Physics 153 – Elements of Physics

Topics:

Term 1: Thermodynamics & Waves
Heat & temperature, heat transfer, phases of matter, work & energy, entropy, ideal gas processes and heat engines
Periodic motion, simple harmonic motion (including springs, pendulums, and other systems), wave motion, superposition of waves, sound.

Term 2: Electricity & Magnetism

Wave optics, electrostatics and magnetism, DC and AC circuits.

Lab:

The lab will experimentally explore these topics in term 2 with weekly labs. In addition, there will be a lab exam.

Required Materials:

"University Physics with Modern Physics"

Access code for MasteringPhysics (bundled with text or purchased separately)

iClicker

Materials and pre-reading quizzes will be posted on Connect (log in with your CWL at connect.ubc.ca)

Two lab books one for lab and one for lecture activities.

What to expect:

“Lecture” time will consist of a mixture of lecture, clicker questions, discussions, and activities for you to work on with your peers. These learning exercises are designed to encourage you to attempt to use the new skills you are building in an environment where you can receive feedback. When we ask questions in clas, it is not a “test” for evaluating you, but consider it a challenge to yourself. Ask: “Do I know how to apply this concept?”, “Did I follow the last activity?”, “Would I be able to produce a similar result on an exam?”. Being honest with yourself will guide you to the areas you need to work on, and help you gauge your own mastery of the material.

Pre-reading assignments will be given on a weekly basis. These will give you the vocabulary and tools you need to build the skills we will work on in lecture and are an important part of your learning. Pre-reading quizzes on Connect will provide a check that you have absorbed the information and help you prepare for class.

Tutorials will give you a chance to review homework questions and prepare for your next assignment with your peers and teaching assistants. Tutorials begin second week of classes.

Homework assignments provide you with the practice you need to improve your problem solving skills and apply concepts. This practice is essential to your learning! You may discuss concepts and approaches with your peers, but we expect you to submit your own final work. There are two types of homework: MasteringPhysics online questions and full written solutions to be handed in during tutorials.

Midterm and exam questions will be worked problems of similar style to homework and activity problems. The exam will have a set of 10 multiple choice. At least one question will be based on either an activity or previous homework question. Ultimately the learning goals are your guide to what we expect you to be able to do, so consider using these as a study guide alongside reading and practicing problem solving.

Term 1 Heat, Thermodynamics, Oscillations, Waves, and Sound.

Week 1 Concepts of thermodynamics. Zeroth law of thermodynamics. Temperature scales. Gas thermometers.

Week 2 Absolute temperature scales. Thermal expansion, thermal stress. Heat capacity, specific heat, latent heat. Calorimetry.

Week 3 Heat conduction, convection, radiation. Thermal resistances, R values.

Week 4 Ideal gas law and isotherms. Phase changes, phase diagram, critical point, triple point. Relative humidity.

Week 5 Kinetic theory. Equipartition theorem. Maxwell Boltzmann distribution. Van der Waals equation.

Week 6 First law of thermodynamics. Internal energy. Free expansion of gas. Adiabatic expansion, work done on gas.

Week 7 Efficiency of heat engine. Heat pump. Entropy.
Week 8 Simple harmonic motion, angular frequency, velocity, acceleration.

Week 9 Kinetic and potential energy in simple harmonic motion. Damped oscillation and critical damping. Forced harmonic motion, resonance.

Week 10 Traveling waves, energy transmitted. Standing waves.
Week 11 Adding waves. Beats.
Week 12 Doppler effect. Speed of sound.
Week 13 Harmonic analysis and synthesis of wave packets. Dispersion.

Term 2 Electricity and Magnetism + Wave Optics

Week 1 Waves and Optics Week 2 Waves and Optics

Week 3 Review of resistance, circuits, Emf and batteries, circuit analysis. Week 4 RC circuit analysis.
Week 5 Inductors, LR, LCR circuits.

Week 6 Alternating circuit analysis. LCR circuits.
Week 7 Review electric force and fields, Gauss's law
Week 8 Gauss's law and electric flux. Electric potential.
Week 9 Electric potential (continued), calculate electric field from potential, capacitors. Week 10 Magnetic field, Lorentz force, and Cyclotron motion.
Week 11 Biot–Savart law and Ampere's law.
Week 12 Faraday's law.
Week 13 Maxwell's equations, Electromagnetic waves.

