Physics 218—Oscillatory and Wave Phenomena
Lecture: MWF 9:00 a.m.
Lab: Thursday 2:45–4:00 p.m.
Course Description, Spring 2020

Instructor:	Andrew Dougherty	
Office:	HSC 031	610-330-5212
Lab:	HSC 025	610-330-5212
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Web Page:	`http://workbench.lafayette.edu/~doughera/phys218/`	

Office Hours: I will be available during my office hours and on most other days during the free times indicated on my schedule. Please feel free to e-mail, call or stop by at any time and ask a question or set up an appointment.

Classes on Snow Days and Other Emergencies: If I am unable to make it to class, I will send out an email via Moodle or leave a message on my voice mail (610-330-5212).

Web Pages: All course documents will be posted on our course web page. That site will also be available through Moodle `http://moodle.lafayette.edu`.

Description: This course is a continuation of the study of oscillations and waves begun in the fundamental courses, with a significant emphasis on experimental and computational approaches, as well as traditional analytical work. The course will explore oscillatory and wave phenomena found throughout nature. Topics will include vibrations of mechanical systems, oscillations in electrical circuits, the general behavior of damped oscillations and resonance, normal mode analysis, Fourier analysis, standing wave phenomena, and wave propagation.

Prerequisites: Physics 133 or 152. Corequisite: Math 264 (Differential Equations). A familiarity with *Mathematica* will also be assumed.

Student Learning Outcomes: After completing this course, you should be able to

- Identify systems where simple harmonic motion is an appropriate model for motion,
- Apply models of oscillations and waves to appropriate physical systems,
- Use complex numbers to solve problems involving damped, driven harmonic oscillators and traveling waves,
- Recognize and solve for normal modes of oscillation in coupled oscillator systems,
- Apply Fourier analysis to oscillating systems, and
- Apply the basic principles and practices of error analysis in experimental physics.
- Numerically simulate the motion of oscillators.

Texts: *Waves and Oscillations*, by Walter Fox Smith (Oxford University Press), and *An Introduction to Error Analysis*, by John R. Taylor. Additional material will be drawn from your introductory physics text.

We will use *Mathematica* extensively in this class. If you would like a good, relevant introductory book, I recommend *Getting Started with Mathematica*, by C-K. Cheung, Gerard E. Keough, Robert H. Gross, and Charles Landraitis. I will also post various "Getting Started" links on the course web page.

We will also use `python` for numerical simulations. I will post additional links on the course web page.

Attendance: Regular attendance is expected. It is **your** responsibility to keep advised of all assignments. If you will be absent for several classes, you should let me know in advance if possible.

Homework: Homework plays a central role in the study of physics. Assignments are designed both to help you become fluent with the relevant tools and techniques, and to give you deeper exposure to the ideas of the course. Assignments will be given regularly and will ordinarily be due one week after they are given out. The following guidelines will be in effect:

- Problems will be due at the *beginning* of class.
- One homework set may be submitted late without penalty, but any additional sets submitted late will be penalized 10 points (out of 100) for each weekday following the due date. Homework sets submitted after the start of class on the due date will be considered one day late.
- For written homework, please staple your pages together. This ensures your pages don't get lost.
- **Illegible papers will not be accepted**. If I have difficulty reading or understanding your work, I may return it to you ungraded for re-submission. You may resubmit a legible version (along with the original) by the next class meeting, but that version must not have any new content—it must simply be a legible version of the original.

Tests: There will be three tests on the dates indicated on the syllabus. Tests may consist of both an in-class and an out-of-class portion. There will also be a comprehensive final exam at the time determined by the registrar.

Labs: The experimental study of nature is an important part of this course. In addition to performing experiments on specific topics, you will also gain experience in computer acquisition and analysis of data, error analysis, and modern instrumentation techniques.

Numerical Simulations: We will also explore numerical simulations of oscillatory and wave phenomena. Such explorations can provide a different, but important, perspective on natural phenomena. They allow you to change parameters more quickly and conveniently than is usually possible in real experiments. You will also be able to visualize and study phenomena that are difficult to observe directly in the laboratory.

Lab Notebook and Reports: You are required to keep an accurate and complete log of your lab work in this course in a laboratory notebook. This notebook will not be graded, but it must contain all the information needed to analyze your experiments, as was the case in your introductory physics course.

For some experiments, you may work with one or two other students as a team. You must each still submit an individual lab report, though you may certainly work together on the analysis.

For each experiment, you must submit a *brief* report by the due date indicated on the schedule below. This report should not duplicate material in the original hand-out or in your text, but it should include the following:

1. Introduction. Give a *brief* introduction both to the theory and experiment. Specific references to a text or the lab handout should be used instead of laborious copying. Be sure, however, to clearly state the main idea of the experiment and the basic technique to be used.

