularly given at the beginning of the lab period. No quiz makeups for absence or tardiness. Exceptional performance in lab can give an advantage to students whose performance is near the borderline of two grades. One lab report will be collected for each lab group. Every student must write their own conclusion for each lab, every week. You may not leave before your lab group is done: all lab conclusions must be turned in together, and you must be present for your work to be accepted.

EXAMS: Two or three midterm exams and a comprehensive final exam will be given during the quarter as tentatively scheduled on the syllabus. If the class elects to have three midterms (with the third midterm on the last day of class), the lowest midterm score will be dropped from the final grade calculation. With three midterms, make up exams will not be given. If you miss a midterm, it is the score that will be dropped.

EXAM CORRECTIONS: Exam corrections are due one week after exams are returned in class. You must submit correct solutions for all problems that you did not receive full-credit (multiple choice excluded). Exam corrections are mandatory and count towards the quiz component of your grade.

COURSE SUCCESS: Here are some tips for success in this class, especially if you are anxious or struggling. ***1) Find a physics buddy.*** Get their phone number. Those who work homework problems in pairs or small groups are much more likely to be successful through peer instruction, and the social aspect makes doing physics homework more enjoyable. ***2) Read the book.*** I like our textbook a lot; it's cogent, well-written and clear. In my lecture, I generally apply the notation, methods, reasoning, and ordering presented in the textbook. While the book can be a good way to start studying, the best approach is to read the relevant book sections *before coming to class*. You'll find lecture more understandable, and be more inclined to ask questions with lecture serving to illuminate misconceptions. ***3) Utilize the Learning Center.*** Located in 180-272 the learning center offers free physics tutoring. The learning center is open more than 20 hours per week and is available on a drop-in basis. ***4) Attend office hours.*** I am here to help. Email me, come to my office hours, ask as many questions as you need—your questions are not an interruption; answering them is what I'm here to do. I love teaching physics.

ACADEMIC HONESTY: Keep all electronic devices stored and completely out of sight on exam days. I interpret any sighting of a phone during an exam period as evidence of cheating.

PHYSICS 132

Tentative Course Schedule

Winter 2018

WK	TUESDAY	THURSDAY	
1 Jan 7 Jan 13	**9** Ch 15 1/4	**11** Ch 15 2.5/4	**Lab:** Simple Pendulum
2 Jan 14 Jan 20	**16** HW 1 Ch 15 4/4	**18** Ch 16 1.5/3	**Monday 1/15 :** Academic Holiday **Lab:** Simple Harmonic Motion of a Spring **Videos:** Damped Oscillations, Power & Intensity
3 Jan 21 Jan 27	**23** HW 2 Ch 16 3/3	**25** Ch 17 1.5/2	**Lab:** Vibrating Strings **Videos:** Sound Intensity Level, Doppler Effect, Interference in 1D, Interference in 2D
4 Jan 28 Feb 3	**30** HW 3 Ch 17 2/2 Ch 33 .5/1	**1** Ch 33 1/1 Ch 34 .5/4	**Lab:** Sound Resonance in Air Columns **Midterm 1:** Chapters 15, 16, 17 **Note:** Chapter 33 limited to sections 1-5
5 Feb 4 Feb 10	**6** HW 4 Ch 34 2/4	**8** Ch 34 3.5/4	**Lab:** Interference and Diffraction of Light
6 Feb 11 Feb 17	**13** HW 5 Ch 34 4/4 Ch 35 1/2	**15** Ch 35 2/2 Ch 14 .5/1.5	**Lab:** Refraction of Light **Videos:** Hydraulic Lift, Buoyancy **Note:** Chapter 14 limited to sections 1-5
7 Feb 18 Feb 24	**20** **No Class** (Monday Schedule)	**22** Ch 14 1.5/1.5 Ch 18 .5/2	**Lab:** Thin Lenses **HW6:** Collected in Lab **Note:** MT2 delayed due to holiday and lab schedule
8 Feb 25 Mar 3	**27** HW 7 Ch 18 2/2	**1** Ch 19 1.5/3	**Lab:** Temperature and Thermometers **Midterm 2:** Chapters 33, 34, 35
9 Mar 4 Mar 10	**6** HW 8 Ch 19 3/3	**8** Ch 21 1.5/3	**Lab:** Specific Heat, Heat of Transformation
10 Mar 11 Mar 17	**13** HW 9 Ch 21 3/3	**15** *Last Day of Class* **Midterm 3** Chapters 14, 18, 19, 21	**Lab:** Adiabatic Compression
FINAL Mar 18 Mar 25	**20**	**22** **Final Exam** 7:10 PM (53-206)	**Final Exam:** Bring a copy of Equation Sheet 3 with up to one page of notes on the back. Notes must be handwritten, and all writing must be on *back* of equation sheet.

Last Updated 1/7/18

Name: ______________________ Name: ______________________

Name: ______________________

PHYSICS 132 LAB GROUP QUIZ WEEK 2 - DYNAMICS & ENERGY OF SHM

Work with your lab group to complete the problems below. Unless indicated, submit one solution to each problem that the group agrees is correct. You may consult your notes, the textbook or your instructor for help.

1. || A block on a frictionless table is connected as shown in FIGURE P14.73 to two springs having spring constants k_1 and k_2. Show that the block's oscillation frequency is given by

$$f = \sqrt{f_1^2 + f_2^2}$$

where f_1 and f_2 are the frequencies at which it would oscillate if attached to spring 1 or spring 2 alone.

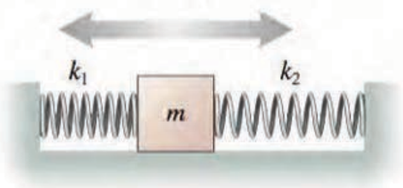
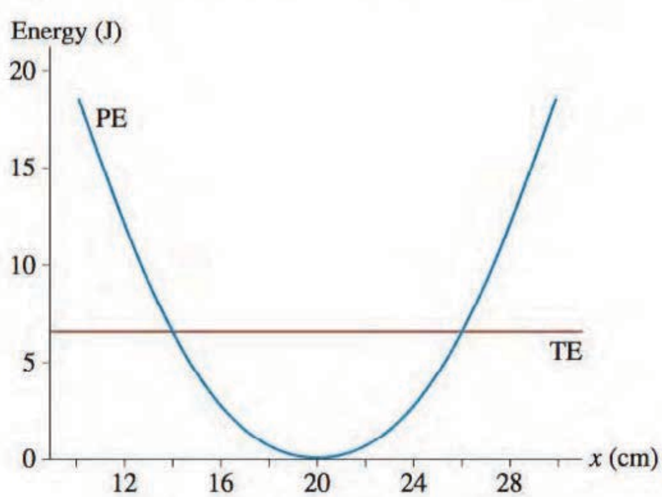


FIGURE P14.73

2. FIGURE Q14.9 shows the potential-energy diagram and the total energy line of a particle oscillating on a spring.
   a. What is the spring's equilibrium length?
   b. Where are the turning points of the motion? Explain.
   c. What is the particle's maximum kinetic energy?
   d. What will be the turning points if the particle's total energy is doubled?



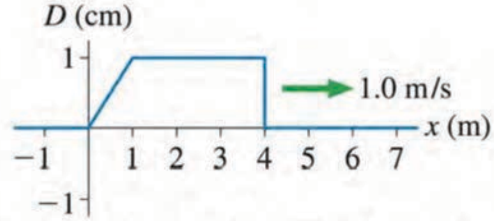
Name: ______________________ Name: ______________________

Name: ______________________

PHYSICS 132 LAB GROUP QUIZ WEEK 3 - TRAVELING WAVE GRAPHS

Work with your lab group to complete the problems below. Unless indicated, submit one solution to each problem that the group agrees is correct. You may consult your notes, the textbook or your instructor for help.

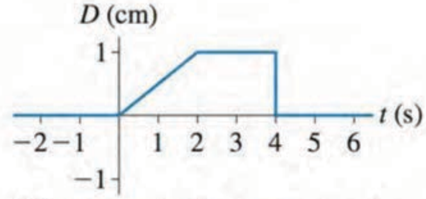
1. ‖ Draw the history graph $D(x = 5.0 \text{ m}, t)$ at $x = 5.0$ m for the wave shown in **FIGURE EX20.5**.



Snapshot graph of a wave at $t = 0$ s

FIGURE EX20.5

2. ‖ Draw the snapshot graph $D(x, t = 0 \text{ s})$ at $t = 0$ s for the wave shown in **FIGURE EX20.6**.



History graph of a wave at $x = 2$ m
Wave moving to the left at 1.0 m/s

FIGURE EX20.6

Name: ______________________ Name: ______________________

Name: ______________________ Name: ______________________

PHYSICS 132 LAB QUIZ GROUP WEEK 4 - SUPERPOSITION

Work with your lab group to complete the problems below. Unless indicated, submit one solution to each problem that the group agrees is correct. You may consult your notes, the textbook or your instructor for help.

For problems marked with a star (★), each group member must submit their own written solution, but collaboration is encouraged.

1. As the captain of the scientific team sent to Planet Physics, one of your tasks is to measure g. You have a long, thin wire labeled 1.00 g/m and a 1.25 kg weight. You have your accurate space cadet chronometer but, unfortunately, you seem to have forgot- ten a meter stick. Undeterred, you first find the midpoint of the wire by folding it in half. You then attach one end of the wire to the wall of your laboratory, stretch it horizontally to pass over a pulley at the midpoint of the wire, then tie the 1.25 kg weight to the end hanging over the pulley. By vibrating the wire, and measuring time with your chronometer, you find that the wire's second-harmonic frequency is 100 Hz. Next, with the 1.25 kg weight still tied to one end of the wire, you attach the other end to the ceiling to make a pendulum. You find that the pendulum requires 314 s to complete 100 oscillations. Pulling out your trusty calculator, you get to work. What value of g will you report back to headquarters?

2. ‖ The three identical loudspeakers in FIGURE P21.69 play a 170 Hz tone in a room where the speed of sound is 340 m/s. You are standing 4.0 m in front of the middle speaker. At this point, the amplitude of the wave from each speaker is a.
   a. What is the amplitude at this point?
   b. How far must speaker 2 be moved to the left to produce a maximum amplitude at the point where you are standing?
   c. When the amplitude is maximum, by what factor is the sound intensity greater than the sound intensity from a single speaker?

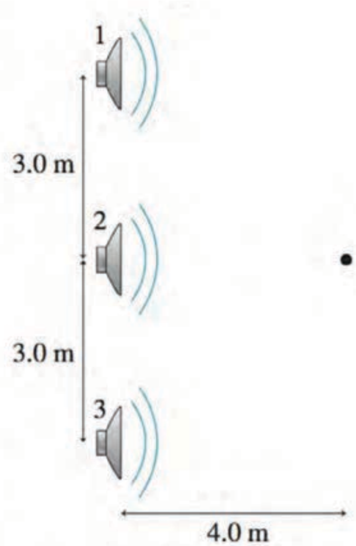


FIGURE P21.69

Name: ______________________ Name: ______________________

Name: ______________________

PHYSICS 132 LAB QUIZ GROUP WEEK 6 - REFLECTION AND REFRACTION

Work with your lab group to complete the problems below. Unless indicated, submit one solution to each problem that the group agrees is correct. You may consult your notes, the textbook or your instructor for help.

1. ‖ The meter stick in **FIGURE P23.45** lies on the bottom of a 100-cm-long tank with its zero mark against the left edge. You look into the tank at a 30° angle, with your line of sight just grazing the upper left edge of the tank. What mark do you see on the meter stick if the tank is (a) empty, (b) half full of water, and (c) completely full of water?

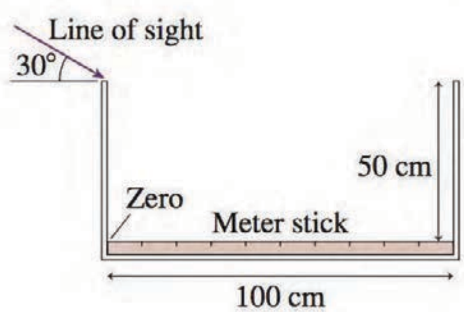


FIGURE P23.45

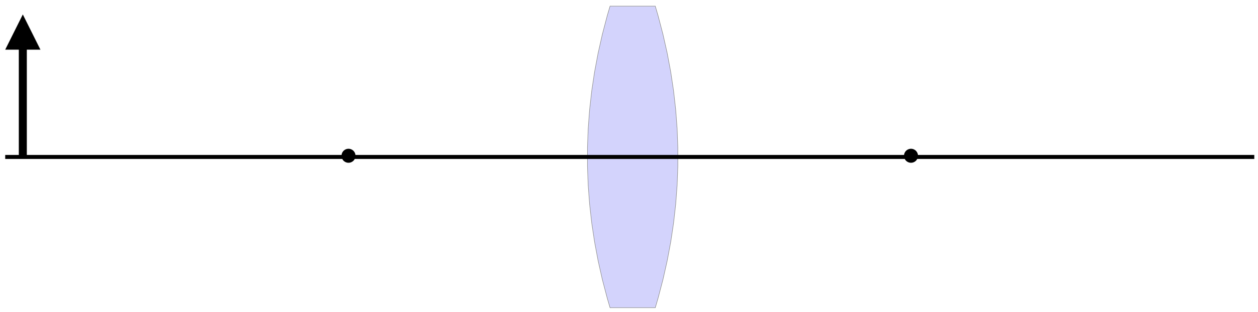
2. ‖ The place you get your hair cut has two nearly parallel mirrors 5.0 m apart. As you sit in the chair, your head is 2.0 m from the nearer mirror. Looking toward this mirror, you first see your face and then, farther away, the back of your head. (The mirrors need to be slightly nonparallel for you to be able to see the back of your head, but you can treat them as parallel in this problem.) How far away does the back of your head appear to be? Neglect the thickness of your head.

Name: ______________________________

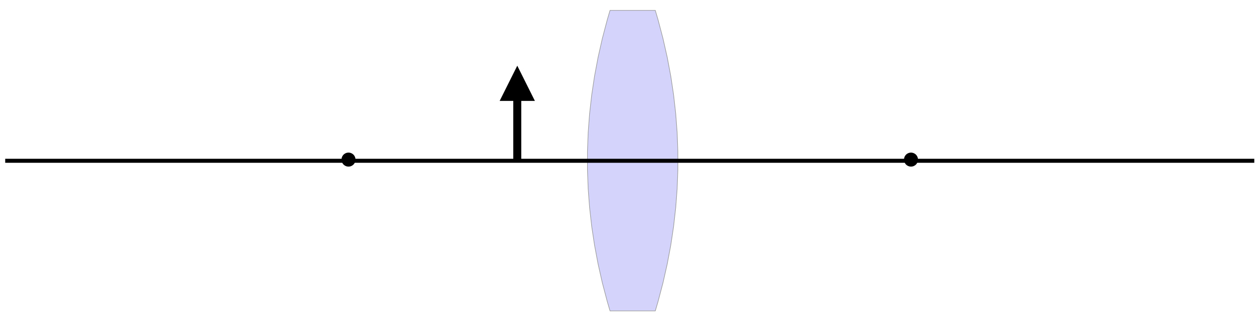
PHYSICS 132 LAB QUIZ WEEK 7

Turn in one ray tracing sheet per student.

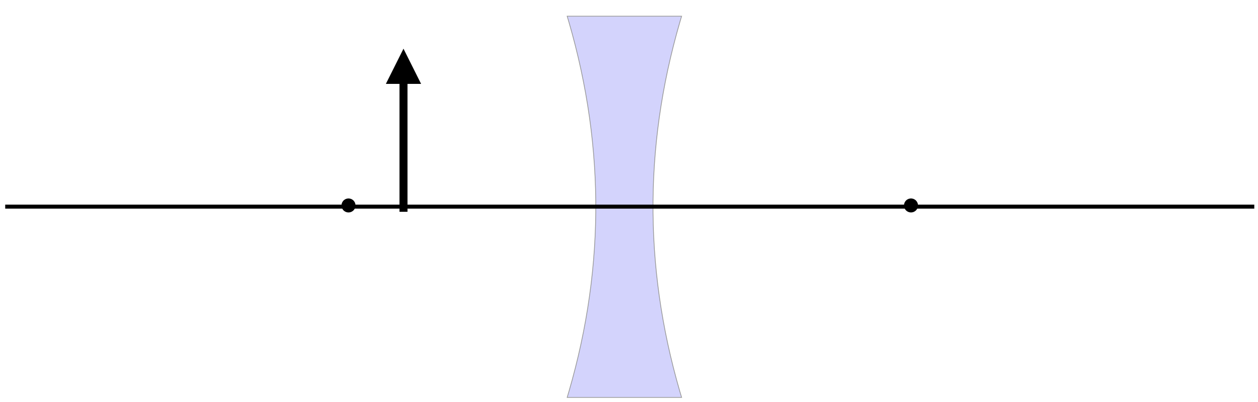
1. *Draw the three principle rays for each of the situations shown.*
2. *Determine the image properties*
3. *Choose one system and use the thin-lens equation to verify your result.*



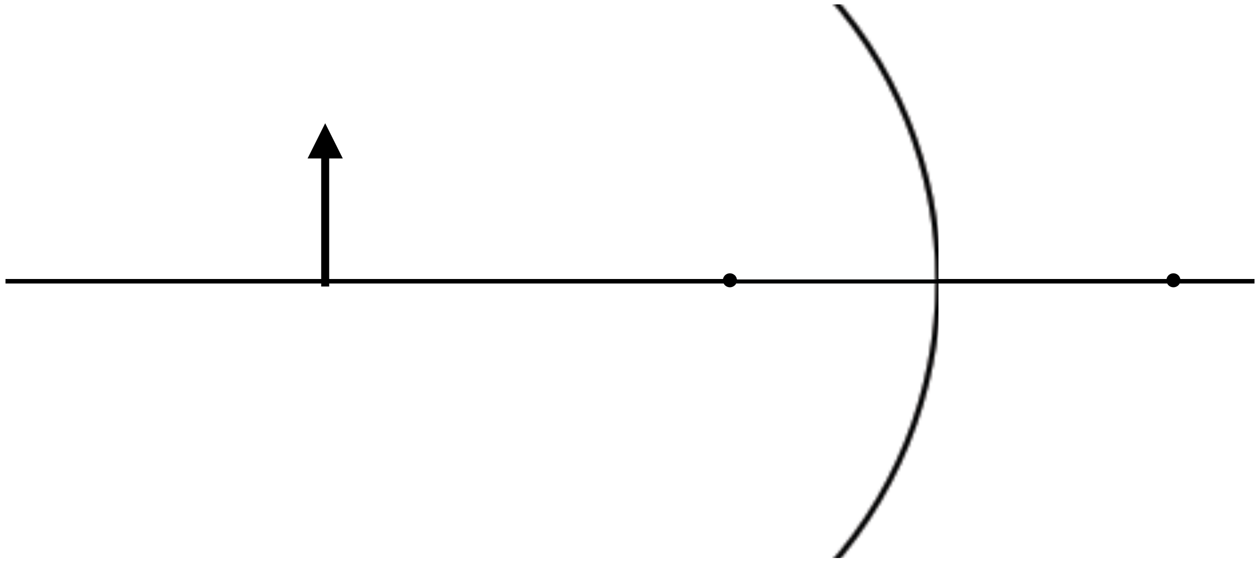
❒ $m < 0$ ❒ $m > 0$ ❒ $|m| < 1$ ❒ $|m| > 1$ ❒ $s' > 0$ ❒ $s' < 0$ ❒ $f < 0$ ❒ $f > 0$



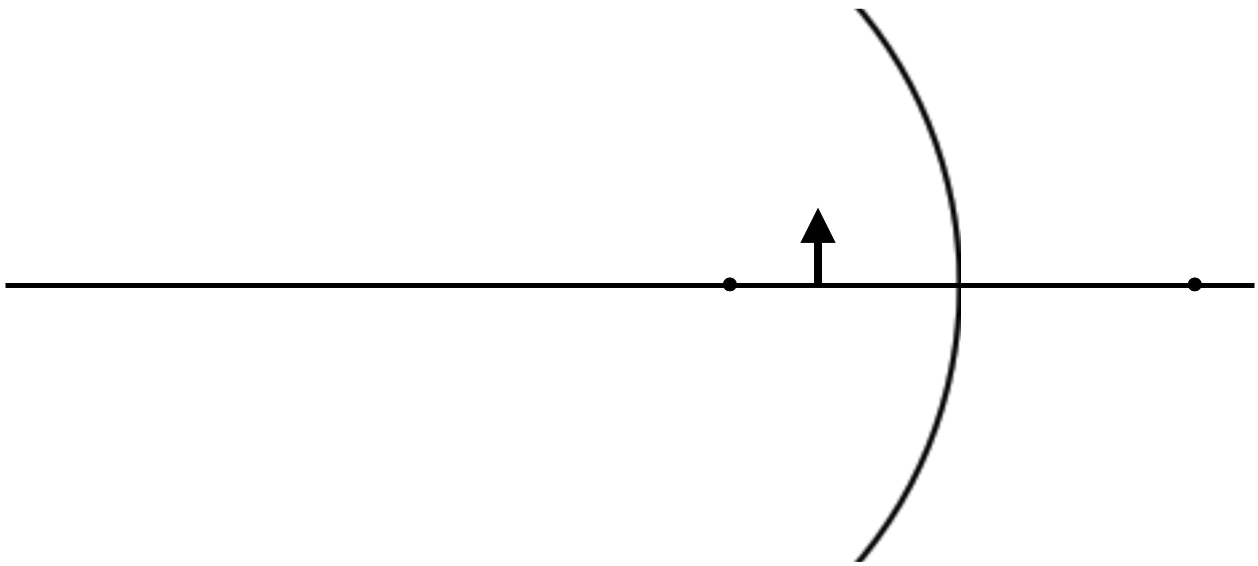
❒ $m < 0$ ❒ $m > 0$ ❒ $|m| < 1$ ❒ $|m| > 1$ ❒ $s' > 0$ ❒ $s' < 0$ ❒ $f < 0$ ❒ $f > 0$



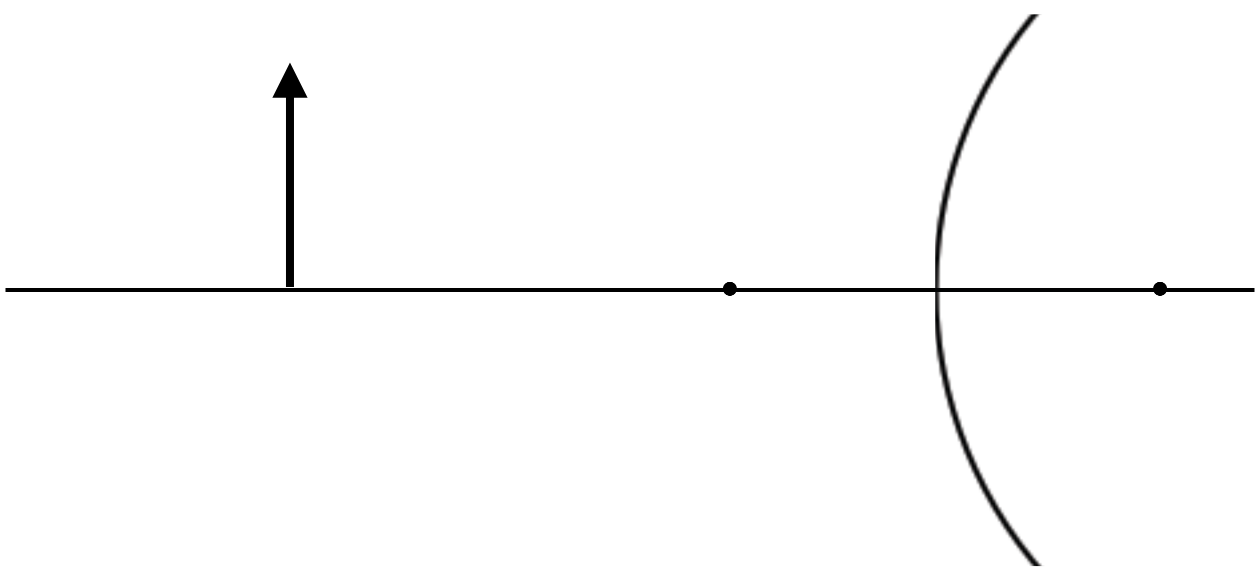
❒ $m < 0$ ❒ $m > 0$ ❒ $|m| < 1$ ❒ $|m| > 1$ ❒ $s' > 0$ ❒ $s' < 0$ ❒ $f < 0$ ❒ $f > 0$



❒ $m < 0$ ❒ $m > 0$ ❒ $|m| < 1$ ❒ $|m| > 1$ ❒ $s' > 0$ ❒ $s' < 0$ ❒ $f < 0$ ❒ $f > 0$



❒ $m < 0$ ❒ $m > 0$ ❒ $|m| < 1$ ❒ $|m| > 1$ ❒ $s' > 0$ ❒ $s' < 0$ ❒ $f < 0$ ❒ $f > 0$



❒ $m < 0$ ❒ $m > 0$ ❒ $|m| < 1$ ❒ $|m| > 1$ ❒ $s' > 0$ ❒ $s' < 0$ ❒ $f < 0$ ❒ $f > 0$

Name: ______________________ Name: ______________________

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PHYSICS 132 LAB GROUP QUIZ WEEK 9 - PRESSURE AND BUOYANCY

Work with your lab group to complete the problems below. Unless indicated, submit one solution to each problem that the group agrees is correct. You may consult your notes, the textbook or your instructor for help.