OVERALL LEARNING GOALS OF 153:

1. Being able to describe a physical situation with a mathematical model
2. identify the appropriate physical concepts that describe a situation, object, or system
3. and calculate the relevant parameters describing the system

GRAPHS

- reading/taking values off a graph
- identifying a critical point or area on a graph
- recognizing the axes of a graph (and the relationship between the graphed quantities)
- connecting aspects of the curve with a physical meaning
- using the trend in the data to help solve a problem
- being able to genearte a graph

EQUATIONS

- identifying which variables change and which stay constant in the problem
- being able to predict how the changes of one variable might affect the other variables
- being able to identify what physical conditions influence a variable
- applying a defintion or standard equation
- being able to manipulate vector quantities
- setting up an equation of conservation (e.g., energy, mass, momentum) and specifically identify and evaluate the before and after pictures
- knowing the conditions for which energy an equation does and does NOT hold true
- being able to apply and explain a rate of change
- being able to qualitatively describe parts of an equation
- setting up the initial conditions

COMBINING IDEAS & SELF CHECKS

- combining content themes in the course, e.g., SHM motion and thermodynamics, to solve a given problem
- including integrating previous expected knowledge !!
- devise problem-solving strategy (identifying the correct process from a choice of 2 or 3, e.g., themo process)
- being able to explain -- in words -- the problem solving method (including all steps)

EVALUATE

- making appropriate estimates of physical quantities describing a physical object (e.g., length, mass, frequency, etc.)
- analytical result should be consistent with your knowledge of the physical system
- evaluating limiting cases of a formula
- solve for relevant parameters in a real physical situation
- construct a qualtitative assessment of a physical situation (e.g., a prediction).
- rationalizing if your answer makes sense e.g., order of magnitude, units, plausible realistic numbers or makes sense physically
- being able to identify all the forces acting in a problem

FIGURES

- being able to generate a simplified figure
- being able to construct a free body diagram when necessary
- being able to draw a diagram reprsenting a physical problem with specific criteria, e.g., weightlessness conditions
- interpretting the figure and how it may change between different regions or at different times according to the problem
- being able to understand a reduced picture (figure) of a physicsal situation and using information from it
- being able to approximate parts of a problem with the correct geometric reprsentation
- being able to draw vectors

Content level goals: THERMODYNAMICS

1. **Heat and temperature and the Zeroth law of thermodynamics:**
   1.1. Be able to explain the difference between heat and temperature
   1.2. Apply the concept of heat flow to real world situations
   1.3. Apply concept of thermometry, ie. using a thermal property to measure temperature
   1.4. Be able to recognize and apply the concept of thermal equilibrium
2. **Thermometry:**
   2.1. Apply concept of thermal equilibrium, for example in thermometry
   2.2. Use a graphical calibration of an instrument (specifically in this case for a thermometer)
   2.3. Apply the ideal gas law as a method of measuring temperature from another measurable property of a gas
   2.4. Judge when an instrument is not appropriate for the measurement
   2.5. Calculate the slope and intercept from a graph
3. **Temperature Scales:**
   3.1. Distinguish the difference between absolute and differential temperature scales (ie. Celsius and Kelvin)
   3.2. Know what "absolute zero" is
4. **Thermal expansion and thermal stress:**
   4.1. Be able to describe and calculate linear, area and volume thermal expansion
   4.2. Be able to explain the importance of thermal expansion and thermal stress in engineering situations
   4.3. Calculate thermal stress
   4.4. Evaluate whether thermal stress and/or thermal expansion is important in given engineering situations
5. **Heat, quantitative:**
   5.1. Be able to describe the flow of energy due to objects that are at different temperatures (equivalent to asking: how do objects come into thermal equilibrium?)
   5.2. Understand that mechanical energy can be converted into thermal energy
   5.3. Be able to define specific heat
   5.4. Perform calculations relating the mass, temperature and heat required to produce temperature changes of objects
   5.5. Define what a phase change is
   5.6. Perform calculations relating heat and phase changes of an object
6. **Pathways for heat:**
   6.1. Know how convection, conduction and radiation provide a pathway for heat
   6.2. Calculate the flow of heat through an object with a simple geometry by conduction
   6.3. Know that electromagnetic waves (ie. light) carry energy
   6.4. Recognize that objects at a given temperature emit a blackbody spectrum of light related to the object's temperature
   6.5. Apply the relationships between the blackbody spectrum and temperature to determine the temperature of an object (Wien's law and Stefan-Boltzmann Law)
   6.6. Perform calculations to describe radiative heat transfer
7. **Integration:**
   7.1. Relate the area under a curve to an integral