2. Procedure. It is not necessary to discuss the procedure unless you make any modifications to the experiment. Sometimes, this section can be skipped.

3. Data. Give a clear presentation of your data.

4. Results and Discussion. This is the heart of the report. You need not reproduce algebra steps, but be sure that enough information is given that another student in a course similar to Phys 218 could understand what you have done. All graphs should be clearly labeled. All quantities should have appropriate units and uncertainties, where applicable. There is no fixed format for this section, but it is important that it be clear, accurate, and complete.

   Note: It is often convenient to combine the data and results sections. If you find yourself duplicating information, go back and think about reorganizing your report.

Lab reports will be graded on a scale of 0-100. The key points you will be graded on are:

1. Evidence that you have identified and understood the key physical concepts involved in the experiment.

2. Quality of data taken—within the limits of the apparatus, this reflects the care with which you performed the experiment.

3. Analysis and interpretation of data.

4. Clarity and organization of your presentation.

Numerical Simulation Reports: For numerical simulations, the precise items you need to submit will be given in the individual handouts. The general criteria for lab reports will also apply to the simulation reports.

In addition, you will be required to e-mail me a copy of your working program. I will attempt to run your program, so it must be submitted in a format that will work. For assignments that require you to make a number of changes to your program, you normally only need submit the working version that you used for the last part of the assignment.

Late Penalties for Reports: For each weekday that a report is late, I will normally deduct 5 points from the maximum possible grade of 100%. I will, of course, allow for extenuating circumstances such as illness.

Final Exam: There will be a comprehensive final exam at a time to be arranged by the registrar. *Please do not make travel plans that conflict with the scheduled exam time.*

Grades: The final grade will be determined from the homework (25%), lab and simulation reports (25%), tests (30%), and final exam (20%). Please feel free to ask any questions about how your grade is determined.

Federal Credit Hour Statement: The student work in this course is in full compliance with the federal definition of a four credit hour course. Please see the Registrar's Office web site `https://registrar.lafayette.edu/wp-content/uploads/sites/193/2013/04/Federal-Credit-Hour-Policy-Web-Statement.doc` for the full policy and practice statement.

Academic Honesty: The fabric of science, and indeed any intellectual endeavor, is built on the integrity of all involved. Accordingly, I take academic honesty very seriously. I expect that you will abide by the "Principles of Intellectual Honesty" appearing in the Lafayette College Student Handbook.

You are encouraged to work together on homework assignments and lab reports, but collaborations should not be one-way only. You are also encouraged to consult other texts for help in homework assignments. You must fully understand whatever work you turn in, and, unless specifically directed otherwise, all work you turn in *as* your own should *be* your own.

Please read the department's Academic Honesty policy for the rules regarding collaboration. Feel free to ask if you have any questions about this policy.

Andrew Dougherty Spring 2020
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Time	**Mon.**	**Tues.**	**Wed.**	**Thurs.**	**Fri.**
8:00					
8:30	*prep*		*prep*		*prep*
9:00	**Phys 218**		**Phys 218**		**Phys 218**
9:30	HSC 042		HSC 042		HSC 042
10:00					
10:30		*prep*		*prep*	
11:00		**Phys 131**		**Phys 131**	
11:30		HSC 100		HSC 100	
12:00					*Physics Club*
12:30		*prep*			
1:00		**Phys 151**		Phys 131	
1:30		**Lab**		Meeting	
2:00		HSC 119		*prep*	
2:30			*Office*	**Phys 218**	
3:00			*Hours*	**Lab**	
3:30				HSC 042	
4:00		Committee	*Physics Club*	Committee	
4:30		Meeting		Meeting	

ACADEMIC HONESTY GUIDELINES
Department of Physics

It is expected that each student taking courses in the Department of Physics is familiar with the statement "Principles of Intellectual Honesty" appearing in the Lafayette College Student Handbook. The following guidelines are intended to indicate how that statement pertains to your work in physics. Your instructor may have further guidelines for your specific course. We assume that students are honest; if you are not certain as to what is expected of you, consult your instructor before proceeding.

I. EXAMINATIONS:

1. Bring only those materials specifically authorized by your instructor. Frequently in the elementary courses, you will be permitted to bring in a formula sheet or you will be provided with one.

2. If you find that the seating arrangement is such that you can see someone else's paper, don't look! Better yet, ask if you can sit in another seat.