For problems marked with a star (★), each group member must submit their own written solution, but collaboration is encouraged.

1. ||| A spring with spring constant 35 N/m is attached to the ceiling, and a 5.0-cm-diameter, 1.0 kg metal cylinder is attached to its lower end. The cylinder is held so that the spring is neither stretched nor compressed, then a tank of water is placed underneath with the surface of the water just touching the bottom of the cylinder. When released, the cylinder will oscillate a few times but, damped by the water, quickly reach an equilibrium position. When in equilibrium, what length of the cylinder is submerged?

2. ||| A spring with spring constant 35 N/m is attached to the ceiling, and a 5.0-cm-diameter, 1.0 kg metal cylinder is attached to its lower end. The cylinder is held so that the spring is neither stretched nor compressed, then a tank of water is placed underneath with the surface of the water just touching the bottom of the cylinder. When released, the cylinder will oscillate a few times but, damped by the water, quickly reach an equilibrium position. When in equilibrium, what length of the cylinder is submerged?

Name: ______________________ Name: ______________________

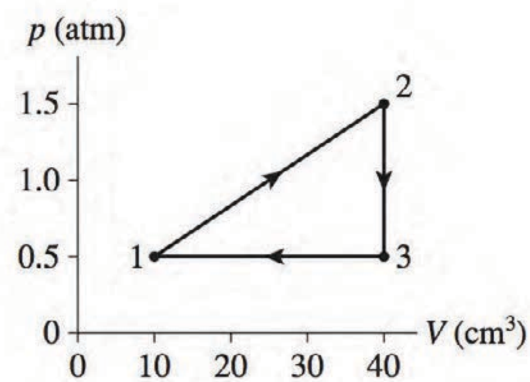
Name: ______________________

PHYSICS 132 LAB GROUP QUIZ WEEK 10

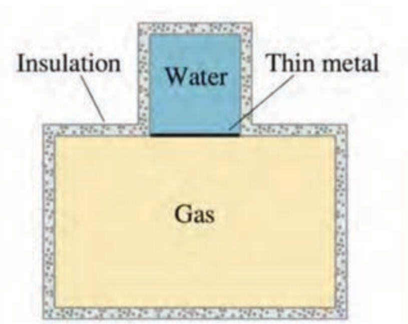
CALORIMETRY AND HEAT ENGINES

Work with your lab group to complete the problems below. Unless indicated, submit one solution to each problem that the group agrees is correct. You may consult your notes, the textbook or your instructor for help.

1. || A heat engine using a diatomic gas follows the cycle shown in FIGURE P19.53. Its temperature at point 1 is 20°C.
   a. Determine W_s, Q, and ΔE_{th} for each of the three processes in this cycle. Display your results in a table.
   b. What is the thermal efficiency of this heat engine?
   c. What is the power output of the engine if it runs at 500 rpm?



2. A beaker with a metal bottom is filled with 20 g of water at 20˚C. It is brought into good thermal contact with a 4000 cm³ container holding 4.0 mol of monatomic gas at 100 atm pressure. Both containers are well insulated from their surroundings. What is the gas pressure after a long time has elapsed? You can assume that the containers themselves are nearly massless and do not outcome.



PHYSICS 132 MIDTERM 1
EQUATION SHEET

SIMPLE HARMONIC MOTION

$x(t) = A\cos(\omega t + \phi_0)$ $\quad \omega = 2\pi f$ $\quad T = \dfrac{1}{f}$ $\quad E = \frac{1}{2}mv^2 + \frac{1}{2}kx^2 = \frac{1}{2}kA^2 = \frac{1}{2}m(v_{\max})^2$

$v(t) = -\omega A\sin(\omega t + \phi_0) = -v_{\max}\sin(\omega t + \phi_0)$ $\quad x(t) = Ae^{\frac{-bt}{2m}}\cos(\omega t + \phi_0)$

$\omega_{\text{spring}} = \sqrt{\dfrac{k}{m}}$ $\quad \omega_{\text{pendulum}} = \sqrt{\dfrac{g}{L}}$ $\quad \omega_{\text{phys-p}} = \sqrt{\dfrac{Mgl}{I}}$ $\quad \omega_{\text{damp}} = \sqrt{\omega_0^2 - \frac{b^2}{4m^2}}$ $\quad \tau = \dfrac{m}{b}$

TRAVELING WAVES

$v = \frac{\lambda}{T} = \lambda f$ $\quad k = \frac{2\pi}{\lambda}$ $\quad D(x,t) = A\sin(kx - \omega t + \phi_0)$ $\quad \Delta\phi_{\text{const.}} = 2\pi\frac{\Delta r}{\lambda} + \Delta\phi_0 = m\cdot 2\pi$

$v_{\text{string}} = \sqrt{T_s/\mu}$ $\quad n = \frac{c}{v}$ $\quad f_{\text{beat}} = f_2 - f_1$ $\quad \Delta\phi_{\text{destr.}} = 2\pi\frac{\Delta r}{\lambda} + \Delta\phi_0 = \left(m + \frac{1}{2}\right)2\pi$

$D(x,t) = A(x)\cos\omega t = 2a\sin kx\cos\omega t$ $\quad I = \frac{P}{a}$ $\quad I_1/I_2 = r_2^2/r_1^2$ $\quad \beta = (10\text{dB})\log_{10}\left(\frac{I}{I_0}\right)$

$\lambda_m = \frac{2L}{m}$ $\quad D_{\text{net}} = \sum_i D_i$ $\quad \lambda' = \lambda_0\sqrt{\dfrac{1 \pm v_s/c}{1 \mp v_s/c}}$ $\quad f_\pm = \dfrac{f_0}{1 \mp v_s/v}$ $\quad f_\pm = (1 \pm v_o/v)f_0$

KINEMATICS

$s = \frac{1}{2}a_s\Delta t^2 + v_{0s}\Delta t + s_0$ $\quad v_s = \dfrac{ds}{dt}$

$v_s = v_{0s} + a_s\Delta t$

$v_s^2 = v_{0s}^2 + 2a_s\Delta s$ $\quad a_s = \dfrac{dv_s}{dt}$

DYNAMICS

$\Sigma\vec{F} = m\vec{a}$

$\vec{F}_{A\text{ on }B} = -\vec{F}_{B\text{ on }A}$

$\vec{F}_{\text{spring}} = -k\vec{x}$

$f_s \leq \mu_s n$ $\quad f_k = \mu_k n$

CIRCULAR MOTION

$s = \theta r$

$v_t = \omega r$ $\quad \omega = \dfrac{d\theta}{dt}$ $\quad \alpha = \dfrac{d\omega}{dt}$

$a_t = \alpha r$

$a_r = a_{\text{centrip}} = \dfrac{v^2}{r} = r\omega^2$

CONSERVATION LAWS

$W_{\text{ext}} = \Delta K + \Delta U + \Delta E_{\text{th}}$ $\quad K_{\text{trans}} = \dfrac{1}{2}mv^2$ $\quad K_{\text{rot}} = \dfrac{1}{2}I\omega^2$ $\quad \vec{p} = m\vec{v}$ $\quad \vec{p}_i = \vec{p}_f$ $\quad \vec{J} = \Delta\vec{p}$

$\Delta E_{\text{th}} = f_k d$ $\quad U_g(y) = mgy$ $\quad U_s(x) = \dfrac{1}{2}kx^2$ $\quad W = \displaystyle\int_{x_1}^{x_2} F_x(x)dx$ $\quad \vec{J} = \displaystyle\int_{t_1}^{t_2}\vec{F}(t)dt = F_{\text{avg}}\Delta t$

ROTATION OF A RIGID BODY

$\tau = rF\sin\phi = rF_\perp = r_\perp F$ $\quad \vec{\tau}_{\text{net}} = I\vec{\alpha}$ $\quad \vec{\ell} = \vec{r}\times\vec{p} = m(\vec{r}\times\vec{v})$ $\quad \ell = I\omega$ $\quad \vec{\ell}_i = \vec{\ell}_f$

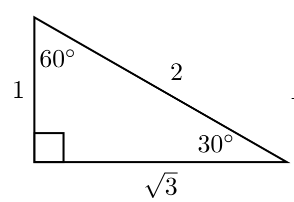
$I_{\text{point}} = \displaystyle\sum_i^N m_i r_i^2$ $\quad I_{\text{sphere}} = \frac{2}{5}MR^2$ $\quad I_{\text{pipe}} = \frac{1}{2}MR_1^2 + R_2^2$ $\quad I_{\text{log or disk}} = \frac{1}{2}MR^2$ $\quad I_{\text{hoop}} = MR^2$

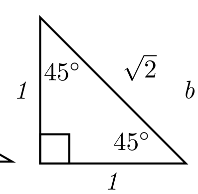
$I_{\text{baton}} = \frac{1}{12}ML^2$ $\quad I_{\parallel} = I_{\text{com}} + Md^2$

$n_{\text{air}} = 1.003$ $\quad n_{\text{water}} = 1.33$ $\quad n_{\text{glass}} = 1.5$

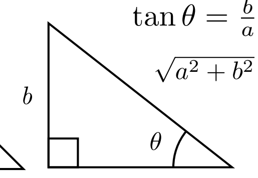
$v_{\text{sound}} = 343\,\frac{\text{m}}{\text{s}}$ $\quad g = 9.8066\,\frac{\text{m}}{\text{s}^2}$ $\quad I_0 = 10^{-12}\,\frac{\text{W}}{\text{m}^2}$

$c = 2.99782\times 10^8\,\frac{\text{m}}{\text{s}}$ $\quad \tan\theta \approx \sin\theta \approx \theta$ (small θ)





$\tan\theta = \frac{b}{a}$



PHYSICS 132 MIDTERM 2
EQUATION SHEET

SIMPLE HARMONIC MOTION

$x(t) = A\cos(\omega t + \phi_0)$ $\quad \omega = 2\pi f$ $\quad T = \dfrac{1}{f}$ $\quad E = \frac{1}{2}mv^2 + \frac{1}{2}kx^2 = \frac{1}{2}kA^2 = \frac{1}{2}m(v_{\text{max}})^2$

$v(t) = -\omega A\sin(\omega t + \phi_0) = -v_{\text{max}}\sin(\omega t + \phi_0)$ $\quad x(t) = Ae^{\frac{-bt}{2m}}\cos(\omega t + \phi_0)$

$\omega_{\text{spring}} = \sqrt{\dfrac{k}{m}}$ $\quad \omega_{\text{pendulum}} = \sqrt{\dfrac{g}{L}}$ $\quad \omega_{\text{phys-p}} = \sqrt{\dfrac{Mgl}{I}}$ $\quad \omega_{\text{damp}} = \sqrt{\omega_0^2 - \frac{b^2}{4m^2}}$ $\quad \tau = \dfrac{m}{b}$

TRAVELING WAVES

$v = \frac{\lambda}{T} = \lambda f$ $\quad k = \frac{2\pi}{\lambda}$ $\quad D(x,t) = A\sin(kx - \omega t + \phi_0)$ $\quad \Delta\phi_{\text{const.}} = 2\pi\frac{\Delta r}{\lambda} + \Delta\phi_0 = m\cdot 2\pi$

$v_{\text{string}} = \sqrt{T_s/\mu}$ $\quad n = \frac{c}{v}$ $\quad f_{\text{beat}} = f_2 - f_1$ $\quad \Delta\phi_{\text{destr.}} = 2\pi\frac{\Delta r}{\lambda} + \Delta\phi_0 = \left(m + \frac{1}{2}\right)2\pi$

$D(x,t) = A(x)\cos\omega t = 2a\sin kx\cos\omega t$ $\quad I = \frac{P}{a}$ $\quad I_1/I_2 = r_2^2/r_1^2$ $\quad \beta = (10\text{dB})\log_{10}\left(\frac{I}{I_0}\right)$

$\lambda_m = \frac{2L}{m}$ $\quad D_{\text{net}} = \sum_i D_i$ $\quad \lambda' = \lambda_0\sqrt{\dfrac{1 \pm v_s/c}{1 \mp v_s/c}}$ $\quad f_{\pm} = \dfrac{f_0}{1 \mp v_s/v}$ $\quad f_{\pm} = (1 \pm v_o/v)f_0$

OPTICS

$n = \dfrac{c}{v}$ $\quad \lambda = \dfrac{\lambda_0}{n}$ $\quad \theta_i = \theta_r$ $\quad n_1\sin\theta_1 = n_2\sin\theta_2$ $\quad d\sin\theta_m = m\lambda$ $\quad a\sin\theta_p = p\lambda$

$\dfrac{1}{s} + \dfrac{1}{s'} = \dfrac{1}{f}$ $\quad m = \dfrac{h'}{h} = -\dfrac{s'}{s}$ $\quad f = \dfrac{R}{2}$ $\quad \sin\theta_{\text{crit}} = \dfrac{n_2}{n_1}$ $\quad d\sin\theta_m = \left(m + \frac{1}{2}\right)\lambda$

$1/f = (n-1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$ $\quad \dfrac{n_1}{s} + \dfrac{n_2}{s'} = \dfrac{n_2 - n_1}{R}$

KINEMATICS

$s = \frac{1}{2}a_s\Delta t^2 + v_{0s}\Delta t + s_0$ $\quad v_s = \dfrac{ds}{dt}$

$v_s = v_{0s} + a_s\Delta t$

$v_s^2 = v_{0s}^2 + 2a_s\Delta s$ $\quad a_s = \dfrac{dv_s}{dt}$

DYNAMICS

$\Sigma\vec{F} = m\vec{a}$

$\vec{F}_{A\text{ on }B} = -\vec{F}_{B\text{ on }A}$

$\vec{F}_{\text{spring}} = -k\vec{x}$

$f_s \le \mu_s n$ $\quad f_k = \mu_k n$

CIRCULAR MOTION

$s = \theta r$

$v_t = \omega r$ $\quad \omega = \dfrac{d\theta}{dt}$ $\quad \alpha = \dfrac{d\omega}{dt}$

$a_t = \alpha r$

$a_r = a_{\text{centrip}} = \dfrac{v^2}{r} = r\omega^2$

CONSERVATION LAWS

$W_{\text{ext}} = \Delta K + \Delta U + \Delta E_{\text{th}}$ $\quad K_{\text{trans}} = \dfrac{1}{2}mv^2$ $\quad K_{\text{rot}} = \dfrac{1}{2}I\omega^2$ $\quad \vec{p} = m\vec{v}$ $\quad \vec{p}_i = \vec{p}_f$ $\quad \vec{J} = \Delta\vec{p}$

$\Delta E_{\text{th}} = f_k d$ $\quad U_g(y) = mgy$ $\quad U_s(x) = \dfrac{1}{2}kx^2$ $\quad W = \displaystyle\int_{x_1}^{x_2} F_x(x)dx$ $\quad \vec{J} = \displaystyle\int_{t_1}^{t_2}\vec{F}(t)dt = F_{\text{avg}}\Delta t$

ROTATION OF A RIGID BODY

$\tau = rF\sin\phi = rF_\perp = r_\perp F$ $\quad \vec{\tau}_{\text{net}} = I\vec{\alpha}$ $\quad \vec{\ell} = \vec{r}\times\vec{p} = m(\vec{r}\times\vec{v})$ $\quad \ell = I\omega$ $\quad \vec{\ell}_i = \vec{\ell}_f$

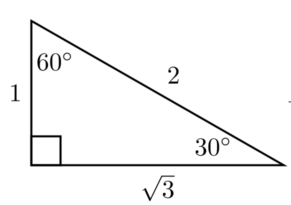
$I_{\text{point}} = \displaystyle\sum_i^N m_i r_i^2$ $\quad I_{\text{sphere}} = \frac{2}{5}MR^2$ $\quad I_{\text{pipe}} = \frac{1}{2}MR_1^2 + R_2^2$ $\quad I_{\text{log or disk}} = \frac{1}{2}MR^2$ $\quad I_{\text{hoop}} = MR^2$

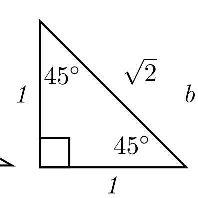
$I_{\text{baton}} = \frac{1}{12}ML^2$ $\quad I_{\parallel} = I_{\text{com}} + Md^2$

$n_{\text{air}} = 1.003$ $\quad n_{\text{water}} = 1.33$ $\quad n_{\text{glass}} = 1.5$

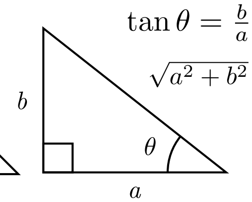
$v_{\text{sound}} = 343\,\frac{\text{m}}{\text{s}}$ $\quad g = 9.8066\,\frac{\text{m}}{\text{s}^2}$ $\quad I_0 = 10^{-12}\,\frac{\text{W}}{\text{m}^2}$

$c = 2.99782\times 10^8\,\frac{\text{m}}{\text{s}}$ $\quad \tan\theta \approx \sin\theta \approx \theta$ (small θ)





$\tan\theta = \frac{b}{a}$



PHYSICS 132 MIDTERM 3
EQUATION SHEET

SIMPLE HARMONIC MOTION

$x(t) = A\cos(\omega t + \phi_0)$ $\quad \omega = 2\pi f$ $\quad T = 1/f$ $\quad E = \frac{1}{2}mv^2 + \frac{1}{2}kx^2 = \frac{1}{2}kA^2 = \frac{1}{2}m(v_{\max})^2$

$v(t) = -\omega A\sin(\omega t + \phi_0) = -v_{\max}\sin(\omega t + \phi_0)$ $\quad x(t) = Ae^{\frac{-bt}{2m}}\cos(\omega t + \phi_0)$ $\quad \tau = m/b$

$\omega_{\text{spring}} = \sqrt{k/m}$ $\quad \omega_{\text{pendulum}} = \sqrt{g/L}$ $\quad \omega_{\text{phys-p}} = \sqrt{Mgl/I}$ $\quad \omega_{\text{damp}} = \sqrt{\omega_0^2 - b^2/(4m^2)}$

TRAVELING WAVES

$v = \frac{\lambda}{T} = \lambda f$ $\quad k = \frac{2\pi}{\lambda}$ $\quad D(x,t) = A\sin(kx - \omega t + \phi_0)$ $\quad \Delta\phi_{\text{const.}} = 2\pi\frac{\Delta r}{\lambda} + \Delta\phi_0 = m\cdot 2\pi$

$v_{\text{string}} = \sqrt{T_s/\mu}$ $\quad n = c/v$ $\quad f_{\text{beat}} = f_2 - f_1$ $\quad \Delta\phi_{\text{destr.}} = 2\pi\frac{\Delta r}{\lambda} + \Delta\phi_0 = \left(m + \frac{1}{2}\right)2\pi$

$D(x,t) = A(x)\cos\omega t = 2a\sin kx\cos\omega t$ $\quad I = \frac{P}{A}$ $\quad I_1/I_2 = r_2^2/r_1^2$ $\quad \beta = (10\text{dB})\log_{10}\left(\frac{I}{I_0}\right)$

$\lambda_m = \frac{2L}{m}$ $\quad D_{\text{net}} = \sum_i D_i$ $\quad \lambda' = \lambda_0\sqrt{\frac{1\pm v_s/c}{1\mp v_s/c}}$ $\quad f_\pm = \frac{f_0}{1\mp v_s/v}$ $\quad f_\pm = (1 \pm v_o/v)f_0$

OPTICS

$d\sin\theta_m = \left(m + \frac{1}{2}\right)\lambda$

$n = c/v$ $\quad \lambda = \lambda_0/n$ $\quad \theta_i = \theta_r$ $\quad n_1\sin\theta_1 = n_2\sin\theta_2$ $\quad \sin\theta_{\text{crit}} = n_2/n_1$ $\quad d\sin\theta_m = m\lambda$

$\frac{1}{s} + \frac{1}{s'} = \frac{1}{f}$ $\quad m = \frac{h'}{h} = -\frac{s'}{s}$ $\quad \frac{n_1}{s} + \frac{n_2}{s'} = \frac{n_2 - n_1}{R}$ $\quad \frac{1}{f} = (n-1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$ $\quad a\sin\theta_p = p\lambda$

FLUIDS AND THERMODYNAMICS

$\Delta E_{\text{th}} = W + Q$ $\quad pV = nRT = Nk_BT$ $\quad T_K = T_C + 273$

$p = F/A$ $\quad p = p_0 + \rho gh$ $\quad F_B = m_f g = \rho_f V_f g$ $\quad W = -\int_{V_i}^{V_f} pdV$ $\quad C_p = C_V + R$

$W_{\text{isobaric}} = -p\Delta V$ $\quad Q = Mc\Delta T$ $\quad Q = \pm ML$ $\quad Q = nC\Delta T$ $\quad \Delta E_{\text{th}} = nC_V\Delta T$

$W_{\text{isothermal}} = -nRT\ln(V_f/V_i)$ $\quad W_{s\ \text{(gas on environment)}} = -W$ $\quad E_{\text{per DOF}} = \frac{1}{2}Nk_BT = \frac{1}{2}nRT$ $\quad \gamma = C_P/C_V$

$W_{\text{adiabatic}} = \Delta E_{\text{th}} = -\left(\frac{p_f V_f - p_i V_i}{1-\gamma}\right)$ $\quad pV^\gamma = \text{const.}$ $\quad \eta = W_{\text{out}}/Q_H$ $\quad \eta_{\text{Carnot}} = 1 - T_C/T_H$

KINEMATICS

$s = \frac{1}{2}a_s\Delta t^2 + v_{0s}\Delta t + s_0$

$v_s = v_{0s} + a_s\Delta t$ $\quad v_s = \frac{ds}{dt}$

$v_s^2 = v_{0s}^2 + 2a_s\Delta s$ $\quad a_s = \frac{dv_s}{dt}$

DYNAMICS

$\Sigma\vec{F} = m\vec{a}$ $\quad \vec{F}_{\text{A on B}} = -\vec{F}_{\text{B on A}}$

$f_s \le \mu_s n$ $\quad f_k = \mu_k n$

$\vec{F}_{\text{spring}} = -k\vec{x}$

CIRCULAR MOTION

$s = \theta r$ $\quad \omega = \frac{d\theta}{dt}$ $\quad \alpha = \frac{d\omega}{dt}$

$v_t = \omega r$ $\quad a_t = \alpha r$

$a_r = a_{\text{centrip}} = \frac{v^2}{r} = r\omega^2$

CONSERVATION LAWS

$W_{\text{ext}} = \Delta K + \Delta U + \Delta E_{\text{th}}$ $\quad K_{\text{trans}} = \frac{1}{2}mv^2$ $\quad K_{\text{rot}} = \frac{1}{2}I\omega^2$ $\quad \vec{p} = m\vec{v}$ $\quad \vec{p}_i = \vec{p}_f$ $\quad \vec{J} = \Delta\vec{p}$

$\Delta E_{\text{th}} = f_k d$ $\quad U_g(y) = mgy$ $\quad U_{\text{spring}} = \frac{1}{2}kx^2$ $\quad W = \int_{x_1}^{x_2} F_x(x)dx$ $\quad \vec{J} = \int_{t_1}^{t_2}\vec{F}(t)dt = F_{\text{avg}}\Delta t$

ROTATION OF A RIGID BODY

$\tau = rF\sin\phi = rF_\perp = r_\perp F$ $\quad \vec{\tau}_{\text{net}} = I\vec{\alpha}$ $\quad \vec{\ell} = \vec{r}\times\vec{p} = m(\vec{r}\times\vec{v})$ $\quad \ell = I\omega$ $\quad \vec{\ell}_i = \vec{\ell}_f$

$I_{\text{point}} = \sum_i^N m_i r_i^2$ $\quad I_{\text{sphere}} = \frac{2}{5}MR^2$ $\quad I_{\text{baton}} = \frac{1}{12}ML^2$ $\quad I_{\text{log or disk}} = \frac{1}{2}MR^2$ $\quad I_\parallel = I_{\text{com}} + Md^2$

$k_B = 1.38064\times 10^{-23}$ J/K $\quad R = 8.314598$ J/mol K $\quad N_A = 6.02214\times 10^{23}$ particles/mol

$c_{\text{ice}} = 2090$ J/kg K $\quad c_{\text{water}} = 4190$ J/kg K $\quad c_{\text{steam}} = 1996$ J/kg K $\quad L_{f,\ \text{water}} = 334$ kJ/kg $\quad L_{v,\ \text{water}} = 2265$ kJ/kg

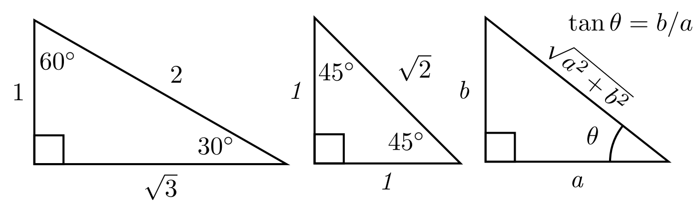
$C_{v,\text{mono}} = 12.5$ J/mol K $\quad C_{v,\text{dia}} = 20.8$ J/mol K

1 atm $= 101{,}300$ Pa $\quad \gamma_{\text{mono}} = 1.67$ $\quad \gamma_{\text{dia}} = 1.4$

$n_{\text{air}} = 1.003$ $\quad n_{\text{water}} = 1.33$ $\quad n_{\text{glass}} = 1.5$

$v_{\text{sound}} = 343\,\frac{\text{m}}{\text{s}}$ $\quad g = 9.8066\,\frac{\text{m}}{\text{s}^2}$ $\quad I_0 = 10^{-12}\,\frac{\text{W}}{\text{m}^2}$

$c = 2.99782\times 10^8\,\frac{\text{m}}{\text{s}}$ $\quad \tan\theta \approx \sin\theta \approx \theta$ (small θ)



Experiment 1

Uncertainty in Measurement

References: Many sections of this text adapted and summarized from *An Introduction to Error Analysis: The Study of Uncertainties in Physical Measurements* by John R. Taylor. University Science Books. 2007.

