Foundations of Physics III – Waves, Optics, & Thermal Physics

Fall 2018 | Physics 211 | Adam Tomei Whitten

Course Information

Lecture: MWF 10:20-11:15 in PEngl 167
Texts: *University Physics (Sears & Zemansky), 14th Ed.*
Hugh D. Young and Roger A. Freeman, ISBN: 978-0-321-97361-0
Six Ideas That Shaped Physics, Unit T, 3rd Ed.
Thomas A. Moore, ISBN: 978-0-07-760096-9

Introduction

This course focuses on fluid mechanics, wave, optics, and thermodynamics. We will first look at fluid statics: density, pressure, and how pressure varies with depth in a fluid. This leads to an understanding of buoyancy. Then we will look at fluid dynamics by applying Newton's laws and the conservation of energy. After a short review of periodic motion we will investigate transverse and longitudinal wave. This sets the stage for studying the interference and diffraction of light waves, but we will first look at optics from a geometric perspective. We will finish up the semester by investigating thermodynamics from a statistical mechanics perspective.

About the Textbooks and Reading Preparation for Class

The chapter readings of the textbook present the theoretical framework required to delve into the more interesting Physics applications which are introduced as examples and problems within the readings. Therefore, to make the most effective use of class time, you must read the material beforehand. Doing this will allow you and your fellow students to jump straight into the core Physics content which will better prepare you for the homework and tests.

Course Objectives

While this is a calculus-based course emphasizing analytical reasoning and problem-solving techniques, some of the topics encountered will only require algebra. After completing this course students will be able to:

- ☐ define density.
- ☐ calculate the pressure at depth in a fluid.
- ☐ calculate buoyant forces.
- ☐ describe the difference between laminar and turbulent fluid flow.
- ☐ apply Bernoulli's equation to relate pressure and speed at different points in a flowing fluid.
- ☐ describe how viscous flow and turbulent flow differ from ideal flow.
- ☐ describe the difference between a longitudinal and a transverse wave.
- ☐ apply the equation relating velocity, frequency, and wavelength to wave motion.
- ☐ apply the mathematical expression for sinusoidal periodic waves to calculate displacements, speeds, and accelerations of particles in the wave's medium.
- ☐ calculate the speed of transverse waves.
- ☐ calculate the rate of energy transport in a mechanical wave.
- ☐ apply boundary conditions and the principle of superposition to describe wave interference.
- ☐ analyze standing waves on a string.
- ☐ describe a sound wave in terms of particle displacements and pressure variations.
- ☐ calculate the speed of sound in different materials.
- ☐ calculate the intensity of a sound wave.
- ☐ apply the principle of standing waves to determine normal modes for a pipe or wind instrument.
- ☐ describe why resonance occurs.

- ☐ calculate points of constructive and destructive interference of sound waves.
- ☐ calculate beat frequencies.
- ☐ apply the Doppler effect equation to determine wavelength, frequency, or velocity.
- ☐ describe how shock waves occur.
- ☐ describe the relationship between light rays and wavefronts.
- ☐ apply the lays of reflection and refraction.
- ☐ apply the concept of total internal reflection to calculate critical angles or indices of refraction.
- ☐ describe how the speed of light in a material leads to dispersion.
- ☐ apply Malus' law to determine intensities of light.
- ☐ apply Brewster's law to calculate polarizing angles or indices of refraction.
- ☐ apply the principles of reflection and refraction to determine object distance, image distances, focal lengths, and magnifications from plane and curved surfaces.
- ☐ apply the lensmaker's equation to determine focal length, index of refraction, or radius of a lens.
- ☐ apply the principles of geometric optics to describe how eyes, cameras, magnifiers, microscopes, and telescopes work.
- ☐ analyze double slit interference patterns to determine slit spacing, wavelength of light, fringe spacing, or light intensity.
- ☐ analyze thin film interference to determine film thickness or wavelength of light.
- ☐ explain diffraction in terms of Huygen's principle.
- ☐ analyze single slit diffraction patterns to determine slit width, wavelength of light, fringe spacing, or light intensity.
- ☐ analyze diffraction gratings to determine slit spacing, wavelength of light, and resolving power.
- ☐ determine the resolving power of a circular aperture.
- ☐ identify if a process is reversible or irreversible.
- ☐ identify if internal energy changes are due to heat, work, or some other form of energy transfer.
- ☐ describe the nature of temperature and how it is measured (0^{th} Law of Thermodynamics).
- ☐ apply the 1^{st} Law of Thermodynamics.
- ☐ calculate changes in temperatures of objects in thermal contact.
- ☐ calculate thermal expansions.
- ☐ describe the difference between microstates and macrostates of a system.
- ☐ apply the Einstein model of a solid to determine the final state of solids in thermal contact.
- ☐ use the probabilities of macrostates to explain irreversibility.
- ☐ calculate entropy using statistical mechanics.
- ☐ explain the 2^{nd} Law of Thermodynamics using statistical mechanics.
- ☐ calculate a system's internal energy temperature dependence, $U(T)$.
- ☐ use Boltzmann factors to calculate the probabilities of macrostates.
- ☐ use the partition function to calculate internal energies and heat capacities of Einstein solids.
- ☐ use the partition function to calculate internal energies and heat capacities of ideal gases.
- ☐ apply kinetic theory to derive the ideal gas law.
- ☐ apply the Maxwell-Boltzmann distribution to calculate molecular speeds in a gas.
- ☐ apply the Planck distribution to calculate photon emission rates.
- ☐ calculate heat transfer, work done, and change in internal energy for a gas undergoing constrained processes (isothermal, isobaric, isochoric, adiabatic).
- ☐ calculate the entropy of an ideal gas using the Sackur-Tetrode equation.
- ☐ calculate changes in entropy of an ideal gas using replacement processes (adiabatic, isothermal, isochoric heating).
- ☐ calculate efficiencies of heat engines.
- ☐ calculate coefficients of perfomance of refrigerators and heat pumps.
- ☐ apply physical concepts to model climate change.