3. If you use a calculator, clear the answer before setting the calculator aside.

4. If you fail to hand in your paper at the end of the period you will be awarded a grade of zero for that test.

II. TAKE-HOME EXAMINATIONS: Take-home examinations are often assigned in some courses. Specific rules governing such tests will be announced by your instructor. The overriding principle, however, is that any work submitted be your own or be specifically credited to its source. There should be no discussion of the test questions with *anyone* other than the instructor.

III. HOMEWORK: You must acknowledge *all* collaborators. You are encouraged to learn from one another. You should first try to do homework problems on your own; after all you will have to do similar problems on your own in tests. However, discussion of difficult problems with others can help you to develop your own analytical skills and is encouraged, provided that, *after discussion* you write up solutions *on your own.* Do *not* borrow or lend homework papers. There is an important difference between discussing a problem with someone and copying his or her work. There have been students who have loaned papers to friends for a few minutes to "check answers", and been horrified to find themselves charged with academic dishonesty because their "friends" copied their solutions.

Please Note: The same ethical standards of academic integrity and honesty apply to the on-line homework as to the written homework, except that there is no place for you to specifically acknowledge collaboration. However, the same general rules apply.

IV. LABORATORY: Usually two or more students will work together in performing experiments and will submit reports of their work. In some courses, a single joint report may be submitted. Specific instructions will be announced by your instructor. If the words used to describe some part of the experiment are taken from some other source (such as the lab manual), then the source should be cited. (Reference to the lab manual can usually substitute for laborious copying.) If you consult with *anyone* about the experiment (e.g. students in your lab class other than your lab partner), that consultation should be acknowledged in your report. Do *not* borrow or lend a completed lab book or any portion of one.

V. PAPERS: Refer to the statement "Principles of Intellectual Honesty" in the Student Handbook.

		Physics 218 Lab Schedule, Spring 2020	
Date		**Experiment**	**Report Due**
Jan.	30	Numerical Simulations in *Mathematica*	
Feb.	6	The Pendulum	*Mathematica* Report
	13	The Torsional Oscillator: Part 1	Pendulum Report
	20	The Torsional Oscillator: Part 2	Torsion 1 Report
	27	Resonance in AC Circuits	Torsion 2 Report
Mar.	5	Introduction to Numerical Simulations in Python	Resonance Report
	12	Simulating a Damped, Driven Oscillator	Python Report
	16–20	*Spring Break*	
	26	Coupled Oscillator Simulations	Duffing Report
Apr.	2	Coupled Oscillators *continued*	
	9	Vibrating String Simulations	Coupled Oscillators Report
	16	Wave Simulations Part I	String Simulations Report
	23	Wave Simulations Part II	Waves I Report
	30	Nonlinear Wave Simulations	Waves II Report
May	7		Nonlinear Waves Report

Revised April 16, 2020

Syllabus		Physics 218	Spring 2020
Jan.	27	Introduction & Overview	Smith 1.1–1.5
	29	Expansions and Complex Numbers	Smith 1.6–1.9
	31	Wavefunctions and Uncertainty; HW #1	Smith 1.11–1.12
Feb.	3	Examples of Oscillation	Smith 2.1–2.5
	5	Brief Introduction to Error Analysis	Taylor Ch. 1–4
	7	More Examples of Oscillation; HW #2	Smith 2.6
	10	Damping	Smith 3.1–3.4
	12	Propagating Uncertainties	Taylor Ch. 4,5
	14	Types of Damping; HW #3	Smith 3.5–3.6
	17	Curve-fitting	Taylor Ch. 8
	19	**Hour Test I**	
	21	Resonance	Smith 4.1–4.4
	24	Resonance Applications	Smith 4.5–4.8
	26	Coupled Oscillators	Smith 5.1–5.4
	28	Normal Modes; HW #4	Smith 5.5
Mar.	2	Hilbert Space	Smith 5.6
	4	Brief Introduction to Numerical Simulations	
	6	Python Simulations	
	9	Energy Levels	Smith 5.7
	11	Damped, Driven Coupled Oscillators	Smith 5.8–5.9
	13	Eigenvalues and Matrices; HW #5	Smith 6.1–6.3
	16–20	*Spring Break*	
	23	*continued*	
	25	Eigenvalue problems	Smith 6.4–6.5
	27	*continued*; HW #6	Smith 6.6–6.7
	30	**Hour Test II**	
Apr.	1	Beaded String	Smith 7.1–7.3
	3	Normal Modes for Strings	Smith 7.4–7.6
	6	k-space	Smith 7.7–7.8
	8	Fourier Analysis	Smith 8.1–8.4
	10	Fourier Transform; HW #7	Smith 8.5–8.6
	13	Applications	Smith 8.7
	15	AC Circuits	Smith 1.10
	17	AC Circuits and Filters; HW #8	
	20	Waves in One and Two Dimensions	Smith 9.1
	22	Circular Drum; Traveling Waves	Smith 9.2–9.5
	24	Waves in Media; HW #9	Smith 9.6–9.11
	27	Dispersion & Group Velocity	Smith 9.12
	29	*continued*; HW #10	
May	1	**Hour Test III**	
	4	Boundaries	Smith 10.1–3
	6	Reflection and Transmission	Smith 10.5–7
	8	Refraction; Evanescent Waves; HW #11	Smith 10.8–9
		Final Exam (cumulative)	