Introduction

Since the analysis of uncertainties is essential to any scientific measurement, many of the laboratory exercises in undergraduate physics labs emphasize the estimation and propagation of experimental uncertainty. In this lab, we investigate what is meant by experimental uncertainty, we develop techniques for estimating uncertainty and for using uncertainties in calculations.

What is uncertainty?

If you were to measure the width of this piece of paper using a ruler, you would likely find it to be around 21.6cm. But, is the paper *exactly* 21.6 cm? A careful ruler-user can probably consistently distinguish 21.6 cm from 21.7 cm, but can unlikely tell a 21.60 cm sheet from 21.61 cm. It would be foolish, using the same ruler, to say that the sheet of paper is 21.6030524 cm wide. The best we can say (with a ruler) is that the the width of the paper is closer to the 21.6 cm mark than any other mark. It's our best guess for the width. Taking the resolution of the ruler to be 0.1cm, we can say explicitly that the width is between 21.55 cm and 21.65 cm.

When stating measured values, we state our best guess for the measurement x_{best} and its uncertainty δx as

$$x_{\text{best}} \pm \delta x$$

The quantity δx is called the *uncertainty* of the measurement.

For the width w of this paper, the measurement is correctly written as

$$w = 21.6 \pm 0.05 \text{ cm}$$

If a careful experimenter wanted to make a better measurement, she could use a better instrument, and get a result with a smaller uncertainty. But does she know how wide the sheet of paper is *exactly*? That's a tough question. The width is likely to be different at the top of the sheet than at the bottom, or near the middle. With very precise measurements, mechanical vibrations cause trouble. Variations in humidity and temperature cause the sheet to grow and shrink. Microscopically, thermal energy keeps the atoms in the paper constantly vibrating and moving. It's *impossible* to define exactly what we mean by the *width* of the paper— it's not a well-defined quantity. So, we say what we know: our best guess and its uncertainty: $w = 21.6 \pm 0.05$ cm. Uncertainties are usually rounded to one significant figure.

Another source of uncertainty, *systematic errors*, are caused by mis-calibrated measurement equipment or a improper measurement technique. Anytime an instrument has an out-of-date calibration, or is otherwise unverified, the experimenter runs the risk of taking inaccurate measurements. In the undergraduate lab, systematic errors are not typically encountered. But in the real world, systematic errors happen and must carefully be avoided in experimental measurements.

Key ideas

1. No measurement can be made with absolute certainty.

It's all about comparisons

If I say that it's 311 Kelvin outside today, that my dog has a mass of 1.3 slugs and that I ate a 2.5 megajoule breakfast today, it probably doesn't mean much to you. These unfamiliar units illustrate an important point about measurements: they allow us to make comparisons. Using familiar units, I'd say it is 100°F today, my dog weighs 41 lbs, and I ate a 600 Calorie breakfast. This allows you to make a comparison to warmer or colder days, bigger or smaller dogs and to conclude that I should eat a healthier breakfast. Comparisons are the reason that we take any measurement. Any single measured quantity is completely uninteresting.

In lab, we compare our measurements to accepted values or to a value predicted by a physical model. Two measurements correctly stated with uncertainty, are *consistent* with one another when they are equal within their uncertainties. For two values p and q, does

$$p_{\text{best}} \pm \delta p = q_{\text{best}} \pm \delta q\ ?$$

If this equality is true, p and q are said to be consistent.

As experimenters, we strive to make measurements of high precision. We want to be *certain* that measurements are consistent with predictions. So, measurements of low uncertainty are preferred. But avoid the temptation to underestimate uncertainty, it's better to be unsure than wrong.

Key ideas

1. Any single measured quantity is completely uninteresting.
2. We use a measurement and its uncertainty to *make a comparison* between the measurement and the accepted value or prediction.
3. It is better to be accurate than precise.

Today's Game

Game rules

In today's lab, we will be playing a game. The goal of the game is to make *accurate* measurements with the *lowest possible uncertainty* for the instrument and technique used. You will be instructed to make several measurements using different techniques. With your lab group, make your best measurement and estimate its uncertainty. Higher precision answers are rewarded with more points, while inaccurate answers receive no points. You will then bring your measurement to the lab instructor, where it will be compared against a very high precision measurement. Consistent measurements will be awarded using the formula

$$\text{awarded points} = \sqrt{\frac{x_{\text{best}}}{\delta x}} - 1 \tag{1}$$

Accurate measurements of higher precision receive more points. Measurements with a relative uncertainty $\delta x / x_{\text{best}}$ of 25% receive 1 point. 10% → 2 points, 5% → 3 points, 1% → 9 points, 0.1% → 30 points.

- **Measurements inconsistent with the high-precision standard measurement will receive 0 game points.**
- **Explicitly follow the instructions for each measurement technique.**
- **Do not use measurement tools until instructed to do so.**
- **Chip Values:** White: 1 point, Red: 5 points, Blue 10 points, Green: 25 points, Black: 50 points

⋆ The lab group with the most points at the end of the lab-period will win a prize ⋆

Game Round 1: Estimating instrument uncertainty

Metal block

The uncertainty of a measurement depends on the tool used and the skill of the experimenter. Work as a group to estimate the uncertainty in the length offered by three measurement techniques.

SUBMISSION B1: State the length (with uncertainty) of the longest side of the block with **no external tools or objects used for scale**. You may handle the block if you like. Submit your measurement on a post-it note. Inches or centimeters are acceptable units. Calculate the payout (using Equation 1) you will receive if your measurement and uncertainty are consistent with the accepted value. The submission should include the block letter, your estimate of the length, the uncertainty, and the payout amount.

SUBMISSION B2: Measure the length of the longest side of the block in centimeters using the ruler. Calculate the payout (using Equation 1) you will receive if your measurement and uncertainty is consistent with the accepted value. Submit your measurement and its uncertainty on a post-it note. The submission should include the block letter, your measurement of the length, the uncertainty, and the payout amount.

SUBMISSION B3: Measure the length of the longest side of the block using the vernier calipers. Calculate the payout (using Equation 1) you will receive if your measurement and uncertainty is consistent with the accepted value. Submit your measurement and its uncertainty on a post-it note. The submission should include the block letter, your measurement of the length, the uncertainty, and the payout amount.

Unknown mass

SUBMISSION M1: State the mass (with uncertainty) of the provided mass with **no external tools or objects used for scale**. You may handle the mass if you like. Submit your measurement on a post-it note. Grams, kilograms, ounces or pounds are acceptable units. The submission should include the block letter, your estimate of the mass, the uncertainty, and the payout amout.

SUBMISSION M2: Measure the mass provided in grams using the triple beam balance. Submit your measurement and its uncertainty on a post-it note. The submission should include the mass letter, your measurement of the mass, the uncertainty, and the payout amount.

Lens focal length

Sometimes the uncertainty of a measurement is not limited by the scale of the instrument used. For example, when a lens forms an in-focus image of a distant object onto a screen, the distance between the screen and the lens is called the *focal length*. When we try to measure this focal length, it may be difficult to identify the center of the lens, or determine exact in-focus position for the screen.

SUBMISSION L1: Place a piece of white paper on the table. Position the lens above the paper, and adjust the paper-to-lens distance required to form an image (on the paper) of the fluorescent lights overhead. Using a ruler, measure the this paper-to-lens distance in centimeters. Submit your measurement and its uncertainty on a post-it note. The submission should include your measurement of the length, the uncertainty, and the payout amount.

Key ideas

1. It is important to make a reasonable estimate of the uncertainty of the measurement technique used.
2. A measurement is often more uncertain than the scale on an instrument suggests

---

Using uncertainties in calculations

The following formulas are reproduced, without proof, from Taylor (2007) cited above. **These formulas are shown for three variables x, y, z but can easily be generalized for more (or fewer) variables.** If the various quantities x, y, z are measured with small uncertainties $\delta x, \delta y, \delta z$, and the measured values are used to calculate some quantity q, then the uncertainties in x, y, z cause an uncertainty in q as follows:
When q is a **sum or difference** like $q = x + y - z$,

$$\delta q^* = \sqrt{(\delta x)^2 + (\delta y)^2 + (\delta z)^2} \tag{2}$$

If q is a **product or quotient** like $q = \frac{xz}{y}$,

$$\delta q = |q|\sqrt{\left(\frac{\delta x}{x}\right)^2 + \left(\frac{\delta y}{y}\right)^2 + \left(\frac{\delta z}{z}\right)^2}. \tag{3}$$

If q is a **power** of x and y like $q = \frac{zx^m}{y^n}$,

$$\delta q = |q|\sqrt{\left(m\frac{\delta x}{x}\right)^2 + \left(n\frac{\delta y}{y}\right)^2 + \left(\frac{\delta z}{z}\right)^2}. \tag{4}$$

If q is related to x by an **exactly-known coefficient** B then $q = Bx$ and

$$\delta q = |B|\delta x. \tag{5}$$

Example 1

The total mass of a bag of apples is $m_t = 2.1 \pm 0.1$ kg. The grocer tells you that the mass of the bag is $m_b = 0.22 \pm 0.03$ kg. What is the mass (and uncertainty) of the apples alone (m_a)?

$$m_a = m_t - m_b = 2.1 \text{ kg} - 0.22 \text{ kg} = 1.88 \text{ kg}$$

From Equation 2 we calculate the uncertainty in the apple mass to be

$$\delta m_a = \sqrt{(\delta m_t)^2 + (\delta m_b)^2} = \sqrt{(0.1)^2 + (0.03)^2} = 0.104\text{kg}$$

With the correct number of significant figures,

$$m_a \pm \delta m_a = 1.8 \pm 0.1 \text{ kg}.$$

Example 2

If a certain object has a mass m of 50.0 ± 0.2 kg and a volume V of 0.250 ± 0.005 m^3, the density ρ is given by

$$\rho = \frac{m}{V} = \frac{50 \text{ kg}}{0.250 \text{ m}^3} = 200 \frac{\text{kg}}{\text{m}^3}.$$

According to Equation 3, the uncertainty in the density $\delta\rho$ is given by

$$\delta\rho = \rho\sqrt{\left(\frac{\delta m}{m}\right)^2 + \left(\frac{\delta V}{V}\right)^2} = \left(200\frac{\text{kg}}{\text{m}^3}\right)\sqrt{\left(\frac{0.2}{50}\right)^2 + \left(\frac{.005}{0.250}\right)^2} = 4.1\frac{\text{kg}}{\text{m}^3}.$$

The density is calculated to be

$$\rho = 200. \pm 4\frac{\text{kg}}{\text{m}^3}.$$

Key ideas

1. When uncertain measured values are used in calculations, *error propagation* is the set of tools used to determine the uncertainty in the calculated result.

Game Round 2: Calculated Uncertainties

Area of a metal block

SUBMISSION A1: Using the vernier calipers, measure, in mm, the two longest sides of the the metal block and calculate its area (mm^2), and the uncertainty in the area calculation. Submit your measurement and its uncertainty on a half sheet of paper. The submission should include your calculation of the area, the calculation of the uncertainty (with all details), and the payout amount.

Period of a turntable

SUBMISSION T1: Using the stopwatch, measure, in seconds, the amount of time it takes for the turn table to make one rotation. Measure the duration of one rotation directly, stopping the watch after exactly one rotation. Note: although the stopwatch measures in increments of 0.01 s, the uncertainty in this measurement is much greater that 0.01 s, and is limited by the inconsistencies in human reaction time. With your group, discuss the best approach for estimating the uncertainty in the time measurement process. Submit your measurement and its uncertainty on a post-it note. The submission should include your measurement of the period, estimate of uncertainty, and the payout amount.

SUBMISSION T2: If we measure the duration of several rotations of the turntable, we can significantly reduce the uncertainty in the duration of one rotation. Use this technique, along with Equation 5 to make a better measurement of the single-rotation duration. Submit your measurement and its uncertainty on a post-it note. The submission should include your measurement of the period, estimate of uncertainty, and the payout amount.

Repeated Measurements

When measuring the period of the turntable above, we identified the greatest source of uncertainty as the reaction-time of the experimenter. Even a careful experimenter is just as likely to overshoot her measurement as undershoot. Reaction-time is a source of *random error* in an experiment. There are many sources of random errors in any particular measurement.

Suppose we need to measure some quantity x and have determined the systematic errors to be negligible. The remaining sources of uncertainty are random, so we should be able to detect them by repeating the measurement several times. Suppose we repeat the measurement five times, and record the (unitless) values

$$45, 46, 46, 49, 43$$

What should we take for our best estimate x_{best} of the quantity x?

Reasonably, we can use the *average* or mean $\overline{x}$ of the five values as an estimate of x_{best}

$$x_{\text{best}} = \overline{x} = \sum_{i=1}^{N} \frac{x_i}{N} \tag{6}$$

For the five values above, we find

$$x_{\text{best}} = \overline{x} = \sum_{i=1}^{N} \frac{x_i}{N} = \frac{45+46+46+49+43}{5} = 45.8.$$

By taking several measurements we can also get a sense of the uncertainty in our experiment. The *standard deviation*

$$\sigma = \sqrt{\frac{1}{N-1}\sum_{i=1}^{N}(x_i - \overline{x})^2}$$

is a measure that is used to quantify the amount of variation in a set of data. Data sets with large variations have a larger uncertainty than those with small variations. σ measures how much uncertainty is in *any one data point* x_i. But, when we combine several (N) measurements x_i to make an improved estimate of the measurement $x_{\text{best}} = \overline{x}$, we expect x_{best} to be closer to the true value than one measurement taken alone. When several individual measurements are combined as an average, we estimate the uncertainty using the *standard deviation of the mean*, given by

$$\sigma_{\overline{x}} = \frac{\sigma}{\sqrt{N}} = \sqrt{\frac{1}{N(N-1)}\sum_{i=1}^{N}(x_i - \overline{x})^2} \tag{7}$$

Note the factor of $\sqrt{N}$ in the denominator: If we collect more data points, the uncertainty is reduced.

For the five data points shown above the uncertainty is given by

$$\begin{aligned}\sigma_{\overline{x}} &= \sqrt{\frac{1}{N(N-1)}\sum_{i=1}^{N}(x_i - \overline{x})^2} \\ &= \sqrt{\frac{1}{5(5-1)}\left((45-45.8)^2 + (46-45.8)^2 + (46-45.8)^2 + (49-45.8)^2 + (43-45.8)^2\right)} = 1.6\end{aligned}$$

The measurement is correctly reported as 45.8 ± 1.6.

Game Round 3: Repeated Measurements

Falling time of an Atwood machine

SUBMISSION P1: Using a stop watch, measure the amount of time it takes for the left block of the Atwood machine to fall between the two arrows. Start and stop the timer when the bottom edge of the block passes the arrow. **Make the measurement only once**, and submit your best measurement for the fall time and its uncertainty. Submit your measurement and its uncertainty on a post-it note. The submission should include your measurement of the fall time, estimate of uncertainty, and the payout amount.

SUBMISSION P2: Using a stop watch, measure the amount of time it takes for the left block of the Atwood machine to fall between the two arrows. Start and stop the timer when the bottom edge of the block passes the arrow. **Make the measurement five times**, and submit your best measurement for the fall time and its uncertainty. Submit your measurement and its uncertainty on a half sheet of paper. The submission should include your calculation of the mean fall time, the calculation of the uncertainty, and the payout amount.

SUBMISSION P3: Using a stop watch, measure the amount of time it takes for the left block of the Atwood machine to fall between the two arrows. Start and stop the timer when the bottom edge of the block passes the arrow. **Make the measurement twenty times**, and submit your best measurement for the fall time and its uncertainty. Submit your measurement and its uncertainty on a half sheet of paper. The submission should include your calculation of the mean fall time, the calculation of the uncertainty, and the payout amount. You may use a graphing calculator or computer to assist in statistical calculations.

Key ideas

1. Measurements that can be repeated should be.
2. By taking repeated measurements, we can estimate the uncertainty in the measured value.
3. With *more* repeated measurements, we reduce the uncertainty.
4. We use *statistical analysis* to estimate the uncertainty of repeated measurements
5. *Error propagation* and *statistical analysis* are distinct tools, and both are important.

Weakest Link Rule

To make a rigorous measurements and comparisons, we must apply the tools of statistical analysis and propagate uncertainties described above. However, a full error analysis is laborious and time consuming and not appropriate for every task and measurement. In many cases, we can apply a simpler, short-hand technique called the *Weakest Link Rule.* In any measurement, the percent uncertainty in the calculated value of some quantity is at least as great as the greatest percentage uncertainty of the values used to make calculation. In many cases, the overall uncertainty is dominated by a single measurement—the weakest link. To apply weakest link analysis,

1. Estimate the absolute uncertainty in each measured quantity used to find the calculated quantity.
2. Calculate the relative uncertainty in each measured quantity.
3. Pick the largest relative uncertainty. We call this largest relative uncertainty the weakest link.
4. We say that the relative uncertainty in our calculated value is equal to the weakest link (the largest relative uncertainty in our measured values). We can then apply the relative uncertainty of the weakest link to the calculated quantity to determine its absolute uncertainty.

Example 3

Here's an example: You've been asked to estimate the volume of your laptop computer. First, you measure the length, width, and thickness with a meter stick (which has an absolute uncertainty of 0.05cm)

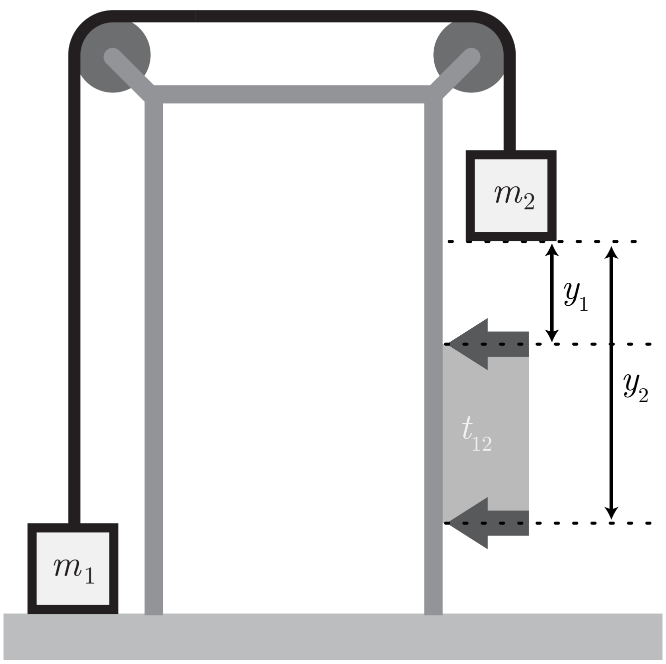
Measurement	Value	Relative Uncertainty
Length (L)	39.4 ± 0.05 cm	0.05 cm/39.4 cm = 0.00127 = 0.127%
Width (W)	28.7 ± 0.05 cm	0.05 cm/28.7 cm = 0.00174 = 0.174%
Thickness (T)	4.3 ± 0.05 cm	0.05 cm/4.3 cm = 0.0116 = 1.16%

From this table, you can see that the thickness has by far the largest relative uncertainty— the thickness measurement is our weakest link! The volume of the laptop is $V = LWT = (39.4\text{ cm})(28.7\text{ cm})(4.3\text{ cm}) = 4862\text{ cm}^3$. Since the thickness measurement has the largest relative uncertainty (1.16%) we say this is the relative uncertainty in our final calculated volume V. To determine the absolute uncertainty of our calculated volume, we multiply the volume by the relative uncertainty of the weakest link:

$$\Delta V = V \times (\text{Weakest Relative Uncertainty}) = (4862\text{ cm}^3)(0.0116) = 56\text{ cm}^3$$

So, the final estimate for the volume of the laptop is $4862 \pm 56\text{ cm}^3$.

Questions and Calculations

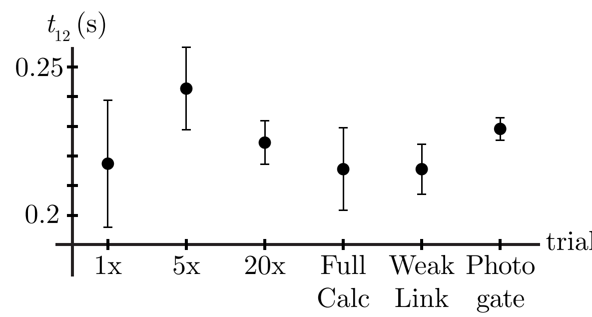


Newton's laws predict that the amount of time it should take for the right mass of the above Atwood machine to fall through the arrows in the figure above is given by

$$t_{12} = \sqrt{\frac{2(m_2+m_1)}{g(m_2-m_1)}}\left(\sqrt{y_2}-\sqrt{y_1}\right) \tag{8}$$

Assume $g = 9.81\frac{\text{m}}{\text{s}^2}$, with negligible uncertainty (pretend $\delta g = 0$). Carefully measure the distances y_1 and y_2 and the masses m_2 and m_1, with their uncertainties and calculate the predicted time t_{12}, that the mass will travel between the arrows.