Homework

Working problems is essential to your development of an understanding of the material. They will give you the vital practice needed to help you perform well on the exams. It is very important for you to try to complete the problems independently before conferring with your colleagues or accessing internet resources. It is relatively easy to read and understand someone else's approach to the solution – it is just as easy to forget it by the time of the exam. Working the solution yourself will help you retain the concepts and methods used. See the schedule for assigned homework problems – they are due at the beginning of the second class period after they are assigned.

Grading

Your grade will be based on a weighted average of homework, three 55-minute exams, and a comprehensive final exam as follows:

Item and Weight	
Homework	25%
3 Tests	45%
Final Exam	30%

Grading Scale

A	93-100	C	73-77
AB	88-92	CD	68-72
B	83-87	D	60-67
BC	78-82	F	0-59

Final Exam: Thu, Dec 13, 1:00–3:00 pm

Schedule: UP = *University Physics*; SI = *Six Ideas That Shaped Physics*

Date	Reading	Topic	Homework
8/27	UP 12.1-3	Fluids, Pressure, Buoyancy	UP 12.4,16,28
8/29	UP 12.4-5	Fluid Flow, Bernoulli's Equation	UP 12.36,42
8/31	UP 12.6	Viscosity, Turbulence, SHM review	UP 12.53,71
9/3	UP 15.1-2	Mechanical Waves	UP 15.3,4,6
9/5	UP 15.3-4	Describing Waves	UP 15.12,19,20
9/7	UP 15.5-6	Energy, Interference, Superposition	UP 15.24,35
9/10	UP 15.7-8	Standing Waves	UP 15.36,38,68
9/12	UP 16.1-3	Sound Waves	UP 16.2,10,24
9/14	UP 16.4-6	Resonance, Interference	UP 16.28,32,36
9/17	UP 16.7-9	Beats, Doppler Effect, Shock Waves	UP 16.40,54,57
9/19	**UP 12,15,16**	**Test 1: Fluid Mechanics and Waves**	
9/21	UP 33.1-3	Light Reflection and Refraction	UP 33.6,7,8,17
9/24	UP 33.4-6	Dispersion, Polarization, Scattering	UP 33.23,28
9/26	UP 33.7,34.1	Huygen's Principle, Plane Surfaces	UP 33.49,50; 34.2
9/28	UP 34.2-3	Reflection, Refraction	UP 34.8,12,18,23
10/1	UP 34.4-5	Thin Lenses, Cameras	UP 34.31,42,45
10/3	UP 34.6-7	The Eye, Magnifiers	UP 34.51,56
10/5	UP 34.8, 35.1	Microscopes, Telescope, Coherence	UP 34.60,63
10/8–10/9		**Free Days**	
10/10	UP 35.2-3	Interference	UP 35.14,22
10/12	UP 35.4-5	Thin Films, Michelson Interferometer	UP 35.26,31
10/15	UP 36.1-3	Edge and Single Slit Diffraction	UP 36.47,49
10/17	UP 36.4-6	Multi-slit Diffraction	UP 36.22,24,36
10/19	UP 36.7-8	Apertures, Holography, review	UP 36.42
10/22	**UP 33-36**	**Test 2: Optics**	
10/24	SI T1	Temperature	SI T1B.2,B.4,M.2,R.2
10/26	UP 17.4-7	Thermal Expansion, Heat, Phase Changes	UP 17.18,28,37,65
10/29	SI T2.1-3	Macrostates and Microstates	SI T2B.3,B.9,D.2
10/31	SI T2.2-7	Thermal Contact, Irreversibility	SI T2M.3,M.6,M.9
11/2	SI T3	Entropy and Temperature	SI T3B.3,B.5,B.7,B.9
11/5	SI T4.1-2	Boltzmann Factor & Partition Function	SI T4B.3,B.5,M.3
11/7	SI T4.3-4	Quantum Systems	SI T4B.7,B.10,M.8,D.3
11/9	SI T5.1-2	Monatomic Gases	SI T5B.3,B.5,B.7
11/12	SI T5.3-5	Diatomic Gases, Equipartition, Ideal Gases	SI T5B.8,B.13,M.3,M.7
11/14	SI T6.1-2	Quantum States, Maxwell-Boltzmann	SI T6B.5,M.2,R.1
11/16	SI T6.3-4	Photon Gas, Blackbodies	SI T6B.10,B.12
11/19	SI T7	Gas Processes	SI T7B.7,B.9,B.11,D.2
11/21–11/23		**Thanksgiving Break**	
11/26	SI T8.1-3	ΔS at constant T	SI T8B.2,B.3,D.5
11/28	SI T8.4-5	ΔS for changing T	SI T8B.7,M.6,M.7
11/30	SI T9.1-3	Heat Engines	SI T9B.4,M.8,D.5
12/3	SI T9.4-6	Refrigerators, Carnot Cycle	SI T9B.8,M.10,R.1
12/5	SI T1-T-10	Climate Change & Review	SI T10B.1,B.4,B.7
12/7	**SI T1-T10**	**Test 3: Thermal Physics**	
12/10	All	Review	
12/13	**Final Exam 1:00–3:00 pm**		