Complex Numbers

$e^{i\theta} = \cos\theta + i\sin\theta \qquad \cos\theta = \frac{e^{i\theta} + e^{-i\theta}}{2} \qquad \sin\theta = \frac{e^{i\theta} - e^{-i\theta}}{2i} \qquad Z_R = R \qquad Z_C = \frac{1}{i\omega C}$
$Z_L = i\omega L$

Expansions

$\cos(x) \approx 1 - \frac{1}{2!}x^2 + \dots \qquad \sin(x) \approx x - \frac{1}{3!}x^3 + \dots \qquad e^x \approx 1 + x + \frac{1}{2!}x^2 + \dots$
$(1+x)^n \approx 1 + nx + \dots$

Damped Harmonic Oscillator

$m\ddot{x} = -kx - b\dot{x} \qquad \omega_0 = \sqrt{k/m} \qquad \gamma = b/m \qquad \omega_v = \omega_0\sqrt{1 - \frac{\gamma^2}{4\omega_0^2}} \qquad A(t) = A_0 e^{-\gamma t/2}$
$Q = \frac{\omega_0}{\gamma} \qquad \tau = \frac{1}{\gamma} \qquad Re = \frac{\rho v L}{\mu}$

Forced Vibrations and Resonance

$m\ddot{x} = -kx - b\dot{x} + F_0\cos(\omega t) \qquad x(t) = A\cos(\omega t - \delta) \qquad A(\omega) = \frac{F_0/m}{\sqrt{(\omega_0^2 - \omega^2)^2 + (\gamma\omega)^2}}$
$\tan\delta(\omega) = \frac{\gamma\omega}{(\omega_0^2 - \omega^2)} \qquad \omega_m = \omega_0\sqrt{1 - \frac{1}{2Q^2}} \qquad \bar{P}(\omega) = \frac{F_0^2\omega_0}{2kQ}\frac{1}{\left(\frac{\omega_0}{\omega} - \frac{\omega}{\omega_0}\right)^2 + \frac{1}{Q^2}}$

Coupled Oscillators

$\omega_0 = \sqrt{\frac{T}{ma}} \qquad \omega_n = 2\omega_0 \sin\left[\frac{n\pi}{2(N+1)}\right] \qquad A_{jn} = C_n \sin\left(\frac{jn\pi}{N+1}\right)$

Fourier Series

$f(x) = \frac{a_0}{2} + \sum_{n=1}^{\infty}\left[a_n\cos k_n x + b_n \sin k_n x\right] \qquad k_n = n\frac{2\pi}{\lambda}$
$a_n = \frac{2}{\lambda}\int_0^\lambda \cos k_n x f(x)dx \qquad b_n = \frac{2}{\lambda}\int_0^\lambda \sin k_n x f(x)dx$

Some Fourier Series

Square Wave

The Fourier Series for a square wave of height $\pm h$ and period λ is

$$square(x) = \frac{4h}{\pi}\left[\sin\left(\frac{2\pi x}{\lambda}\right) + \frac{1}{3}\sin\left(3\times\frac{2\pi x}{\lambda}\right) + \frac{1}{5}\sin\left(5\times\frac{2\pi x}{\lambda}\right)\dots\right]$$

Triangle Wave

The Fourier Series for a triangle wave of height $\pm h$ and period λ is

$$triangle(x) = \frac{8h}{\pi^2}\left[\sin\left(\frac{2\pi x}{\lambda}\right) - \frac{1}{3^2}\sin\left(3\times\frac{2\pi x}{\lambda}\right) + \frac{1}{5^2}\sin\left(5\times\frac{2\pi x}{\lambda}\right)\dots\right]$$

Sawtooth Wave

The Fourier Series for a sawtooth wave of height $\pm h$ and period λ is

$$saw(x) = \frac{2h}{\pi}\left[\sin\left(\frac{2\pi x}{\lambda}\right) - \frac{1}{2}\sin\left(2\times\frac{2\pi x}{\lambda}\right) + \frac{1}{3}\sin\left(3\times\frac{2\pi x}{\lambda}\right) - \frac{1}{4}\sin\left(4\times\frac{2\pi x}{\lambda}\right)\dots\right]$$