1. Calculate the uncertainty in the fall time δt_{12}, by generalizing and applying equations 3 and 4.
2. Calculate the uncertainty in the fall time δt_{12} using the weakest link method. Is your result reasonable? Why or why not?
3. Is the value you calculated for t_{12} consistent with the measurements you made in Game Round 3? On graph paper, plot the measured values and calculated value with error bars, as shown in the figure below. Ask your instructor for the photogate measurement.



Uncertainty in Measurement: Original LabView Software

In order to aid in the administration of the *Uncertainty in Measurement* laboratory exercise detailed on the preceding pages, I wrote three LabView applications to automate the precision measurement of the turntable period (using a Vernier-branded rotation sensor) and the in-situ precision measurement of the Atwood machine fall time (using a pair Vernier photogates). These applications allow the automated and continous collection of the precision measurements required to check students' measurements for the game exercise incorporated into this lab. A third VI, the Instructor Console references a spreadsheet of standard measurements and retrieves the precision measurements produced by the Turntable and Atwood VIs to streamline checking student measurements. The results are displayed on a chart with appropriate error bars. The application front panels are shown in figure 1.

Figure 1: Custom LabView VIs automate the task of collecting standard measurements and reporting them to the instructor for the competition incorporated into my *Uncertainty in Measurement* laboratory exercise. The VIs aim to streamline the student and instructor experience and serve to facilitate the adoption of the exercise with other instructors.

Lecture Slides

I utilize slides as a multimedia accompaniment to my lecture presentation, not the focus. When an image, video, sound or animation can add to my explanation, I include it my slide deck. The slide deck is posted to the course website and updated regularly. For my most recent Physics 132 offering (Fall 2016), the slide deck contained 106 slides, including 29 original mathematica animations.

Mathematica Animations

A main topic of Physics 132 is oscillations and waves. Due to their dynamic nature—changing in both space and time—waves computer animations are an excellent tool to help students visualize and conceptually understand key wave properties. I have used Mathematica (figure 2) to develop versatile code for producing longitudinal and transverse animations. My Physics 132 Mathematica animation library contains 29 original animations, covering wave velocity, snapshot and history graphs, small angle approximation, standing waves and sound propagation.

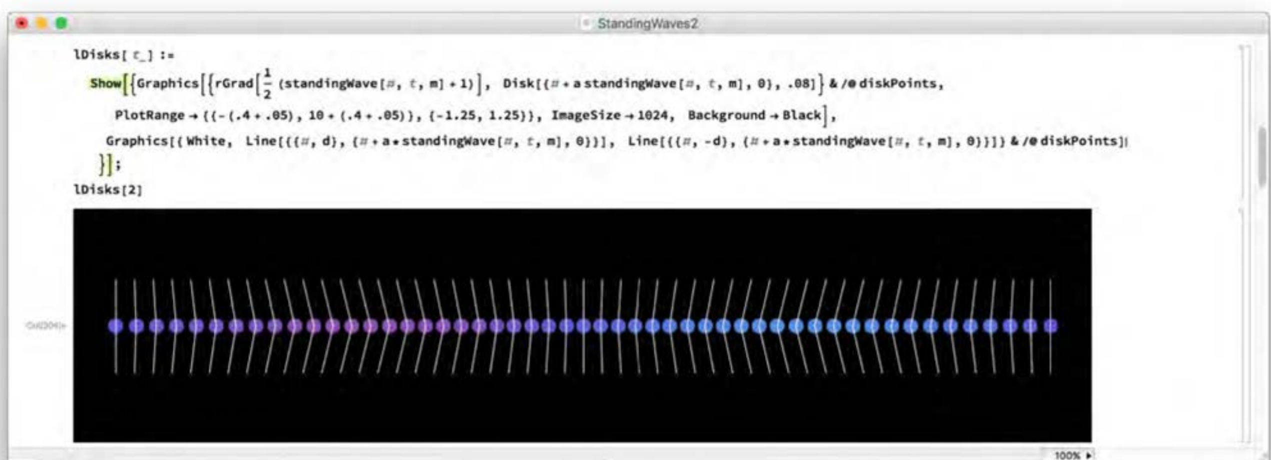


Figure 2: The dynamic nature of wave-phenomenon makes computer animations an excellent tool for illustrating their properties. I wrote a Mathematica notebook longitudinal and transverse wave animation generator for producing high-resolution animations integrated into my lecture.

Other slide content

In addition to animations, my Physics 132 presentation features many other multimedia elements, including photographs, videos, clicker-type questions, and book illustrations. Figure 3 shows a sample of several Physics 132 lecture slides.

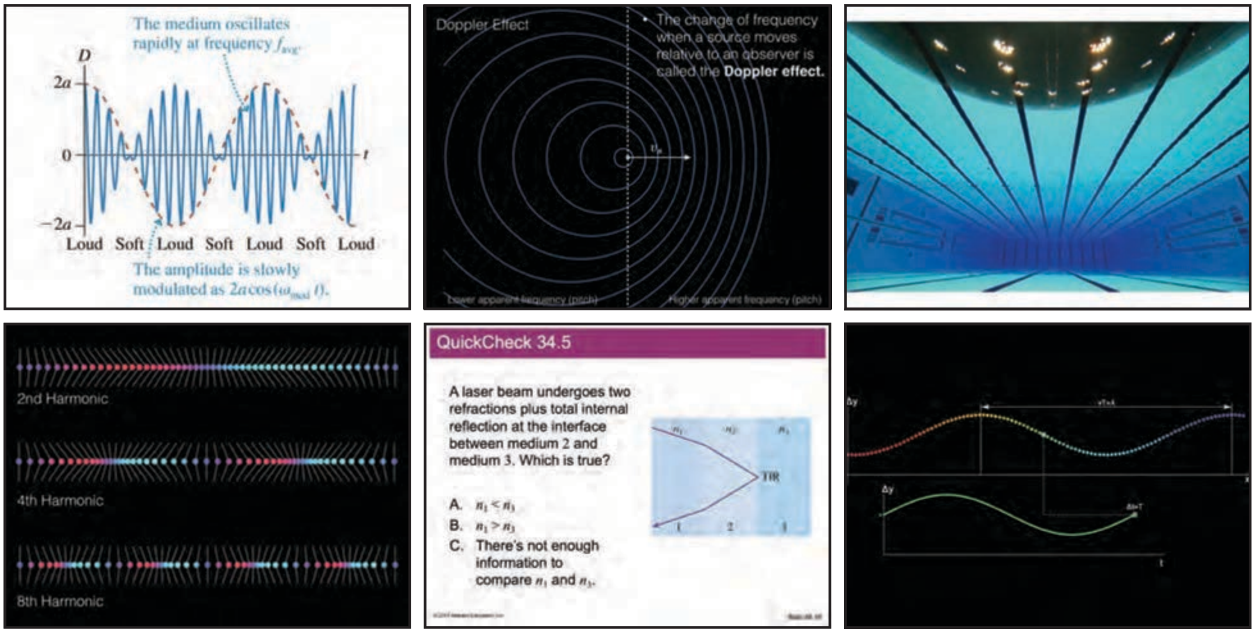


Figure 3: I use my slide deck as a multimedia accompaniment to lecture, incorporating photos, videos, original animations, clicker-type questions and book illustrations.

Course Website

The Physics 132 Course Website (`http://physicscloud.net/132`), shown above in figure 4 is the central communication hub for the class. The website provides student access to the course

- Syllabus
- Objectives
- Schedule
- Homework assignments
- Instructor-prepared homework solutions
- Equation sheets
- Midterm solutions
- Lab Manual
- Supplemental lecture videos
- Homework solution videos (select problems)

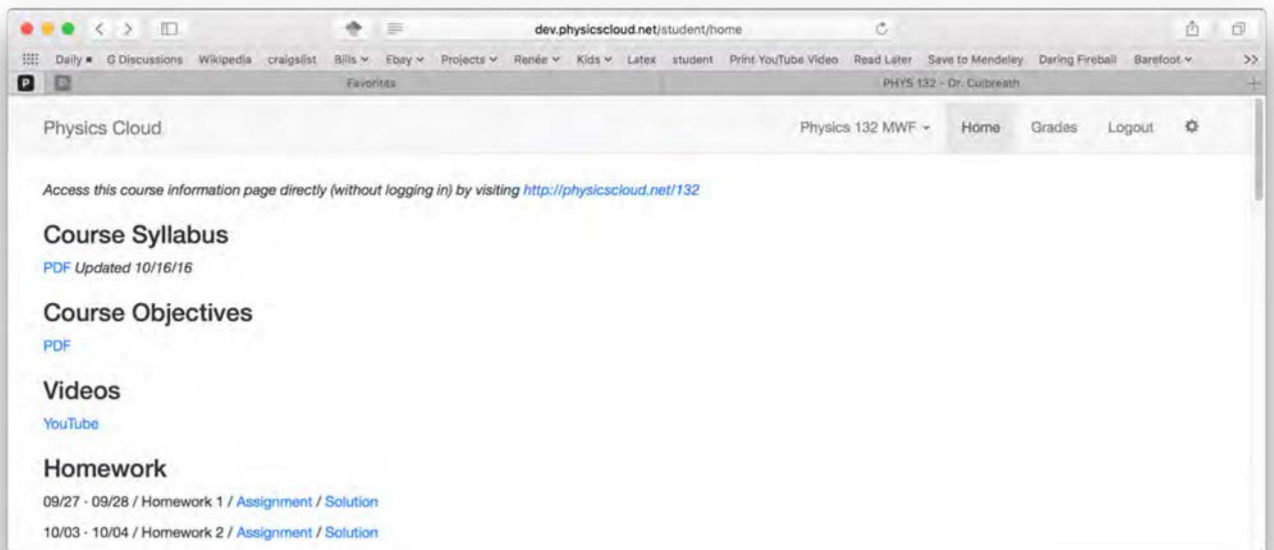


Figure 4: The course website is the central communication hub for the class and is updated several times per week. Visit the site at `http://physicscloud.net/132`

Homework Assignments are posted at least one week before their due date. Homework assignments (figure 5) often include links to one or two homework solution videos (see *Online Videos* on page 47). Changes to the course schedule are relayed by email and updated on the site.

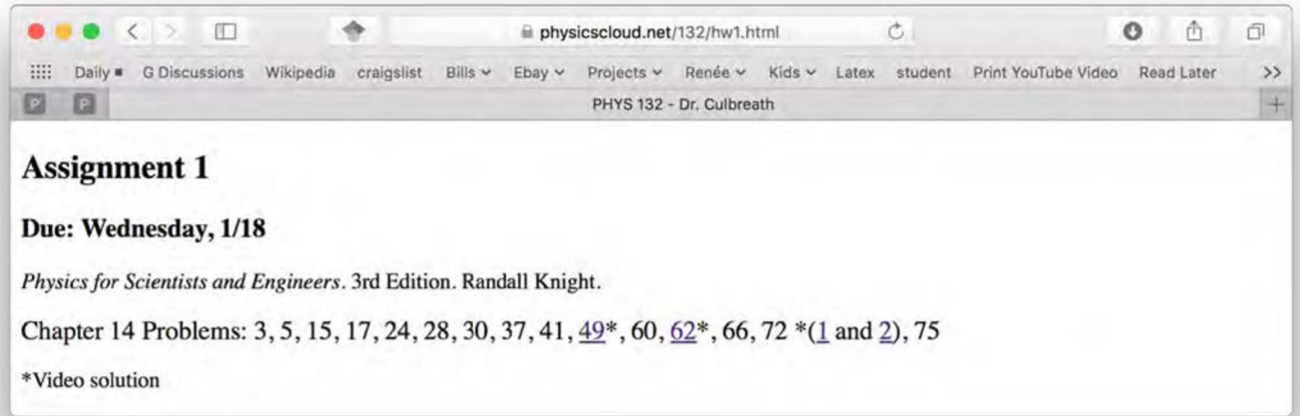


Figure 5: Homework assignments are posted to the course website at least one week before their due date and often include links to 1–3 instructor-prepared solution videos.

Homework and Exam solutions

Instructor prepared homework solutions are posted to the course website on the same day that homework is collected. The homework solutions detail the step-by-step approach to solving the problem, and often include explanatory notes and commentary, as shown in figure 6. In addition, detailed exam solutions are posted after students receive their graded exams. For both exams and homework, I require students to submit corrections which reference the posted solutions and remedy mistakes in their original work[‡].

[‡]The corrections policy is detailed in the course syllabus (page 13)

Figure 6: Instructor prepared homework solutions are posted to the course website the same day that homework is collected, and often contain explanatory notes and commentary. At the end of the Fall 2016 quarter, the PHYSICS 132 COURSE WEBSITE contained 268 pages of handwritten instructor-prepared solutions.

Course Videos

A full general description of my online video content can be found on page 76. Listed below is the content I produced and is available on my course website specifically for Physics 132.

Table 1: Physics 132 Step-by-step Solution Videos

Topic	Duration	URL
Ch 22 #36	6:05	youtube.com/watch?v=5zvtKxY-0Dg
Ch 22 #70	6:28	youtube.com/watch?v=I_JJ5bS-zzs
Ch 21 #74	5:29	youtube.com/watch?v=W_opX2byMwI
Ch 21 #77	6:15	youtube.com/watch?v=yzek8qJ6boA
Ch 14 #72	18:25	youtube.com/watch?v=-ziz7R3GijE
Ch 14 #62	5:20	youtube.com/watch?v=YQjk2831gvI
Ch 14 #49	7:19	youtube.com/watch?v=IGVrH1UBNRY
Conceptual 2D Interference	8:11	youtube.com/watch?v=bcx65yaYkLQ
Quantitative 2D Interference	7:51	youtube.com/watch?v=bcx65yaYkLQ
1D Interference	9:52	youtube.com/watch?v=FmwmjKRtt2w
Comparing Two Gases (Ch 16)	4:20	youtube.com/watch?v=vwYGx1VNt9Q
PV Diagram Example	3:34	youtube.com/watch?v=QO6zmI1LpOk

Table 2: Physics 132 Supplemental Lecture and Tutorial Videos

Topic	Duration	URL
Introduction to Buoyancy	15:24	youtube.com/watch?v=r4wm-F673tw
Buoyancy example	5:49	youtube.com/watch?v=3Oc-9AnCW1g
Hydraulic example	5:56	youtube.com/watch?v=p3TyVLGXk8s
Hydraulic Lift	9:36	youtube.com/watch?v=-Enbr7zvbes
Introduction to Power and Intensity	12:12	youtube.com/watch?v=Nt2MtQp5Jgo
Doppler Effect Example Problem	5:16	youtube.com/watch?v=G6sfu9PV9nk
Sound Intensity Level (dB)	13:34	youtube.com/watch?v=PndztQ6Olkw
Damped Oscillation Example Problem	6:34	youtube.com/watch?v=8gDO2680-Ys
Doppler Effect Lecture Notes	6:39	youtube.com/watch?v=X5hyjpHLlzY
Interference in One Dimension	9:24	youtube.com/watch?v=bHlJx-rNZlc
Interference in Two Dimensions	10:01	youtube.com/watch?v=2SSj5hxVwrU
Interference in Two Dimensions	10:01	youtube.com/watch?v=2SSj5hxVwrU
Introduction to Exponential Decay	14:58	youtube.com/watch?v=qgTQO2LqxaM
Isobaric Processes	6:37	youtube.com/watch?v=ef4mzQLuMJw

PHYSICS 133

Course Syllabus/Winter 2018

INSTRUCTOR: Dr. Christopher Culbreath **OFFICE**: Jesperson Hall (116) 108

OFFICE HOURS: M 11:10 AM—12 PM (Baker 180-272) • T/R 1:10 PM—3 PM (Baker 6th Floor Lobby)
EMAIL: cculbrea@calpoly.edu **WEB:** http://physicscloud.net/133

LECTURE: T/R 3:10-4:30 in Baker Science (180-265)
LAB: 180-265

COURSE DESCRIPTION: This course is the last module of the 3-quarter introductory physics sequence with calculus for science and engineering students. The course topic is electricity and magnetism. It requires calculus and will make use of quite a bit of trigonometry and algebra.

COURSE OBJECTIVES: The course objectives are: i) to understand concepts relevant to electrodynamics such as electric and magnetic fields, forces, potentials, electric circuits, and electromagnetic induction, and ii) to master problem-solving techniques related to these concepts.

TEXT: *Physics for Scientists and Engineers: A Strategic Approach with Modern Physics*, by Randall D. Knight, 4th Edition. Lab handouts are distributed digitally on the course website. Please read and print lab handouts ahead of time.

COURSE WEBSITE: The course website is **http://physicscloud.net/133/** ***The website is a source of essential information for this course.*** Assignments, solutions, the syllabus, course objectives, course schedule, lab handouts and exam solutions will all be posted to the site. Please check it regularly. I do not use the campus Poly Learn system.

PREREQUISITES: Prior completion of PHYS 141 (or equivalent) is a required prerequisite.

GRADING: Homework 10% • Quizzes, Other 10% • Two Exams 20% each • Final 30% • Lab 10%
No individual assignments will be curved, and no letter grades will be assigned until the end of the term. At the end of the quarter, every student's weighted point total will be ranked and the distribution curved such that C, C+ and C- grades indicate performance not far from the average. *A*s are reserved for exceptional performance and are typically awarded to 18%-or-less of the class.

CLICKER QUESTIONS: During lecture, real-time feedback, and attendance will be provided by multiple-choice conceptual and discussion questions. Answers are registered through multi-colored answer cards passed out on the first day of class, and are expected at each class meeting.

HOMEWORK: Homework will generally be collected Friday. Homework corrections (described below) will be collected every Wednesday. Homework is due at the beginning of class. Late homework will receive a 33% deduction, and be graded on a credit/no-credit basis.

HOMEWORK PRESENTATION: Homework problems should be worked on blank, unruled, paper or quad-ruled, engineering-type graph paper. ***Do not use regular lined notebook paper.*** Blank printer paper is everywhere; use that instead. Clearly indicate the problem number on each page. Bind all pages of the homework set with a single staple in the upper-left corner. Number the pages in the upper right corner. Whenever possible, the solution should ***include a figure or sketch*** that illustrates the key parameters of the problem. Answers must be reported using a reasonable number of significant figures. Try to make your calculation as clear and tidy as possible; little effort will be made to decipher sloppy work. ***Work problems symbolically until the last step***, at which point you can plug-in actual numbers and recover a numeric answer. ***All numeric values must include units:*** if you write down a number, it must include appropriate units, even in intermediate calculation steps. If you don't want to include units, work symbolically until the last step.

HOMEWORK GRADING: As decided by class vote, homework will either be graded using a 1-2-3 or lottery grading scheme. Under the 1-2-3 scheme, each problem is worth three points. 1 point is awarded for submitting a reasonable solution *on time*, and the remaining 2 points are awarded with crude precision: 2 points for a correct, complete solution that fully adheres to the presentation guidelines above, 0 points for a solution obviously less than 50% complete/correct, and 1 point for any solution in between. With a lottery-type grading scheme, 0-3 problems per assignment are chosen at random to be graded rigorously with 10 points possible per problem.

PHYSICSCLOUD.NET At the beginning of the quarter you will receive email to signup for my course-management system at physicscloud.net. In addition to viewing your course grade and assignment statistics, physicscloud.net is used for scheduling review sessions, and for voting on important ***course options*** such as the total number of midterms and the homework grading scheme.

LAB: The three-hour lab meets weekly. Prepare for lab each week by reading the lab handout before coming to class. The lab schedule is attached to this syllabus. ***Attendance and participation for every lab exercise is required.*** If you miss a lab, your course performance will be considered Incomplete—and you must make up all missing lab assignments in a future quarter to receive a passing grade. If you must miss lab, you can make it up the same week in another section, but you must make arrangements with the appropriate lab instructor to participate in an alternate lab session. Exceptions to the lab attendance policy will only be made on a one-time basis, and only for a compelling reason. Quizzes will be regularly given at the beginning of the lab period. No quiz makeups for absence or tardiness. Exceptional performance in lab can give an advantage to students whose performance is near the borderline of two grades. One lab report will be collected for each lab group. You may not leave before your lab group is done, you must be present for your work to be accepted.

EXAMS: Two or three midterm exams and a comprehensive final exam will be given during the quarter as tentatively scheduled on the syllabus. If the class elects to have three midterms (with the third midterm on the last day of class), the lowest midterm score will be dropped from the final grade calculation. With three midterms, make up exams will not be given. If you miss a midterm, it is the score that will be dropped.

EXAM CORRECTIONS: Exam corrections are due one week after exams are returned in class. You must submit correct solutions for all problems that you did not receive full-credit (multiple choice excluded). Exam corrections are mandatory and count towards the quiz component of your grade.

COURSE SUCCESS: Here are some tips for success in this class, especially if you are anxious or struggling. ***1) Find a physics buddy.*** Get their phone number. Those who work homework problems in pairs or small groups are much more likely to be successful through peer instruction, and the social aspect makes doing physics homework more enjoyable. ***2) Read the book.*** I like our textbook a lot; it's cogent, well-written and clear. In my lecture, I generally apply the notation, methods, reasoning, and ordering presented in the textbook. While the book can be a good way to start studying, the best approach is to read the relevant book sections *before coming to class*. You'll find lecture more understandable, and be more inclined to ask questions with lecture serving to illuminate misconceptions. ***3) Utilize the Learning Center.*** Located in 180-272 the learning center offers free physics tutoring. The learning center is open more than 20 hours per week and is available on a drop-in basis. ***4) Attend office hours.*** I am here to help. Email me, come to my office hours, ask as many questions as you need—your questions are not an interruption; answering them is what I'm here to do. I love teaching physics.

ACADEMIC HONESTY: Keep all electronic devices stored and completely out of sight on exam days. I interpret any sighting of a phone during an exam period as evidence of cheating.

PHYSICS 133

Tentative Course Schedule

Winter 2018

Last Updated 1/7/18

WK	TUESDAY	THURSDAY	
1 Jan 7 Jan 13	**9** Ch 22 1/3.5	**11** Ch 22 2.5/3.5	**Lab:** Electrostatics
2 Jan 14 Jan 20	**16** HW 1 Ch 22 3.5/3.5 Ch 23 1/4	**18** Ch 23 3.5/4	**Monday 1/15 :** Academic Holiday **Thursday Lab:** Electric Field I
3 Jan 21 Jan 27	**23** HW 2 Ch 23 4/4 Ch 24 1/2.5	**25** Ch 24 2.5/2.5	**Monday Lab:** Electric Field I **Thursday Lab:** Electric Field II
4 Jan 28 Feb 3	**30** HW 3 Ch 25 1.5/4	**1** Ch 25 3/4	**Monday Lab:** Electric Field and Potential **Thursday Lab:** Midterm 1 (Chapters 22, 23, 24)
5 Feb 4 Feb 10	**6** HW 4 Ch 25 4/4 Ch 26 .5/3	**8** Ch 26 2/3	**Monday Lab:** Midterm 1 (Chapters 22, 23, 24) **Thursday Lab:** Electric Field and Potential
6 Feb 11 Feb 17	**13** HW 5 Ch 26 3/3 Ch 27 .5/1	**15** Ch 27 1/1 Ch 28 1/3	**Lab:** Circuits I
7 Feb 18 Feb 24	**20** **No Class** (Monday Schedule)	**22** Ch 28 2.5/3	**Lab:** Circuits II
8 Feb 25 Mar 3	**27** HW 7 Ch 28 3/3 Ch 29 1/4	**1** Ch 29 3.5/4	**Lab:** Earth's Magnetic Field **Midterm 2** (Chapters 25, 26, 27, 28)
9 Mar 4 Mar 10	**6** HW 8 Ch 29 4/4 Ch 30 .5/3	**8** Ch 30 2/3	**Lab:** Current Balance
10 Mar 11 Mar 17	**13** HW 9 Ch 30 3/3	**15** *Last Day of Class* **Midterm 3** (Chapters 29, 30)	**Lab:** Faraday's Law
FINAL Mar 18 Mar 25	**20** **Final Exam** 4:10 PM (180-265)	**22**	**Final Exam:** Bring a copy of Equation Sheet 3 with up to one page of notes on the back. Notes must be handwritten, and all writing must be on *back* of equation sheet.

Name: ______________________________ Name: ______________________________

Name: ______________________________

PHYSICS 133 LAB QUIZ GROUP QUIZ WEEK 1 - ELECTROSTATICS

Work with your lab group to complete the problems below. Unless indicated, submit one solution to each problem that the group agrees is correct. You may consult your notes, the textbook or your instructor for help.

||| Suppose the magnitude of the proton charge differs from the magnitude of the electron charge by a mere 1 part in 10^9.

a. What would be the force between two 2.0-mm-diameter copper spheres 1.0 cm apart? Assume that each copper atom has an equal number of electrons and protons.

b. Would this amount of force be detectable? What can you conclude from the fact that no such forces are observed?

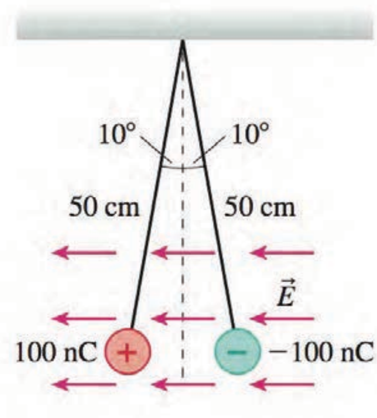
Name: ______________________________ Name: ______________________________

Name: ______________________________

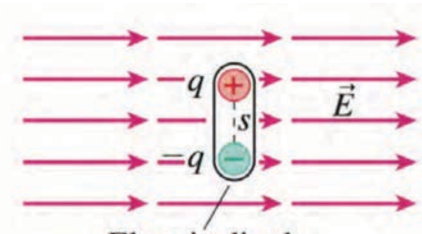
PHYSICS 133 LAB QUIZ GROUP QUIZ WEEK 2 - ELECTRIC FIELD

Work with your lab group to complete the problems below. Unless indicated, submit one solution to each problem that the group agrees is correct. You may consult your notes, the textbook or your instructor for help.

1. The identical small spheres shown in **FIGURE CP25.74** are charged to $+100$ nC and -100 nC. They hang as shown in a 100,000 N/C electric field. What is the mass of each sphere?



2. ‖ An electric dipole consists of two opposite charges $\pm q$ separated by a small distance s. The product $p = qs$ is called the *dipole moment*. **FIGURE P25.56** shows an electric dipole perpendicular to an electric field $\vec{E}$. Find an expression in terms of p and E for the magnitude of the torque that the electric field exerts on the dipole.



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Name: ______________________________

PHYSICS 133 LAB QUIZ GROUP QUIZ WEEK 3 - ELECTRIC FIELD

Work with your lab group to complete the problems below. Unless indicated, submit one solution to each problem that the group agrees is correct. You may consult your notes, the textbook or your instructor for help.

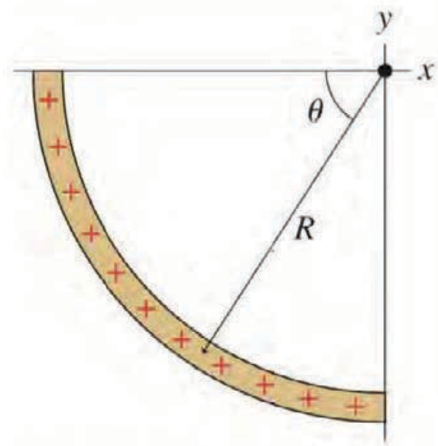


FIGURE P26.45

‖ A plastic rod with linear charge density λ is bent into the quarter circle shown in FIGURE P26.45. We want to find the electric field at the origin.

a. Write expressions for the x- and y-components of the electric field at the origin due to a small piece of charge at angle θ.

b. Write, but do not evaluate, definite integrals for the x- and y-components of the net electric field at the origin.

c. Evaluate the integrals and write $\vec{E}_{\text{net}}$ in component form.

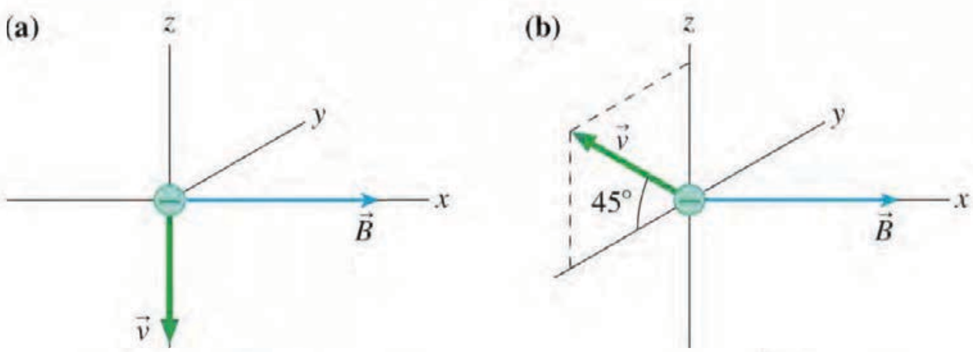
Name: ______________________________ Name: ______________________________

Name: ______________________________

PHYSICS 133 LAB QUIZ GROUP QUIZ WEEK 8 - MAGNETIC FORCES

Work with your lab group to complete the problems below. Unless indicated, submit one solution to each problem that the group agrees is correct. You may consult your notes, the textbook or your instructor for help.

1. || An electron moves in the magnetic field $\vec{B} = 0.50\,\hat{\imath}$ T with a speed of 1.0×10^7 m/s in the directions shown in FIGURE EX32.27. For each, what is magnetic force $\vec{F}$ on the electron? Give your answers in component form.



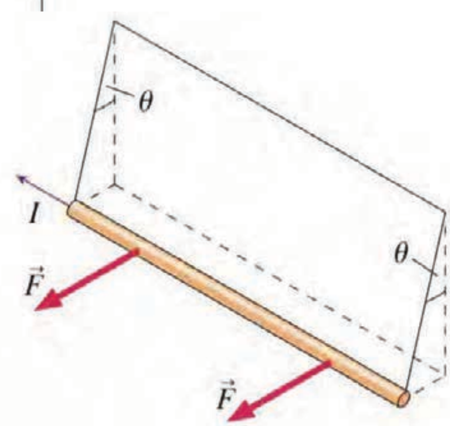


FIGURE P32.71

2. || a. In FIGURE P32.71, a long, straight, current-carrying wire of linear mass density μ is suspended by threads. A magnetic field perpendicular to the wire exerts a horizontal force that deflects the wire to an equilibrium angle θ. Find an expression for the strength and direction of the magnetic field $\vec{B}$.

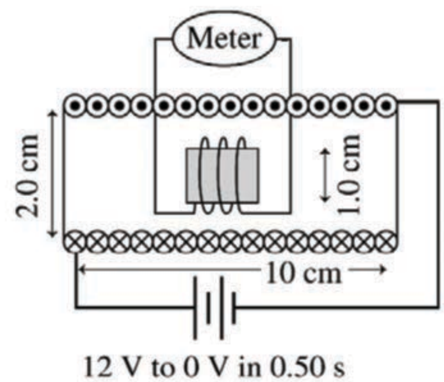
b. What $\vec{B}$ deflects a 55 g/m wire to a 12° angle when the current is 10 A?

Name: ______________________________ Name: ______________________________

Name: ______________________________

PHYSICS 133 LAB QUIZ GROUP QUIZ WEEK 10 - FARADAY'S LAW

Work with your lab group to complete the problems below. Unless indicated, submit one solution to each problem that the group agrees is correct. You may consult your notes, the textbook or your instructor for help.



1. The outer coil of wire is 10 cm long, 2.0 cm in diameter, wrapped tightly with one layer of 0.50-mm-diameter wire, and has a total resistance of 1.0 Ω. It is attached to a battery, as shown, that steadily decreases in voltage from 12 V to 0 V in 0.50 s, then remains at 0 V for $t > 0.5$ s. The inner coil of wire is 1.0 cm long, 1.0 cm in diameter, has 10 turns of wire, and has a total resistance of 0.010 Ω. It is connected, as shown, to a current meter.

    a. As the voltage to the outer coil begins to decrease, in which direction (left-to-right or right-to-left) does current flow through the meter? Explain.

    b. Draw a graph showing the current in the inner coil as a function of time for $0 \le t \le 1$ s. Include a numerical scale on the vertical axis.

PHYSICS 133

Midterm 1 Equation Sheet

ELECTROSTATICS

$$F_{\text{point}} = \frac{K|q_1||q_2|}{r^2} \qquad \lambda = \frac{Q}{L} \qquad E_{\text{plane}} = \frac{\eta}{2\varepsilon_0}$$

$$K = \frac{1}{4\pi\varepsilon_0} \qquad \eta = \frac{Q}{A} \qquad (E_{\text{disk}})_z = \frac{\eta}{2\varepsilon_0}\left[1 - \frac{z}{\sqrt{z^2+R^2}}\right]$$

$$\vec{E} = \frac{\vec{F}_{\text{on q}}}{q} \qquad \rho = \frac{Q}{V} \qquad \vec{p} = (qs, \text{ from - to +})$$

$$\vec{E}_{\text{point}} = \frac{Kq}{r^2}\hat{r} \qquad |\vec{\tau}_{\text{dipole}}| = |\vec{p} \times \vec{E}| = pE\sin\theta$$

$$\vec{E}_{\text{net}} = \sum \vec{E}_i \qquad \Phi_e = \vec{E} \cdot \vec{A} \qquad \vec{E}_{\text{dipole bisecting plane}} = -\frac{K\,\vec{p}}{r^3}$$

$$dE_{\text{point}} = \frac{K\,dq}{r^2} \qquad \Phi_e = \oint \vec{E} \cdot d\vec{A} = \frac{Q_{\text{in}}}{\varepsilon_0} \qquad \vec{E}_{\text{dipole axis}} = \frac{K\,2\vec{p}}{r^3}$$

KINEMATICS

$$s = \tfrac{1}{2}a_s\Delta t^2 + v_{0s}\Delta t + s_0 \qquad v_s = \frac{ds}{dt}$$

$$v_s = v_{0s} + a_s\Delta t$$

$$v_s^2 = v_{0s}^2 + 2a_s\Delta s \qquad a_s = \frac{dv_s}{dt}$$

DYNAMICS

$$\Sigma\vec{F} = m\vec{a}$$

$$\vec{F}_{A\,\text{on}\,B} = -\vec{F}_{B\,\text{on}\,A}$$

$$\vec{F}_{\text{spring}} = -k\vec{x}$$

$$f_s \le \mu_s n \qquad f_k = \mu_k n$$

CIRCULAR MOTION

$$s = \theta r$$

$$v_t = \omega r \qquad \omega = \frac{d\theta}{dt} \qquad \alpha = \frac{d\omega}{dt}$$

$$a_t = \alpha r$$

$$a_r = a_{\text{centrip}} = \frac{v^2}{r} = r\omega^2$$

CONSERVATION LAWS

$$W_{\text{ext}} = \Delta K + \Delta U + \Delta E_{\text{th}} \qquad K_{\text{trans}} = \frac{1}{2}mv^2 \qquad K_{\text{rot}} = \frac{1}{2}I\omega^2 \qquad \vec{p} = m\vec{v} \qquad \vec{p}_i = \vec{p}_f \qquad \vec{J} = \Delta\vec{p}$$

$$\Delta E_{\text{th}} = f_k d \qquad U_g(y) = mgy \qquad U_s(x) = \frac{1}{2}kx^2 \qquad W = \int_{x_1}^{x_2} F_x(x)dx \qquad \vec{J} = \int_{t_1}^{t_2} \vec{F}(t)dt = F_{\text{avg}}\Delta t$$

ROTATION OF A RIGID BODY

$$\tau = rF\sin\phi = rF_\perp = r_\perp F \qquad \vec{\tau}_{\text{net}} = I\vec{\alpha} \qquad \vec{\ell} = \vec{r} \times \vec{p} = m(\vec{r} \times \vec{v}) \qquad \ell = I\omega \qquad \vec{\ell}_i = \vec{\ell}_f$$

$$I_{\text{point}} = \sum_i^N m_i r_i^2 \qquad I_{\text{sphere}} = \tfrac{2}{5}MR^2 \qquad I_{\text{pipe}} = \tfrac{1}{2}MR_1^2 + R_2^2 \qquad I_{\text{log or disk}} = \tfrac{1}{2}MR^2 \qquad I_{\text{hoop}} = MR^2$$

$$I_{\text{baton}} = \tfrac{1}{12}ML^2 \qquad I_\parallel = I_{\text{com}} + Md^2$$

CONSTANTS

$K = 8.99 \times 10^9\ \text{N·m}^2/\text{C}^2$

$\varepsilon_0 = 8.85 \times 10^{-12}\ \text{C}^2/\text{N·m}^2$

$e = 1.60 \times 10^{-19}\ \text{C}$

$m_p = 1.67 \times 10^{-27}\ \text{kg}$

$m_e = 9.11 \times 10^{-31}\ \text{kg}$

$g = 9.81\ \text{m/s}^2$

$N_A = 6.02 \times 10^{23}$ particles/mol

INTEGRALS

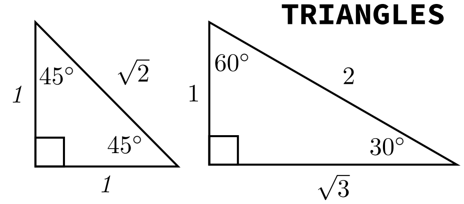
$$\int \frac{x\,dx}{(x^2 \pm a^2)^{3/2}} = -\frac{1}{\sqrt{x^2 \pm a^2}}$$

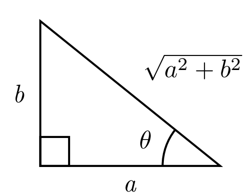
$$\int \frac{dx}{(x^2 \pm a^2)^{3/2}} = \frac{\pm x}{a^2\sqrt{x^2 \pm a^2}}$$

$$\int \frac{dx}{\sqrt{x^2 \pm a^2}} = \ln\left(x + \sqrt{x^2 \pm a^2}\right)$$

$$\int \frac{dx}{x^2 + a^2} = \frac{1}{a}\tan^{-1}\left(\frac{x}{a}\right)$$

TRIANGLES





$\tan\theta = \frac{b}{a}$

PHYSICS 133

Midterm 2 Equation Sheet

ELECTROSTATICS

$F_{\text{point}} = \frac{K|q_1||q_2|}{r^2}$ $\quad \vec{E} = \frac{\vec{F}_{\text{on q}}}{q}$ $\quad \vec{E}_{\text{point}} = \frac{Kq}{r^2}\hat{r}$ $\quad K = \frac{1}{4\pi\varepsilon_0}$ $\quad \lambda = \frac{Q}{L}$ $\quad \eta = \frac{Q}{A}$ $\quad \rho = \frac{Q}{V}$

$\Phi_e = \vec{E}\cdot\vec{A}$ $\quad \Phi_e = \oint \vec{E}\cdot d\vec{A} = \frac{Q}{\varepsilon_0}$ $\quad E_{\text{plane}} = \frac{\eta}{2\varepsilon_0}$ $\quad (E_{\text{disk}})_z = \frac{\eta}{2\varepsilon_0}\left[1 - \frac{z}{\sqrt{z^2+R^2}}\right]$

$\vec{p} = (qs,\ \ominus \text{ to } \oplus)$ $\quad \vec{E}_{\text{dipole axis}} = -\frac{K2\vec{p}}{r^3}$ $\quad \vec{E}_{\text{dipole bs plane}} = -\frac{K\vec{p}}{r^3}$ $\quad |\vec{\tau}| = |\vec{p}\times E| = pE\sin\theta$

$U_{q_1+q_2} = \frac{Kq_1q_2}{r}$ $\quad \Delta U = -W_{(i\to f)} = -\int_i^f \vec{F}\cdot d\vec{s}$ $\quad U_{\text{dipole}} = -\vec{p}\cdot\vec{E}$ $\quad U = qV$

$V_{\text{point}} = \frac{Kq}{r}$ $\quad \Delta V = -\int_i^f \vec{E}\cdot d\vec{s} = -\int_{s_i}^{s_f} E_s ds$ $\quad \vec{E} = -\nabla V$ $\quad E_s = -\frac{dV}{ds} \approx -\frac{\Delta V}{\Delta s}$

CIRCUITS

$\Delta V = IR$ $\quad \Delta V_{\text{loop}} = \sum(\Delta V_i) = 0$ $\quad \sum I_{\text{in}} = \sum I_{\text{out}}$ $\quad R = \frac{\rho L}{A}$ $\quad Q = I\Delta t$ $\quad J = \frac{I}{A}$

$P_{\text{bat}} = I\mathcal{E}$ $\quad P_{\text{R}} = \Delta V_R I$ $\quad C = \frac{Q}{\Delta V_C}$ $\quad C_{\text{plate}} = \frac{\varepsilon_0 A}{d}$ $\quad E_{\text{cap}} = \frac{\Delta V_c}{d}$

KINEMATICS

$s = \frac{1}{2}a_s\Delta t^2 + v_{0s}\Delta t + s_0$

$v_s = v_{0s} + a_s\Delta t$ $\quad v_s = \frac{ds}{dt}$

$v_s^2 = v_{0s}^2 + 2a_s\Delta s$ $\quad a_s = \frac{dv_s}{dt}$

DYNAMICS

$\Sigma\vec{F} = m\vec{a}$

$\vec{F}_{A\,\text{on}\,B} = -\vec{F}_{B\,\text{on}\,A}$ $\quad f_s \le \mu_s n$

$\vec{F}_{\text{spring}} = -k\vec{x}$ $\quad f_k = \mu_k n$

CIRCULAR MOTION

$s = \theta r$ $\quad \omega = \frac{d\theta}{dt}$ $\quad \alpha = \frac{d\omega}{dt}$

$v_t = \omega r$ $\quad a_t = \alpha r$

$a_r = a_{\text{centrip}} = \frac{v^2}{r} = r\omega^2$

CONSERVATION LAWS

$W_{\text{ext}} = \Delta K + \Delta U + \Delta E_{\text{th}}$ $\quad K_{\text{trans}} = \frac{1}{2}mv^2$ $\quad K_{\text{rot}} = \frac{1}{2}I\omega^2$ $\quad \vec{p} = m\vec{v}$ $\quad \vec{p}_i = \vec{p}_f$ $\quad \vec{J} = \Delta\vec{p}$

$\Delta E_{\text{th}} = f_k d$ $\quad U_g(y) = mgy$ $\quad U_s(x) = \frac{1}{2}kx^2$ $\quad W = \int_{x_1}^{x_2} F_x(x)dx$ $\quad \vec{J} = \int_{t_1}^{t_2}\vec{F}(t)dt = F_{\text{avg}}\Delta t$

ROTATION OF A RIGID BODY

$\vec{\ell} = \vec{r}\times\vec{p} = m(\vec{r}\times\vec{v})$ $\quad \ell = I\omega$ $\quad \vec{\ell}_i = \vec{\ell}_f$

$\tau = rF\sin\phi = rF_\perp = r_\perp F$ $\quad \vec{\tau}_{\text{net}} = I\vec{\alpha}$ $\quad I_{\|} = I_{\text{com}} + Md^2$ $\quad I_{\text{point}} = \sum m_i r_i^2$

$I_{\text{baton}} = \frac{1}{12}ML^2$ $\quad I_{\text{sphere}} = \frac{2}{5}MR^2$ $\quad I_{\text{pipe}} = \frac{1}{2}MR_1^2 + R_2^2$ $\quad I_{\text{log or disk}} = \frac{1}{2}MR^2$ $\quad I_{\text{hoop}} = MR^2$

CONSTANTS

$K = 8.99\times10^9\ \text{N}\cdot\text{m}^2/\text{C}^2$

$\varepsilon_0 = 8.85\times10^{-12}\ \text{C}^2/\text{N}\cdot\text{m}^2$

$e = 1.60\times10^{-19}\ \text{C}$

$m_p = 1.67\times10^{-27}\ \text{kg}$

$m_e = 9.11\times10^{-31}\ \text{kg}$

$g = 9.81\ \text{m/s}^2$

$N_A = 6.02\times10^{23}\ \text{particles/mol}$

INTEGRALS

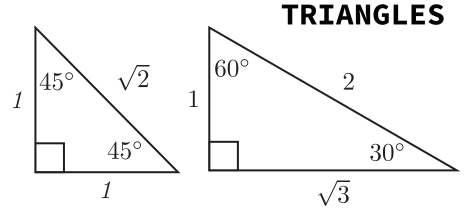
$$\int \frac{x\,dx}{(x^2\pm a^2)^{3/2}} = -\frac{1}{\sqrt{x^2\pm a^2}}$$

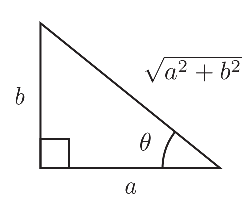
$$\int \frac{dx}{(x^2\pm a^2)^{3/2}} = \frac{\pm x}{a^2\sqrt{x^2\pm a^2}}$$

$$\int \frac{dx}{\sqrt{x^2\pm a^2}} = \ln\left(x+\sqrt{x^2\pm a^2}\right)$$

$$\int \frac{dx}{x^2+a^2} = \frac{1}{a}\tan^{-1}\left(\frac{x}{a}\right)$$

TRIANGLES





$\tan\theta = \frac{b}{a}$

PHYSICS 133

Midterm 3 Equation Sheet

ELECTROSTATICS

$F_{\text{point}} = \frac{K|q_1||q_2|}{r^2}$ $\quad \vec{E} = \frac{\vec{F}_{\text{on q}}}{q}$ $\quad \vec{E}_{\text{point}} = \frac{Kq}{r^2}\hat{r}$ $\quad K = \frac{1}{4\pi\varepsilon_0}$ $\quad \lambda = \frac{Q}{L}$ $\quad \eta = \frac{Q}{A}$ $\quad \rho = \frac{Q}{V}$

$\Phi_e = \vec{E} \cdot \vec{A}$ $\quad \Phi_e = \oint \vec{E} \cdot d\vec{A} = \frac{Q}{\varepsilon_0}$ $\quad E_{\text{plane}} = \frac{\eta}{2\varepsilon_0}$ $\quad (E_{\text{disk}})_z = \frac{\eta}{2\varepsilon_0}\left[1 - \frac{z}{\sqrt{z^2+R^2}}\right]$

$\vec{p} = (qs,\ \ominus \text{ to } \oplus)$ $\quad \vec{E}_{\text{dipole axis}} = -\frac{K2\vec{p}}{r^3}$ $\quad \vec{E}_{\text{dipole bs plane}} = -\frac{K\vec{p}}{r^3}$ $\quad |\vec{\tau}| = |\vec{p} \times \vec{E}| = pE\sin\theta$

$U_{q_1+q_2} = \frac{Kq_1q_2}{r}$ $\quad \Delta U = -W_{(i\to f)} = -\int_i^f \vec{F} \cdot d\vec{s}$ $\quad U_{\text{dipole}} = -\vec{p} \cdot \vec{E}$ $\quad U = qV$

$V_{\text{point}} = \frac{Kq}{r}$ $\quad \Delta V = -\int_i^f \vec{E} \cdot d\vec{s} = -\int_{s_i}^{s_f} E_s ds$ $\quad \vec{E} = -\nabla V$ $\quad E_s = -\frac{dV}{ds} \approx -\frac{\Delta V}{\Delta s}$

CIRCUITS

$\Delta V = IR$ $\quad \Delta V_{\text{loop}} = \sum(\Delta V_i) = 0$ $\quad \sum I_{\text{in}} = \sum I_{\text{out}}$ $\quad R = \frac{\rho L}{A}$ $\quad Q = I\Delta t$ $\quad J = \frac{I}{A}$

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MAGNETOSTATICS

$|\vec{A} \times \vec{B}| = AB\sin\phi$

$\vec{B}_{\text{point}} = \frac{\mu_0}{4\pi}\frac{q\vec{v}\times\hat{r}}{r^2}$ $\quad B_{\text{solenoid}} = \frac{\mu_0 NI}{l} = \mu_0 nI$ $\quad \vec{F}_{\text{on } q} = q\vec{v} \times \vec{B}$ $\quad \vec{\mu} = (IA,\ \text{(S) to (N)})$

$d\vec{B} = \frac{\mu_0}{4\pi}\frac{Id\vec{s}\times\hat{r}}{r^2}$ $\quad \vec{B}_{\text{dipole}} = \frac{\mu_0 2\vec{\mu}}{4\pi z^3}$ $\quad \vec{F}_{\text{wire}} = I\vec{l} \times \vec{B}$ $\quad \Phi_m = \vec{A} \cdot \vec{B} = AB\cos\phi$

$B_{\text{loop}} = \frac{\mu_0 IR^2}{2(z^2+R^2)^{3/2}}$ $\quad B_{\text{wire}} = \frac{\mu_0 I}{2\pi d}$ $\quad \vec{\tau} = \vec{\mu} \times \vec{B}$ $\quad \mathcal{E} = \left|\frac{d\Phi_m}{dt}\right| = \left|\vec{B} \cdot \frac{d\vec{A}}{dt} + \vec{A} \cdot \frac{d\vec{B}}{dt}\right|$

KINEMATICS

$s = \frac{1}{2}a_s\Delta t^2 + v_{0s}\Delta t + s_0$

$v_s = v_{0s} + a_s\Delta t$ $\quad v_s = \frac{ds}{dt}$

$v_s^2 = v_{0s}^2 + 2a_s\Delta s$ $\quad a_s = \frac{dv_s}{dt}$

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$\Sigma\vec{F} = m\vec{a}$

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$\vec{F}_{\text{spring}} = -k\vec{x}$ $\quad f_k = \mu_k n$

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$a_r = a_{\text{centrip}} = \frac{v^2}{r} = r\omega^2$

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$e = 1.60 \times 10^{-19}\text{C}$

$m_p = 1.67 \times 10^{-27}\ \text{kg}$

$m_e = 9.11 \times 10^{-31}\ \text{kg}$

$g = 9.81\ \text{m/s}^2$

$N_A = 6.02 \times 10^{23}$ particles/mole

$\mu_0 = 1.257 \times 10^{-6}\ \text{T}\cdot\text{m/A}$

INTEGRALS

$$\int \frac{xdx}{(x^2 \pm a^2)^{3/2}} = -\frac{1}{\sqrt{x^2 \pm a^2}}$$

$$\int \frac{dx}{(x^2 \pm a^2)^{3/2}} = \frac{\pm x}{a^2\sqrt{x^2 \pm a^2}}$$

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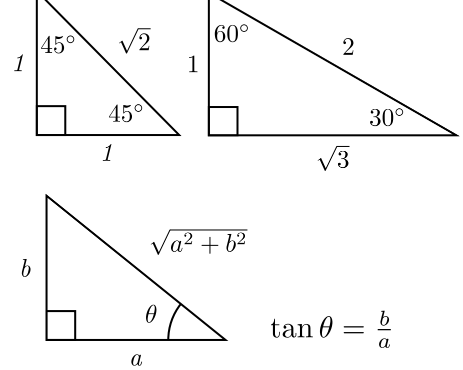
$$\int \frac{dx}{x^2 + a^2} = \frac{1}{a}\tan^{-1}\left(\frac{x}{a}\right)$$

TRIANGLES



$\tan\theta = \frac{b}{a}$

Lecture Slides

I utilize slides as a multimedia accompaniment to my lecture presentation. As a focus of my slides in Physics 133, I've implemented realtime class feedback through analog "clicker" questions. Clicker questions start each lecture and are used when switching topics. I've received overwhelmingly positive student feedback about these multiple choice discussion questions.

I also have produced animations and 3D visualizations of EM fields (Figure 7) using mathematica that are incorporated into my lecture and included in the lecture slide deck.

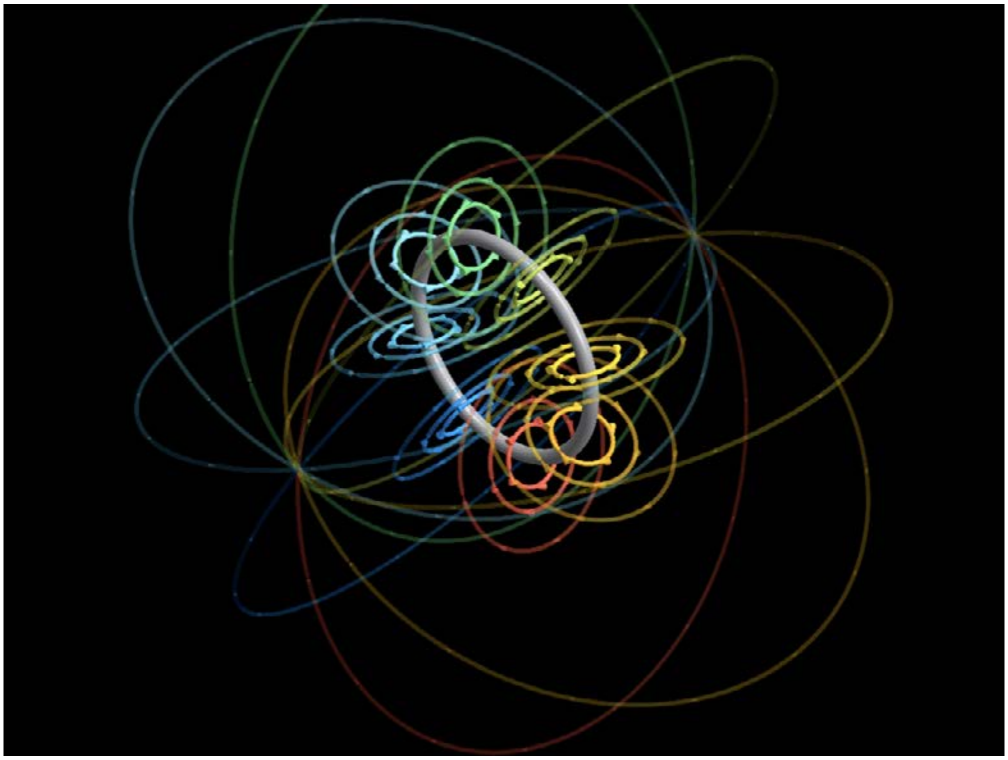


Figure 7: The 3D nature of EM fields make computer animations an excellent tool for illustrating their properties. Here's my attempt at the magnetic field produced by a solenoid.

The a live copy of the complete slide deck is available through a link on my website, and students have cited is an important study resource.

Course Website

The Physics 133 Course Website (`http://physicscloud.net/133`), shown above in figure 8 is the central communication hub for the class. The website provides student access to the course

- Syllabus
- Course Due Dates and Reminders
- Objectives
- Schedule
- Homework assignments
- Instructor-prepared homework solutions
- Equation sheets
- Midterm solutions
- Lab Manual
- Supplemental lecture videos
- Homework solution videos (select problems)

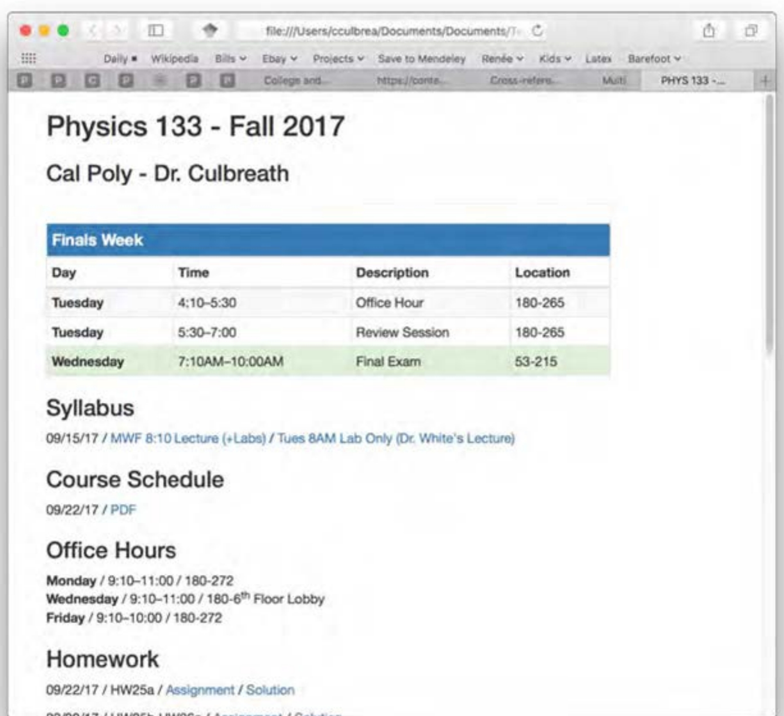


Figure 8: The course website is the central communication hub for the class and is updated several times per week. Visit the site at `http://physicscloud.net/133`

Homework Assignments are posted at least one week before their due date. Homework

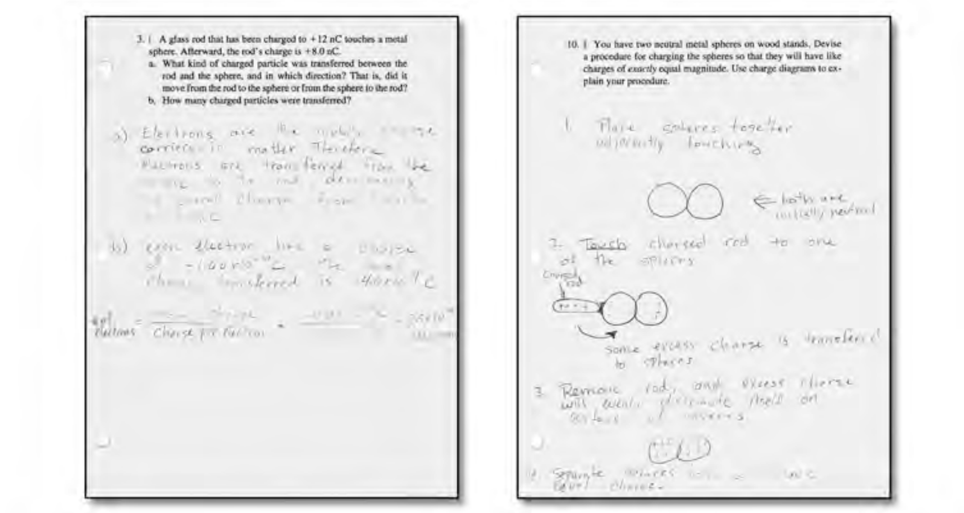


Figure 9: Instructor prepared homework solutions including explanatory notes and commentary.

assignments often include links to one or two homework solution videos (see *Online Videos* on page 74). Changes to the course schedule are relayed by email and updated on the site.

Homework and Exam solutions

Instructor prepared homework solutions including explanatory notes and commentary are posted to the course website the same day that homework is collected, as time allows. The homework solutions detail the step-by-step approach to solving the problem as shown in figure 9. I have completed 30% of the homework solutions for Physics 133, and supplement with the book publisher's solutions as needed. In addition, detailed exam solutions are posted after students receive their graded exams. For exams, I require students to submit corrections which reference the posted solutions and remedy mistakes in their original work.

Online Videos

Overview

The PHYSICS 133 COURSE WEBSITE provides links to my YouTube Channel and content-specific links to videos related to assignments. I produce two types of video content for Physics 133: *Solution Videos* and *Supplemental Lecture Videos*.

Solution Videos

Table 3: Physics 133 Homework Solution Videos

Topic	Duration	URL
Ch 25 #47	7:50	youtube.com/watch?v=dlR7lSEWa3Y
Ch 26 #12	17:48	www.youtube.com/watch?v=Q0haGFlKT8k

Christopher Culbreath

Additional Materials for Examination

Extending Education

Scholarship

Grant Applications

Other

Mid-quarter Anonymous Student Surveys

Extending Education

Online Videos

Overview

I use the Course Website to provide links to my YouTube Channel and content-specific links, to videos related to assignments. I produce two types of video content for my courses: *Step-by-step Solution Videos* and *Supplemental Lecture Videos*.

Step-by-step Solution Videos

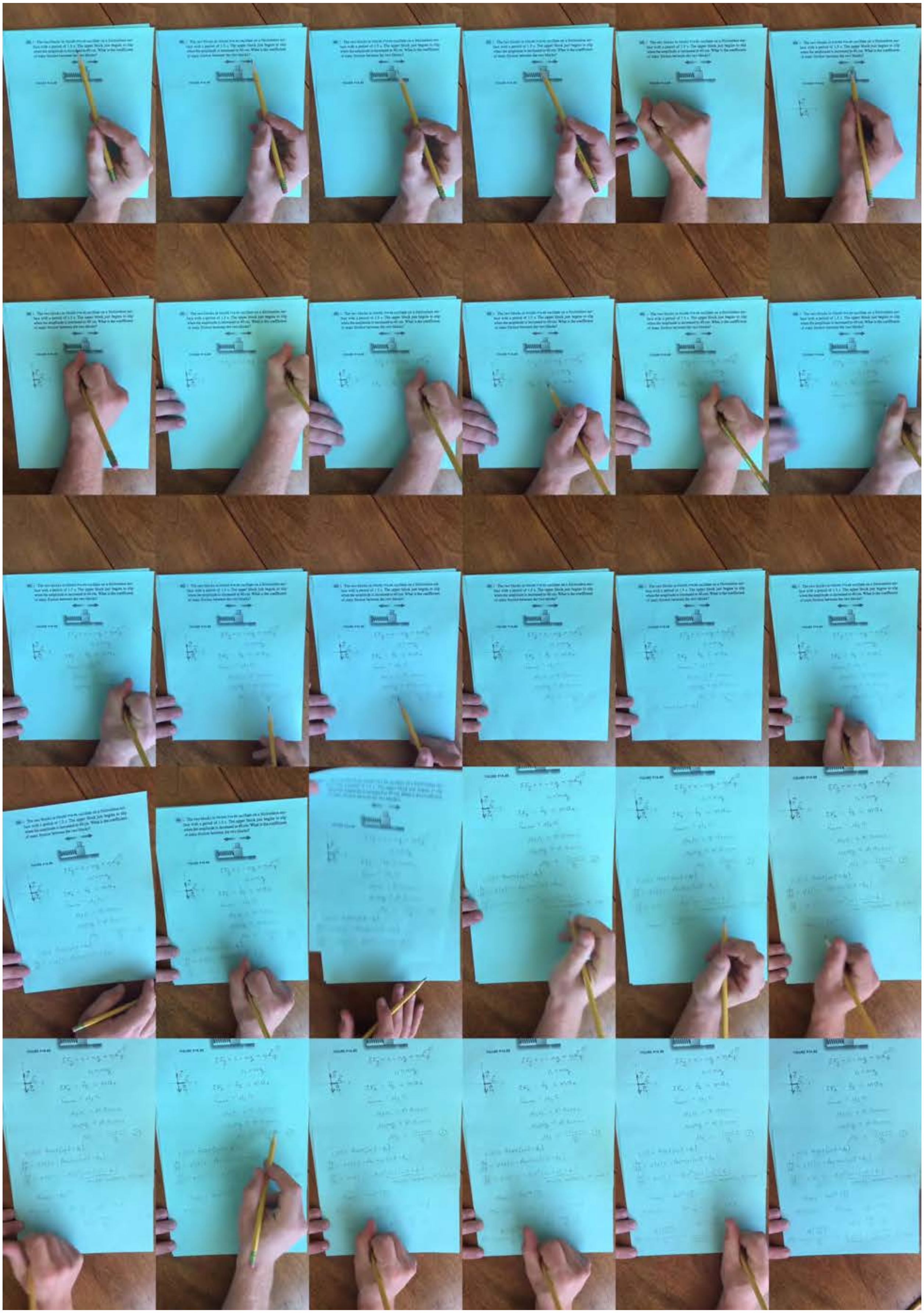
A typical 15-20 problem assignment page includes direct links to one to three YouTube solution videos. The solution videos are produced with a document-camera setup, and provide a detailed, step-by-step solution to the problem along with problem-solving tips and commentary. Since the publisher's printed solutions are widely available to students, I make solution videos available when homework is assigned and encourage students to utilize them with a attempt-and-check strategy and to avoid wrote copying. Students love solution videos, and I have received overwhelmingly positive feedback citing their effectiveness[§] An example solution video is depicted by the frame sequence and transcript that begin on page 77.

Suplemental Lecture Videos

I do everything I can to maximize the impact of my class time with students. My efforts have focused on incorporating demonstrations, clicker-style questions and flipped-classroom problem solving into my lectures without skimping on course content. In order to balance these goals, and to accomodate a wide-range of learning styles, I produce *Supplemental Lecture Videos* that are posted to YouTube and the course website. These videos feature either a document-camera setup with a traditional-style lecture, or a narrated and animated slideshow that detail and explain course content not explicitly reviewed in class. Physics 132 has several small topics which are ideal for the format, leaving lecture time available for innovative and high-impact material.

[§] For example, see the mid-quarter Fall 2016 survey results included on page 94.

Sample Homework Solution Video: Chapter 20, Problem 49 · `youtube.com/watch?v=IGVrH1UBNRY`



Sample Solution Video Transcript
Chapter 14, problem 49

`https://www.youtube.com/watch?v=IGVrH1UBNRY`

All right guys, Dr. Culbreath here with Chapter 14 number 49. It says, "The two blocks in the figure oscillate on a frictionless surface with a period of 1.5 seconds"—This bottom surface down here is frictionless and these two blocks oscillate back and forth—"The upper block just begins to slip when the amplitude is increased to 40cm. What is the coefficient of static friction between the two blocks?" There's friction between this upper block and the lower block. As the blocks oscillate, it's this friction that moves the upper block to the right and moves the upper block to the left. At some point, the acceleration of the oscillation becomes too great and the static friction cannot provide the required force to move the upper block with the lower block so it slips. Since we're dealing with static friction here, this is a clue that we need to use dynamics and Newton's laws to analyze these forces so we can apply our static friction force model.

Let's start with a free body diagram of the upper block. What forces do we have acting on that upper block? We have the force of gravity, which points down. The normal force, which points up. I'm going to consider when the two block assembly is moving to the right, in which case it is the static friction force on this upper block that moves it to the right. That is all of our forces acting on the block. We've completed our free body diagram, the next step is to sum the forces.

I'm going to start in the y direction. The sum of the forces in the y direction is plus the normal force and minus the force of gravity, which I'm going to write as mg, is equal to the mass times the acceleration in the y direction. We're considering oscillations in the x direction, but there's no motion in the y direction so our acceleration in the y direction is equal to zero. That gives us that the normal force is equal to mg. We can repeat this process in the x direction. The sum of the forces in the x direction: We have just our static friction force F_s and that's what gives us our acceleration in the x direction. On the right hand side, we have that equal to m times a.

All right. Now we want to consider the situation just when the block begins to slip. The static friction force as you may recall can have a range of values from zero up unto a maximum value. Above the maximum value, the static friction force gives way and it slips. At this slipping point, our static friction force is equal to that maximum value and $F_{s,\text{max}}$ is given by the coefficient of static friction, μ_s times the normal force n and we can substitute that into this upper equation here and we get μ_s times n is equal to the mass times the maximum allowed acceleration in the x direction and into this expression we can substitute mg for n because we solved for that up here doing the sum of the forces in the y direction.

We're going to get μ_s times mg is equal to the mass times the maximum acceleration in the x direction. Our masses cancel. We get that μ_s is equal to $a_{x,\text{max}}$ divided by g. I'm going to call that equation one.

All right so we come to the end of the line with Newton's laws here and we found that for our maximum allowable acceleration $a_{x,\text{max}}$. Once we've calculated that, we can get a value for the coefficient of static friction but how are we going to figure out what the maximum acceleration is when we have an oscillation of amplitude 40cm? We're going to need to use our oscillation kinematics for that. We're going to have to push the kinematic equation further than we did in class.

Let's go ahead and start with the position equation. We got the position at time t is equal to the amplitude times the cosine of ωt plus the initial phase, ϕ_0. We need to move down the kinematic ladder to the acceleration so starting with the position, if we want the velocity, we take the derivative of the position with respect to time which gives us the velocity. The derivative of cosine is minus sine and we get an ω which multiplies our independent variable t. We're going to get $-A$ times ω times the sine of $\omega t + \phi_0$.

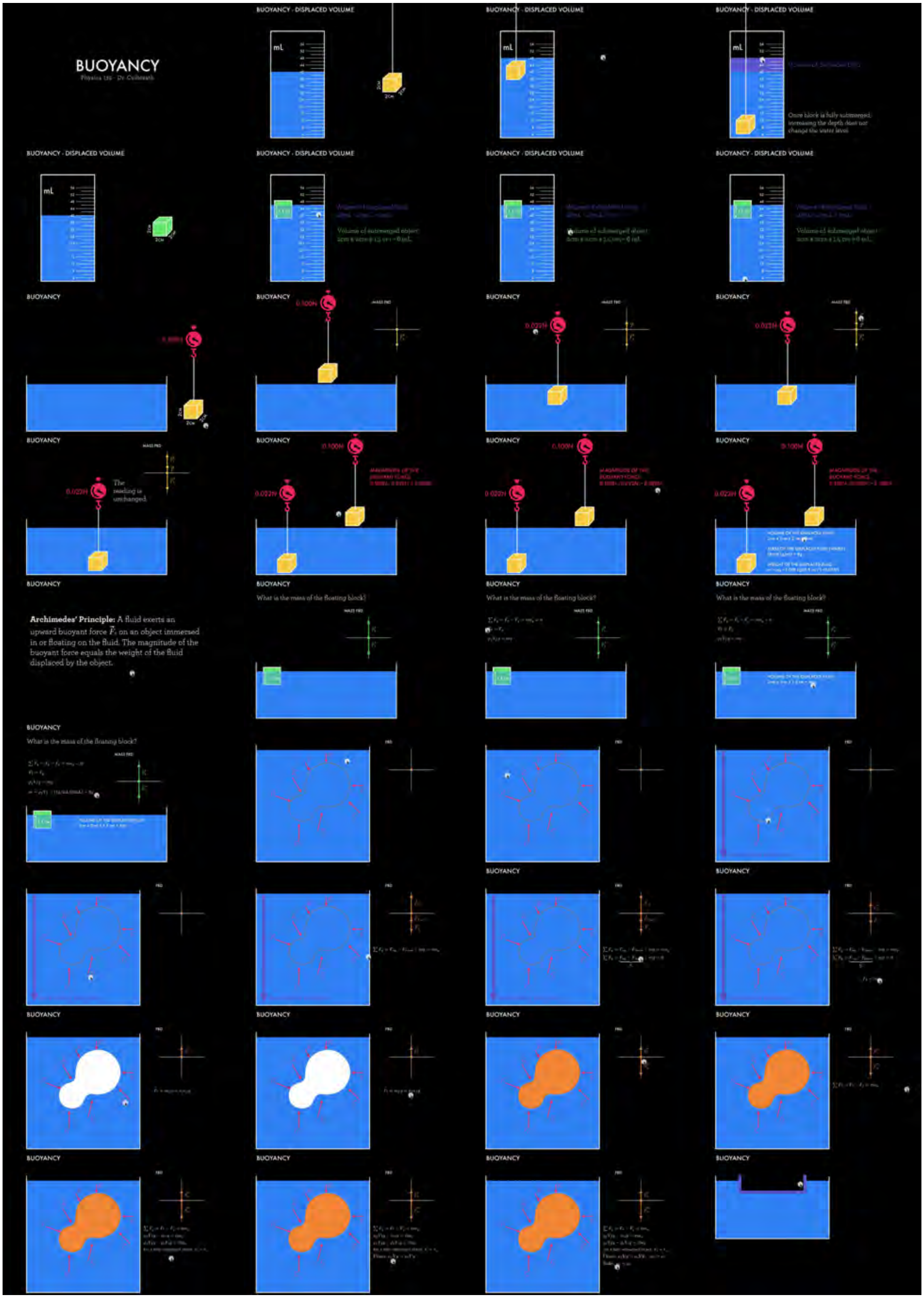
Now if we want the acceleration, we need to carry the kinematic ladder one step further so we want to take the derivative of the velocity with respect to time. That gives us the acceleration. The derivative of sine is cosine. We get another ω out in front so we get $-A$ times ω^2 times the cosine of ωt plus our initial phase ϕ_0. Now, we are looking for the maximum acceleration. We have an expression for our acceleration at any time t, but when is this going to be a maximum?

Cosine here can have any value between plus one and minus one. We can take this to be one and we recover our maximum acceleration and we get that the maximum acceleration is going to be equal to $A\omega^2$. All right. We don't know what ω is so we need to look back at our given information and see if we can get at this ω and it says here that the period of the oscillation is 1.5 seconds so we need to go from period to angular frequency and so we have T is given. T equals 1.5 seconds and we know that the frequency is equal to $1/T$ and we know that ω is equal to 2π times the frequency. So, we get that ω is equal to $2\pi/T$ or...I guess that's all we need. We have T and that gives us an ω.

Now we just need to combine these three equations, one, two, and three. We have 1 which depends on $a_{x,\,\text{max}}$, we have 2 which depends on ω and here we have ω which depends on T so let's go ahead and combine those. We're going to get the amplitude A times ω^2 which is 2π over the period squared. Divided by g and that is going to give us μ_s. This is returning us to equation one here. Last step, we just need to put in some values. This is equal to 0.4 meters—that's our amplitude—divided by 9.8 meters per second squared—that's g—times 2π divided by the period, which is 1.5 seconds.

All this guy gets squared which gives us a value for the coefficient of static friction which is 0.716.

Sample Supplemental Lecture Video: Introduction to Buoyancy



Sample Supplemental Lecture Video Transcript
Introduction to Buoyancy

`https://www.youtube.com/watch?v=r4wm-F673tw`

Hi guys. Dr. Culbreath here with some bonus lecture content on buoyancy. To begin our discussion of buoyancy, we just need to work through some simple experiments. For this first one, we have a graduated cylinder, and we have a mass that is 2cm by 2cm by 2cm that is suspended from a string. We want to consider this situation where we put this mass into the graduated cylinder.

When we put the mass into the graduated cylinder, we see that the water level in the graduated cylinder rises. It was originally at 40mL, and now it is at 48mL. Once the block is submerged, we can also see what happens if we lower the block further down into the graduated cylinder. When we lower the block further down, it doesn't change the depth of the water.

Once the block is fully submerged, increasing the depth has not changed the water level, and this purple volume here is the volume of the displaced fluid. It was originally at 40 mL, and now it's at 48 mL, so we can assume or we can deduce that the volume of this cube itself is 8mL which is consistent with the original dimensions we had. 2cm by 2cm by 2cm adds up to 8 cubic centimeters which is the same as 8 mL. For a fully submerged object, the volume of the displaced fluid is equal to the volume of the object.

Now, let's consider this green cube here which has a somewhat different behavior when we put it in the graduated cylinder. When we put the green cube in the graduated cylinder, it did not sink. It floats, and approximately 1.5cm is submerged relative to its two-centimeter height, and we can see that the behavior of the graduated cylinder was a little bit different as well. Before, when we fully submerged our cube, the water level rose from 40 mL to 48 mL.

In this case, with the floating cube, we see that the water level changed from 40 mL to 46 mL, so the volume of the displaced fluid in this case is that 46 mL minus 40 mL, for a total of 6 mL, and we'll see that this is the same as the volume of the submerged object. We have a cube, so it's 2 cm by 2 cm, and then our depth is 1.5 cm, so that also gives us 6 mL for the submerged volume.

That is an important topic because in the topic of buoyancy, we often talk about the volume of the fluid displaced by the object, so if the object is fully submerged, the volume of fluid displaced is the same as the volume of the entire object. In the case of a floating object like this where we have it partially submerged, the volume of the displaced fluid is just equal to the volume of the object which is actually submerged in the water.

Now, we're going to talk about what we mean by buoyancy, so we're going to take our same yellow cube here, 2cm by 2cm by 2cm, and we've suspended it from a spring scale. Out here in air, this cube has a weight of 0.1 newtons. The gravitational force being pulled down by the cube is balanced by the tension force, and the tension force is measured by the spring scale to be 0.1 newtons.

We can see that on a free-body diagram, we've got the gravity which points down and the tension which points up. Now, let's make a prediction. How does the scale reading change when the mass is lowered into the fluid? Does it change at all? Does the scale reading increase, decrease, or stay the same? We find that when we lower the scale or excuse me, we lower the mass into the water while it's attached to the scale that the scale value decreases. We were at .1 newtons before. Now, we're at 0.022 newtons.

Before, the tension force and the gravitational force balanced each other. We know that the force of gravity is not changing for this cube, but we do also know from our measurement that the tension force has been reduced, so there must be another force at work. In fact, the fluid is exerting an upward force on the mass, and we call that the buoyant force. We give it the symbol F_b.

The next question is, how does the scale reading change if we lower the box further into the water? We're going to have more water on top. We're going to lower it further down. Does the scale reading increase, decrease, or stay the same? If we were to lower the box down further, the reading is, in fact, unchanged. We've done some experiments or at least *virtually* done some experiments here to get a sense of how buoyancy works, and we can just review those numbers.

When the scale was in air, the block was in air, the tension was 0.1 newtons. When it is submerged in the water, it is equal to 0.22 newtons, so that means that whatever force has changed between being in the air and being in the water, meaning the force, the upward force that the fluid is exerting on the mass, which we are calling the "buoyant force," the magnitude of that force must be that additional upward force between the first situation and this situation—which we calculate to be 0.078 newtons.

Just to relate these ideas in a direct way, I guess I can't explain it as anything other than a lucky guess at this point, but it's worthwhile. If we also consider the volume of the displaced fluid here, which we calculated to be 8mL for this cube, we can calculate the mass of the displaced fluid, which is 8 grams, and the *weight* of the displaced fluid is in fact 0.078 newtons. What we read as the difference in these tensions is actually equal to the weight of the fluid displaced by the mass when we lower it into the container.

This brings us to the summary here, Archimedes' principle, and Archimedes' principle says that, "a fluid exerts an upward buoyant force F_b on an object immersed in or floating on the fluid. The magnitude of the buoyant force equals the weight of the fluid displaced by the object." I've shown that through a series of example experiments, but we can do this somewhat more rigorously. But first, let's look at a quick example here, and that is, what is the mass of this floating block?

We are told that the block is submerged 1.5 centimeters, so let's go ahead and complete our free-body diagram. We've got the force of gravity which points down. We've got the buoyant force which points up. If we do the sum of the forces in the y direction, we have plus F_b minus F_g. That's going to be the mass times the acceleration in the y direction. Assuming that this thing is not accelerating up or down, we can set this equal to zero, and we recover that the buoyant force must be equal to the force of gravity, and the buoyant force we said has got a magnitude which is equal to the weight of the fluid displaced by the block.

We can take the density of the fluid times the volume of the fluid. That's going to give us the mass of the fluid times g, so this is going to be the weight of the fluid, and that must be equal to the weight of the block. The volume of the displaced fluid in this case is our 2cm by 2cm by 1.5cm which gives us 6 mL , so we can put 6 mL in for the volume of the fluid. This is water in this case, so we know the density. We know g. In fact, the gs cancel. We are left with the mass of the block is equal to the density of the fluid times the volume of the fluid which is equal to six grams. Six grams.

All right. Now, to put some more rigorous underpinning into Archimedes' principle, we're going to consider a container of fluid. Inside of that container of fluid, we're going to consider an arbitrary volume within the fluid, so this is a three-dimensional volume within the fluid. Since the pressure exists in the fluid, there is going to be forces due to the pressure being exerted along the surface of the fluid everywhere, so the fluid is exerting forces on this volume of fluid that we're interested in.

Since the pressure is omnidirectional, we have forces to the right, and we have forces to the left, and we have forces from the top, and we have forces from the bottom. In a liquid like this, the pressure increases as we go towards the bottom, so along the layer, the pressure is the same, and the pressure is least at the top and greatest at the bottom. That means, since the pressure is the same along the horizontal line, that all of our horizontal forces are going to cancel out. We have forces from the right. We have forces from the left. Those are going to be equal and opposite, but up and down, our forces are not going to cancel out because the forces at the top due to the pressure are going to be smaller than the forces at the bottom due to the pressure because the pressure increases as the depth increases within the fluid.

The net result of all of these pressure forces is we're going to have an up-force and a down-force, and we expect that the force that is exerted...being exerted on the bottom of the volume—or the up-force—should be greater than the down-force because it is at a higher depth, so the pressure is higher.

To summarize that on the free-body diagram, we have an up-force and a down-force. We expect the up-force to be bigger than the down-force, and we also have the force of gravity due to the actual volume of fluid here, so it has mass, and it's going to have a force of gravity, which also points down.

If we do a sum of the forces in the y direction, we get plus F_{up} minus F_{down} minus mg, and that's going to be equal to the mass times the acceleration in the y direction. Since this fluid is in hydrostatic equilibrium, the volume of fluid is not moving up or down, so we can set this equal to zero. On the right-hand side, and we're going to define this quantity of the difference in the pressure forces—the up-force minus the down-force—which is due to our increasing pressure here (we have a gradient). We're going to define this as the buoyant force. This is the force that the fluid, the upward force that the fluid exerts on the volume, and that is exactly what we define the buoyant force as in Archimedes' principle, so we get that the buoyant force is equal to the mass of the fluid times g.

Now, I want to do a thought experiment here where we consider suddenly removing this entire volume of liquid from the container, and the only thing that changes about our free-body diagram is that the gravitational force which points down disappears. The buoyant force which is the up-force minus the down-force still exists. Nothing has changed about the fluid on the outside. Nothing has changed about the forces exerted by the fluid on this volume.

By removing the water inside or the fluid inside of this volume. Nothing has changed about these forces which we're acting on this volume in the first place. It's the geometry, right? That defined it, and nothing has changed about the geometry, so we still have that the buoyant force is equal to the mass of the fluid times g which we can also write instead of the mass of the fluid, as the density of the fluid times the volume of the fluid times g.

Now, if we put an object in the place of the void, then our free-body diagram changes a little bit in that we have the mass of the object or the gravitational force of the object which is now pulling down. We have the buoyant force which is unchanged whose magnitude is just equal to the weight of the fluid that was contained within this shape, and we have the gravitational force which points down. For this free-body diagram that I've shown here, this object sinks, right, because the gravitational force is greater than the buoyancy force, or in other words, this object which has this volume weighs more than water of this same volume—or of the *fluid*—of a volume of fluid the same size.

Let's go ahead and do the sum of the forces. We get that the buoyant force points up, minus the force of gravity which points down, and we can rewrite this in terms of the density of the fluid times the volume of the fluid times g minus, the mass of the object times g. This is just F_g rom our orange object here, and so we can rewrite that as the density of the object times the volume of the object times g.

For a fully submerged object, we have that the volume of the fluid is equal to the volume of the object, so the volume of the displaced fluid is equal to the volume of the object for a fully submerged object. If we compare these two terms, we're going to get a positive acceleration if this term is bigger than this term and a positive acceleration corresponds to our object floating. Meaning, the upward forces exceed the downward forces, and so in that case, that's going to be that the density of the fluid times the volume times gravity must be greater than the density of the object times the volume times gravity.

We can do some cancellation here and say that this is going to—the object is going to float if the density of the object is less than the density of the fluid. It's going to sink if the density of the object is greater than the density of the fluid, and it has what's called "neutral buoyancy." Meaning, it does not have a net force up or down if the density of the fluid is equal to the density of the object.

All right. One last topic, and that's the topic of boats. Instead of considering just a rectangular object here, let's consider a rectangular object that is hollowed out. By hollowing it out, we remove a lot of the mass of this object, but we don't actually change the footprint here for the amount of fluid that's displaced—So the shape of the boat causes it to displace far more water than the volume of the boat's materials alone.

If this was a steel boat, and these were steel plates here, and we just stack the steel plates up, the volume displaced would be much less than this shape here which allows this big empty region inside, allows the boat to displace more water than the materials alone, and a boat will float if its geometry allows it to displace enough water equal to the weight of the boat. If the boat's shape allows it to displace enough water such that the volume of water displaced is equal—excuse me—the weight of the volume of water displaced is equal to the weight of the boat, then the boat will in fact float. Those are my comments on buoyancy. I do have some example problems in some other videos. Thanks a lot. Bye-bye.

Evening Review Sessions

A very popular element of my course has been optional evening review sessions an evening or two before each exam is given. The specific time of the review session is scheduled using physicscloud.net, and I have found that nearly the entire class attends. While I don't prepare a specific lecture, we discuss the whole-arc of the course content covered on the upcoming exam, and it serves as a great opportunity to connect the many individual pieces of the course. In my surveys and course evaluations, students regularly mention the review sessions to be valuable and fun.

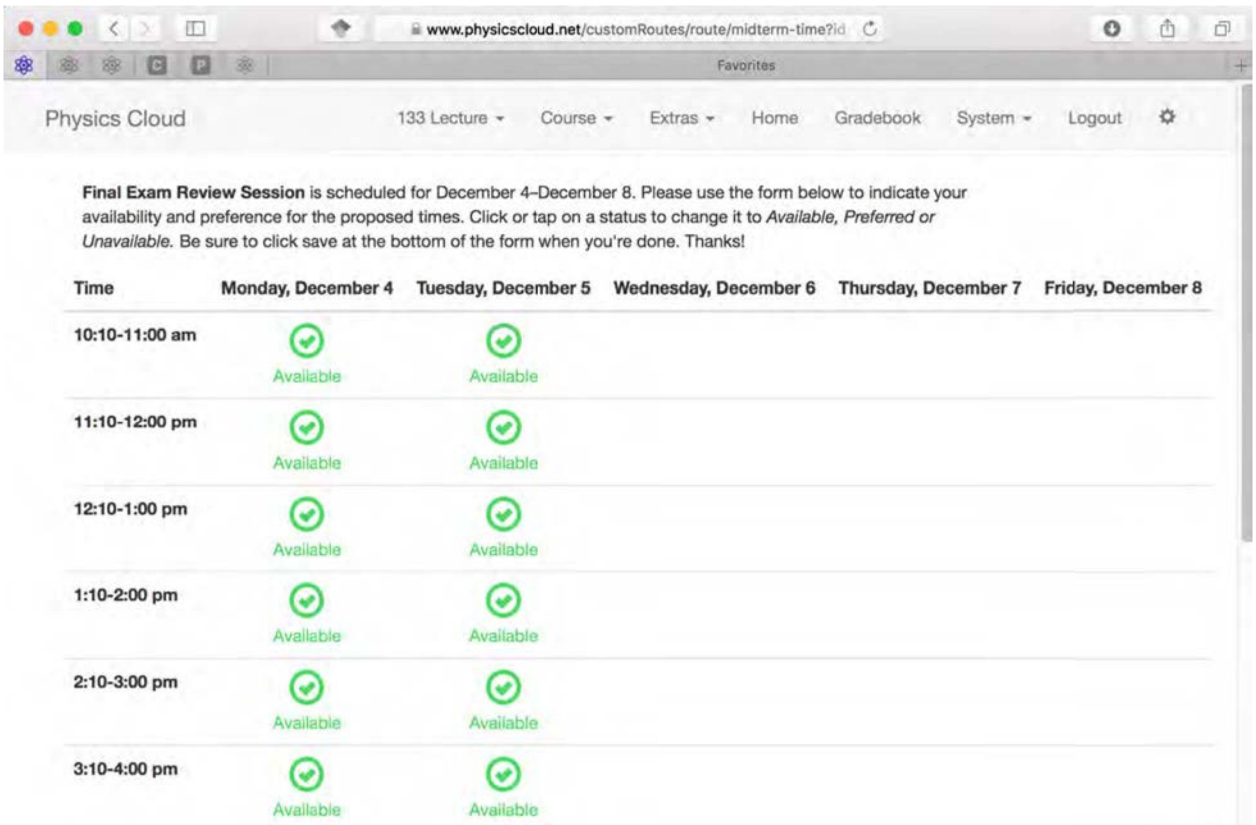


Figure 10: Student schedule availability and preferences are tallies on physicscloud.net for each Midterm review session to maximize accessibility to every one in the course.

physicscloud.net

Overview

Feeling frustrated by the limitations and mobile-unfriendliness of standard university web systems like Blackboard and PolyLearn, I began writing `physicscloud.net` is the Fall of 2014. Physics Cloud is an online gradebook and course management system, custom built to serve the needs of my courses. Physics cloud is a mobile-friendly PHP/MySQL/JavaScript Web 2.0 application built on the high-performance Yii Application Framework[¶]. I designed Physics Cloud to be a versatile platform for both the existing and future online course elements. As a first application, I wrote a gradebook application which provides rich student views detailing their scores and grade calculation, as shown on pages 86 and 85 below. I have also implemented class polling, student preferences, and access-limited grader functionality. Physics cloud is under active development. I plan to use physics cloud as the platform to provide many other online course features including online assignment submission, interactive simulations and student collaboration.

New features recently added to Physics Cloud include surveys and polling, and an interactive outside-of-class meeting scheduler, and a module for making interactive mobile-phone-based flashcards from course rosters for learning student names.

Screenshots

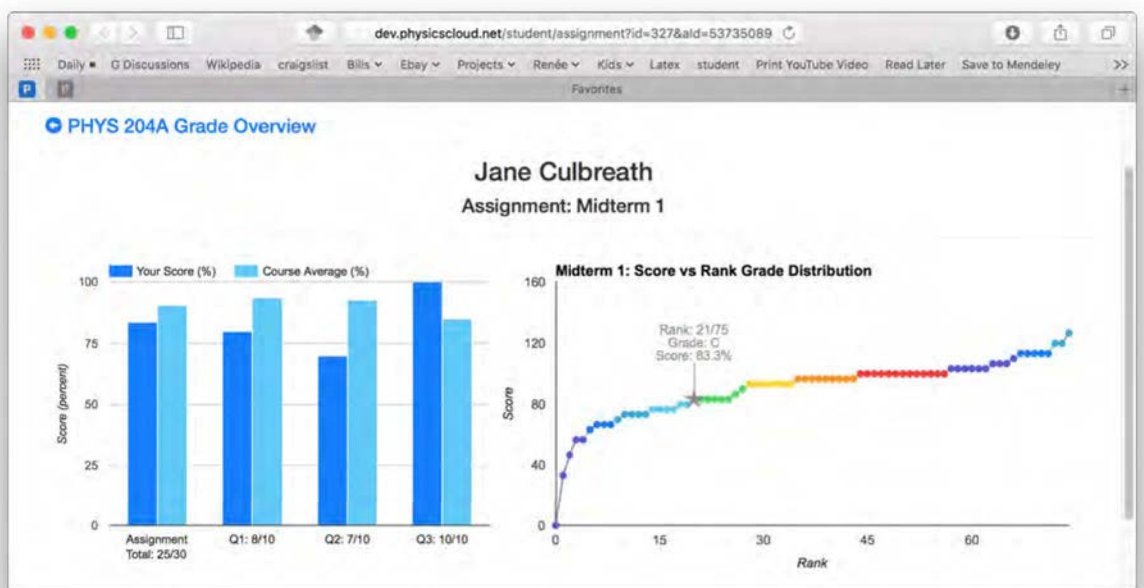
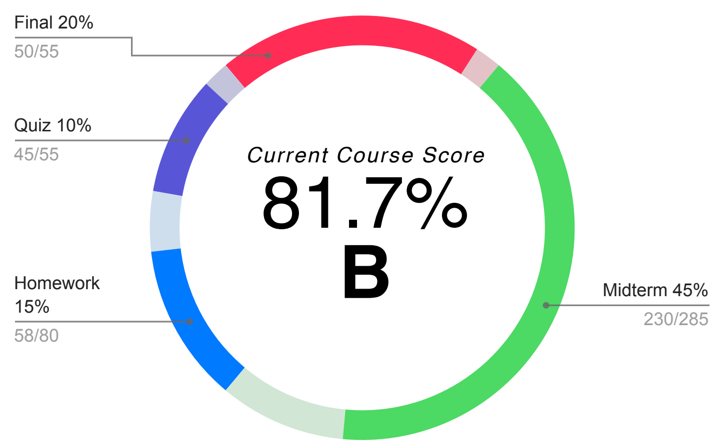


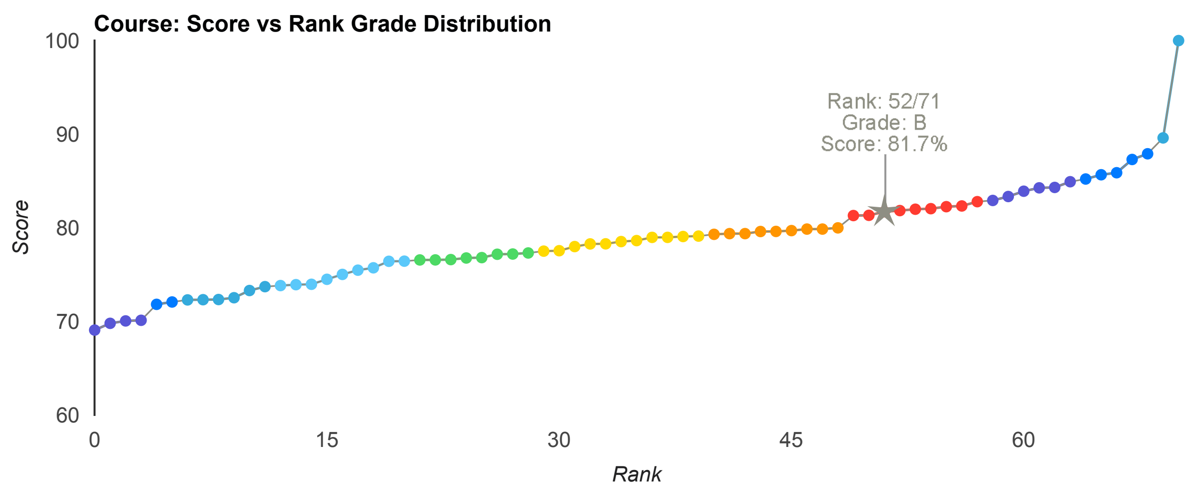
Figure 11: The *Student Assignment View* shows student scores per-question for exams, along with course averages for each problem, the overall course average, and the grade distribution as a function of rank, and a letter grade assignment (if enabled).

[¶] `http://yiiframework.com`

Jane Culbreath

PHYS 204A Grade Overview





Midterm

Assignment Name	Question Scores	Score	Possible	Percent
Midterm 1	Q1: 8/10 , Q2: 7/10 , Q3: 10/10	25	30	83.3%
Midterm 3	Q1: 25/25 , Q2: 25/25	50	50	100.0%
Test 4	Q1: 10/10 , Q2: NS/10 ,	10	---	---
(Score dropped)	Q3: NS/10 , Q4: NS/10			

Exam 3	Q1: 40/10 , Q2: 0/30	40	40	100.0%
Test 6 Problems	Q1: 0/10 , Q2: 0/15 , Q3: 0/20 , Q4: 25/25 , Q5: 30/30 , Q6: 30/35	85	135	63.0%
Midterm 1Q		30	30	100.0%
	Midterm Total:	230	285	80.7%

Quiz

Assignment Name	Question Scores	Score	Possible	Percent
Quiz 1	Q1: 10/20 , Q2: 20/20	30	40	75.0%
Quiz 2	Q1: 5/5 , Q2: 5/5 , Q3: 5/5	15	15	100.0%
	Quiz Total:	45	55	81.8%

Homework

Assignment Name	Question Scores	Score	Possible	Percent
Homework 1		25	30	83.3%
Homework 3		33	50	66.0%
	Homework Total:	58	80	72.5%

Final

Assignment Name	Question Scores	Score	Possible	Percent
Finally	Q1: 0/5 , Q2: 5/5 , Q3: 22/22 , Q4: 23/23	50	55	90.9%
	Final Total:	50	55	90.9%

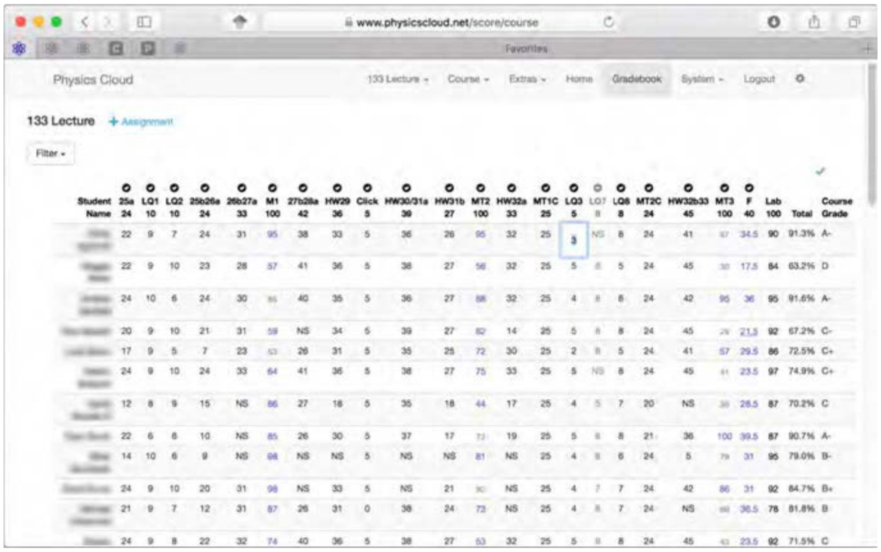


Figure 12: *Instructor Gradebook View*

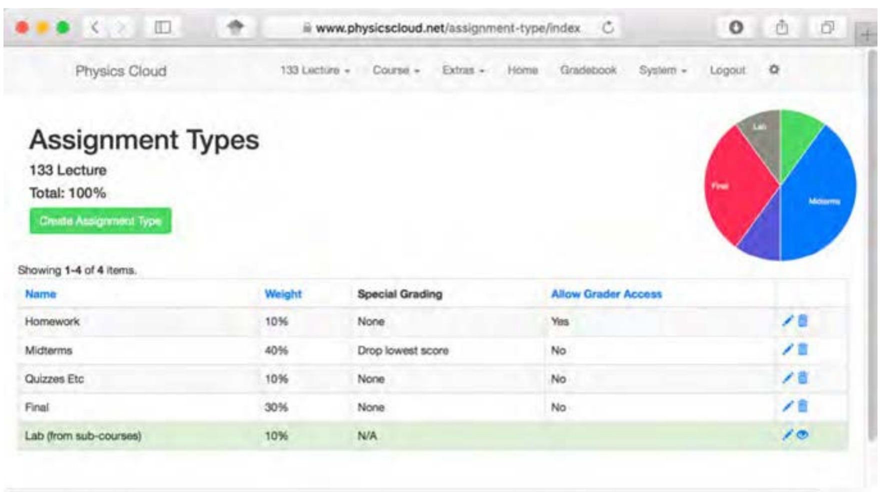


Figure 13: *Assignment Weight Configuration*

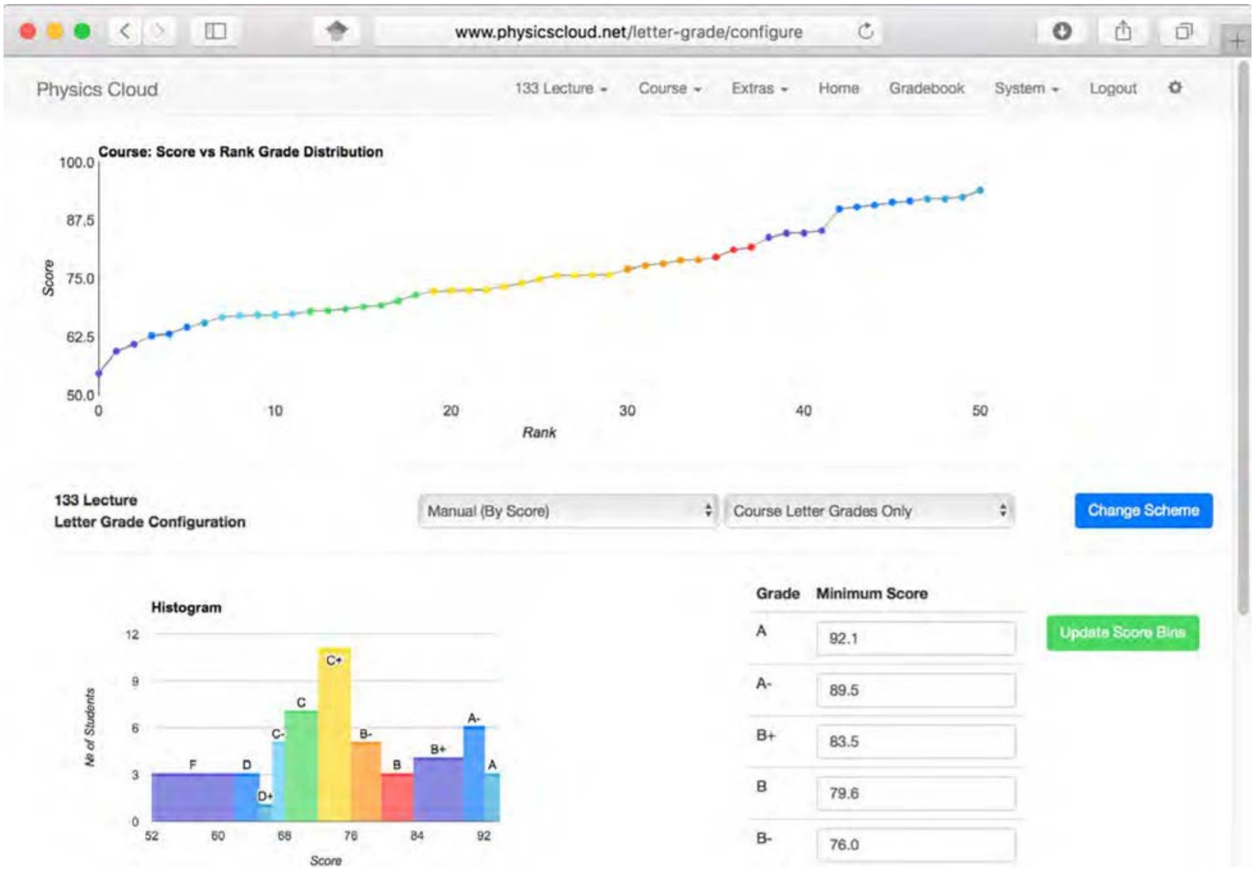


Figure 14: *Instructor Letter Grade Configuration:* Physics Cloud supports several curve schemes, and a responsive interface for observing changes to the letter grade distribution

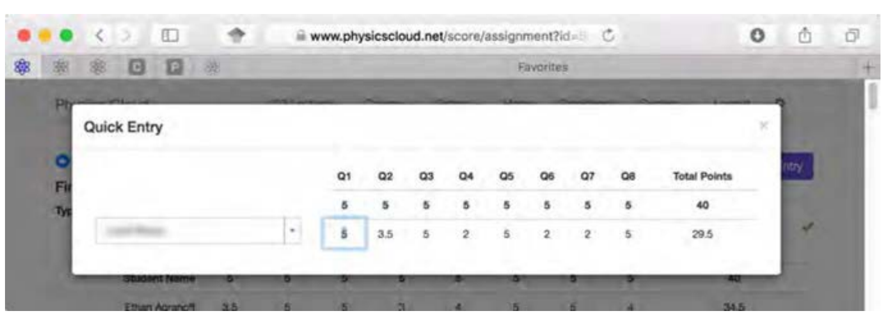


Figure 15: *Grader Quick Entry View:* A smart auto-complete search interface streamlines grade input

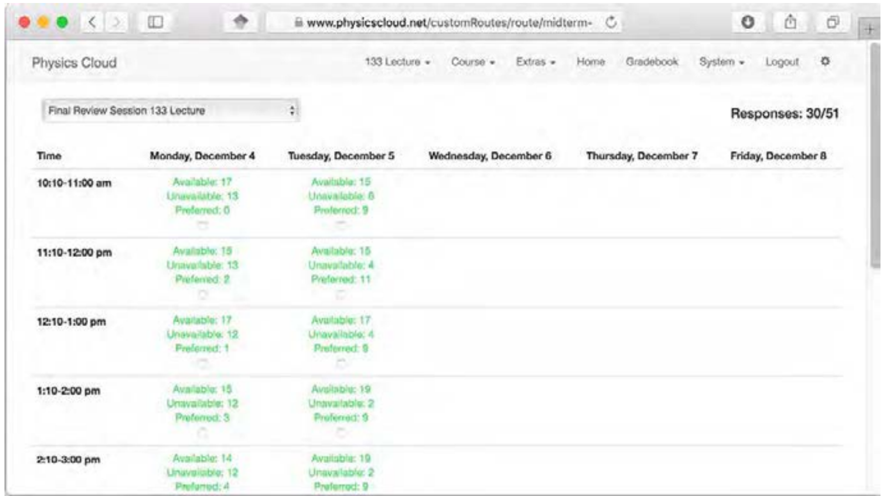


Figure 16: *Event scheduling and availability - Instructor View*

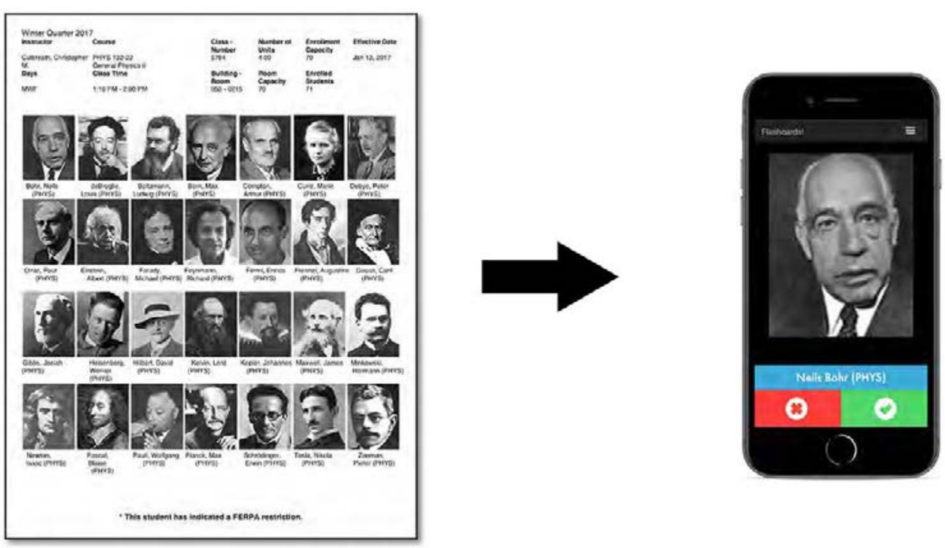


Figure 17: Physics Cloud can turn Cal Poly course rosters into an interactive flashcard game

Scholarship

Submitted Grant Applications

NSF STTR Proposal: Single-crystal shape-memory thermal actuator for rugged fire-suppression sprinkler

Status	*Declined*	**Submitted**	12/15/2016
Type	Sub-Award	**Lead Organization**	TiNi Alloy Company San Leandro, CA
Funding Organization	National Science Foundation	**Program**	Small-business Technology Transfer (STTR)
Award Period	July 2017-June 2017	**Amount**	$134,967

Project Description

The National Science Foundation's Small Business Technology Transfer (NSF-STTR) program provides funds for small businesses to research and develop technological innovations with promising commercial and societal impact. The STTR program is designed for collaborative research efforts between small business and non-profit research institutions. This work is to be funded through a sub-award on a proposal submitted by TiNi Alloy Company of San Leandro, California. TiNi Alloy was founded in 1987 by physicist Dr. A. David Johnson, and is a pioneer and leader in the technology and use of thin film shape memory alloys, with fundamental publications and patents. For the last ten years, TiNi Alloy's efforts have been directed to methods of manufacture, physical characterization, and commercial applications of superelastic single-crystal shape-memory copper-aluminum-nickel alloys (Hereafter referred to as *single-crystal shape-memory alloy(s)*, and abbreviated *SCSMA(s)*.)

While the existence of single-crystal shape-memory alloys has long been established, TiNi Alloy's recent effort in developing and refining the manufacturing of these materials has produced single-crystal copper-aluminum-nickel suitable for commercial applications. The goal of this project is the research and development of a rugged fire-suppression sprinkler based on a patented, novel, thermally-actuated valve constructed from TiNi Alloy's innovative shape-memory material. As an STTR Phase I project, this 12-month effort will be focused on establishing the technical feasibility of a SCSMA heat-actuated valve.

Dr. Johnson has sought the collaboration of my research group for characterizing and understanding the actuation behavior of their SCSMAs and testing and refinement of prototype sprinkler designs.

MATERIALS CHARACTERIZATION

Shape memory alloys are a class of active materials that exhibit a shape-changing solid-state phase transformation that is influenced by alloy composition and changes in temperature and stress. Due to the complexity of this phase-transformation behavior and its dependence on both the mechanical and thermal environment, the development of shape-memory devices requires a detailed understanding and numerical modeling of the material's behavior within the constraints of the device application. The proposed fire sprinkler valve actuator utilizes a specific SCSMA, single-crystal Cu-Al-Ni. Single-crystal Cu-Al-Ni exhibits several unique properties that address the shortcomings of conventional Ni-Ti shape-memory actuators such as a large shape recovery, a pseudo-elastic strain response at constant stress, and a wide range of phase-transition temperatures.

In this work, we will conduct a systematic study to characterize the proposed single-crystal Cu-Al-Ni materials in order to determine the ideal alloy composition and loading conditions for the sprinkler actuator. We will measure the thermoelastic properties of the low- and high-temperature phases, the critical stress and temperature states associated with the phase diagram, and the evolution of strain during loading. These initial measurements will calibrate an empirical model we will develop to optimize the application-specific material parameters, range of ambient conditions, and mechanical specifications of the final device. Beyond this specific device application, we will publish the results of our characterization study in a peer-reviewed journal.

Prototype Refinement

In addition to materials characterization, this project has a significant applied physics/engineering component. Using on-campus machining facilities and working with contracted machinists, we will fabricate, refine and test device prototypes, and investigate the feasibility of alternate designs for demanding applications. We will utilize a 3D solid-modeling CAD package in the mechanical design of prototype devices, and fabricate many of the components in-house. At each design evolution, the prototype will be tested for temperature accuracy, reliability, actuation time and stability. For successful designs, the 3D CAD model will be used to perform finite-element stress analysis as an assessment of the mechanical strength and limiting operating conditions of the prototype device.

Student Involvement

As a Cal Poly graduate and researcher focused on instrumentation and device technologies, I celebrate the value of *Learn by doing*. This project is ideally suited for undergraduate research. Since the project's goal is the development of feasible product, it is enhanced by hands-on, tangible milestones in the form physical prototypes. Further, the project involves several distinct components that are appropriately scaled to the skills and time constraints of undergraduate research efforts. The characterization of SCSMA materials can be cleanly divided into three smaller experiments: mechanical and colorimetric measurements of the phase transition temperatures, the measurement of strain as a function of applied stress, and numerical optimization. Prototyping refinement can be split into separate CAD/design/fabrication and device-testing roles. While each of these roles involve a significant amount of collaboration, the individual components stand on their own as significant undergraduate research efforts. Beyond departmental support for summer research students, the sub-award budget includes 1,200 hours of student researcher compensation —open to applicants in physics, mechanical engineering and materials engineering—to be divided over the 12-month Phase I award period.

Other

Mid-Quarter Student Survey

I value student feedback and utilize a mid-term survey to assess student views on the course. Most importantly, I use surveys to gauge the effectiveness and student interest in new elements worked into the course such as homework corrections, demonstrations, animations and online videos. The Physics 132 Mid-Quarter Survey was conducted anonymously using the online-tool Survey Monkey, the week after the first midterm (week 5). The results are tabulated in table on the next page, and reflect a positive response to many of the new elements incorporated into the class.

Fall 2016 mid-quarter survey · Physics 132

	№	%
Q1. Lecture could be improved with		
a. more example problems	34	53.1%
b. more conceptual discussion	14	21.9%
c. lecture is good as is	16	25.0%
Q2. Powerpoint slides in lecture are		
a. used too often	4	6.3%
b. nicely supplement lecture	47	73.4%
c. don't make a difference in my learning	13	20.3%
Q3. Homework assignments are		
a. too long	27	42.9%
b. too hard	8	12.7%
c. too easy	2	3.2%
d. good as is	26	41.3%
Q4. I prefer homework assignments		
a. that are shorter and collected every class meeting	19	29.7%
b. that are longer and are collected once a week.	45	70.3%
Q5. What homework grading scheme do you prefer?		
a. The 0-1-2 scheme we currently use. Every problem is graded.	58	90.6%
b. A lottery system where 1 or 2 problems are rigorously graded.	6	9.4%
Q6. Lab quizzes are		
a. a waste of time	5	7.9%
b. a great way to learn	43	68.3%
c. could be improved with some changes	15	23.8%
Q7. Homework videos are		
a. unnecessary, and I don't use them	2	3.1%
b. an easy way to the answer, but don't help me learn	17	26.6%
c. a good way to learn physics	45	70.3%
Q8. Homework corrections		
a. should be abolished	6	9.4%
b. are a nice way to review material & reinforce learning	37	57.8%
c. don't make a difference to me	21	32.8%
Q9. Supplemental lecture videos are		
a. a good way to learn physics at home	49	76.6%
b.not useful. I'd rather read the textbook.	10	15.6%
c. could be improved with some changes	5	7.8%
Q10. Would you recommend this instructor?		
Yes	31	48.4%
No	7	10.9%
Too early to tell	26	40.6%

Winter 2017 mid-quarter survey · Physics 132

	№	%
Q1. Lecture could be improved with		
a. more example problems	18	4.0%
b. more conceptual discussion	11	27.5%
c. lecture is good as is	11	27.5%
Q2. Homework assignments are		
a. too long	18	43.9%
b. too hard	3	7.3%
c. too easy	0	0.0%
d. good as is	20	48.8%
Q3. I prefer homework assignments		
a. that are shorter and collected every class meeting	7	17.1%
b. that are longer and are collected once a week.	34	82.9%
Q4. What homework grading scheme do you prefer?		
a. The 0-1-2 scheme we currently use. Every problem is graded.	35	87.5%
b. A lottery system where 1 or 2 problems are rigorously graded.	5	12.5%
Q5. Lab quizzes are		
a. a waste of time	2	4.9%
b. a great way to learn	38	92.7%
c. could be improved with some changes	1	2.4%
Q6. Homework videos are		
a. unnecessary, and I don't use them	2	4.9%
b. an easy way to the answer, but don't help me learn	9	21.9%
c. a good way to learn physics	30	73.2%
Q7. physicscould.net		
a. I regularly check Physics CloudÂăto track my gradeÂăprogress	23	56.1%
b. I rarely check Physics Cloud to track my grade progress	15	36.6%
c. I never check Physics Cloud to track my grade progress	3	7.3%
Q8. The grade curve (check all that apply)		
a. Is a reasonable way to award student letter grades	26	65.0%
b. Is totally confusing	13	32.5%
c. Is unfair	0	0.0%
d. Should be replaced with a direct measure of student success at course objectives, despite lower grades overall.	1	2.5%
e. Should be eliminated by making tests and grading easier	4	10.0%
Q10. Supplemental lecture videos are		
a. a good way to learn physics at home	34	85.0%
b. not useful. I'd rather read the textbook.	2	5.0%
c. could be improved with some changes	4	10.0%
Q10. Would you recommend this instructor?		
Yes	26	63.4%
No	4	9.8%
Too early to tell	11	26.8%

Fall 2017 mid-quarter survey · Physics 132 (1/2)

	№	%
Q1.Do you prefer instructor-prepared or publisher solutions?		
a. Instructor-prepared solutions are way better	18	64.3%
b. Instructor-prepared solutions are a little bit better	4	14.3%
c. I have no preference	4	14.3%
d. I prefer publisher-reprinted homework solutions	1	3.6%
e. I don't use the solutions on physicscloud.net	1	3.6%
Q2. Do you find instructor-prepared video solutions useful for learning physics?		
a. Yes, they are a good way to learn physics	22	78.6%
b. Video solutions are just a quick way to the answer	2	7.1%
c. I don't like video solutions	0	0%
d. I have no opinion on video solutions	4	14.3%
Q3. Do you prefer physicscloud.net or PolyLearn?		
a.PolyLearn is better than physicscloud.net in every way	1	3.6%
b. Physicscloud.net is better in some ways, but not worth using a different system than PolyLearn	4	14.3%
c. Physicscloud.net is better than PolyLearn, and I enjoy using it in this course	19	67.9%
d. I have no opinion of physicscloud.net	3	10.7%
e. Physicscloud.net needs some improvements to be worth using.	1	3.6%
Q4. Are you aware that unauthorized textbook resources, including the publisher's solution guide PDF, can be found (with some modest effort) on the internet? (This survey is totally anonymous)		
a. Yes	25	89.3%
b. No	3	10.7%
Q5. Do you regularly use unauthorized textbook resources when working homework problems or studying for the exam?		
a. Yes, and I find it very useful in learning physics	17	60.7%
b. Yes, but I use them to get done quickly, and it doesn't help me learn much	7	25.0%
c. No, I didn't know these resources existed online	0	0%
d. No, I think that the solutions are cheating	1	3.6%
e. No, reading solutions doesn't help me learn	3	10.7%

Fall 2017 mid-quarter survey · Physics 133 (2/2)

	№	%
Q6. If you use the publisher's solutions when working problems, which best describes your technique?		
a. I follow along each step of the problem, and think about each line before I write it down	6	21.4%
b. I only consult the solution when I get stuck, but otherwise attempt the problem on my own	15	57.1%
c. I just copy the solution, and understand some of it	4	14.3%
d.I don't use unauthorized textbook materials	2	7.14%
Q7. How would you recommend your instructor handle the wide availability of unauthorized textbook materials?		
a. Continue the existing "Don't Ask, Don't Tell" policy	12	44.4%
b. Provide solutions to everyone when homework is assigned	11	40.7%
c. Discourage the use of solutions though a statement in the syllabus	2	7.4%
d. Discourage the use of solutions through "no-cheating" policy, with a penalty for obvious duplication of the publisher solution.	2	7.4%
Q8. Do you like in-class quick-review "clicker" questions?		
a. Yes, they help me learn	24	85.7%
b. Yes, but we did too many	4	14.3%
c. No, they are a waste of time	0	0.0%
d. I don't have an opinion on clicker questions	0	0.0%
Q9. What did you think of your instructor's balance of powerpoint and blackboard lecture?		
a.Too much powerpoint	5	17.9%
b.Too much blackboard lecture	1	3.6%
c.It's a good balance	22	78.6%
Q10. Would you recommend this instructor?		
Yes	25	89.3%
No	2	7.1%
Too early to tell	1	40.6%