7.2. Apply the concept that an integral is the area under a curve to solve or estimate the solution to physical problems that require integration

8. Work:

8.1. Relate Work to the area under a force-distance or pressure-volume diagram (integral)

8.2. Be able to describe the work done by or on a gas

8.3. Calculate the work done by or on a gas from a P-V diagram through a process

9. Work-Energy Theorem and the First law of thermodynamics:

9.1. Calculate the change in kinetic energy for a mechanical process

9.2. Recognize that energy can only be transferred, not destroyed (conservation of energy)

9.3. State the First law of thermodynamics

10. Thermodynamic system and state variables:

10.1. Identify the state variables for an ideal gas and other systems

10.2. Distinguish thermodynamic state variables, which are path independent quantities, from path dependent quantities (like heat and work)

10.3. Interpret and use PVT diagrams to describe thermodynamic systems

10.4. Use the first law to relate heat, work and change in internal energy

10.5. Know the vocabulary of thermodynamic processes: isothermal, isobaric, isochoric, adiabatic, isentropic

10.6. Calculate work, heat an internal energy changes for isothermal, isobaric, isochoric and adiabatic processes

11. Heat Engines:

11.1. Definition of efficiency

11.2. Know that efficiency must be less than 100%

11.3. Calculate net work done by a heat engine cycle

11.4. Calculate net heat transferred during a heat engine cycle

11.5. Derive Carnot engine efficiency from P-V description

11.6. Derive efficiency of a given heat engine

11.7. Recognize that a real heat engine has less than the thermodynamically defined efficiency and performance is based on external factors

12. Entropy and the 2nd law of thermodynamics

12.1. Know that perpetual motions machines are non-physical (somewhere, energy is being added)

12.2. Identify what is the thermodynamic system

12.3. Definition of the 2nd law: The entropy of a closed system cannot decrease

12.4. Know the mathematical definition of entropy (relation to heat and temperature)

12.5. Recognize that entropy is related to the degree of disorder of matter

12.6. Recognize that entropy is a thermodynamic state variable

12.7. Relate changes in entropy to reversibility

12.8. Calculate changes in entropy for reversible processes

12.9. Relate the area under a process curve in S-T representation to the change in entropy

12.10. Derive Carnot engine efficiency from S-T description

Content level goals: Simple Harmonic Motion

1. Simple Harmonic Oscillator:

1. Students should be able to recognize when a motion can be approximated by the motion of simple harmonic oscillator:
   (a) by noticing sinusoidal character of the time dependence of position, velocity, or acceleration
   (b) by noticing that restoring force is proportional and opposite to displacement (at least in some range)
   (c) by noticing that the restoring torque is proportional and opposite to the rotation angle
2. Given the time dependence of <u>one</u> of the following:
   (a) position
   (b) velocity
   (c) acceleration
   Students, should be able to find the time dependence of the other two quantities.
3. Given the time dependence for position, or velocity, or acceleration, students should be able to extract the following parameters of oscillation: frequency, period, amplitude and phase.
   Be able to describe how the parameters of the Simple Harmonic Oscillator (SHO) depend of the mass of the oscillating object **and** characteristic of restoring force (e.g. elastic force, force of gravity, buoyant force, etc)
4. Be able to perform simple experiments to characterize the restoring force and find parameters of the SHO
5. Be able to draw free body diagram for the oscillating object at any point of its trajectory and infer its corresponding time dependence for the acceleration (or velocity and position)
6. Be able to properly identify the restoring force for the vertical spring oscillator and calculate the corresponding parameters of oscillations
7. Be able to recognize when the vertical motion of a real oscillating object can be approximated by a vertical simple harmonic oscillator and find the corresponding parameters of oscillation

2. Simple pendulum:

1. Be able to calculate the restoring force for the simple pendulum and using appropriate approximations, show that is can be treated as a simple harmonic oscillator for small angular displacement
2. Be able to recognize when the angular motion of a real object can be modeled as a simple *physical* pendulum

3. Energy of a simple harmonic oscillator:

1. Be able to calculate the potential and kinetic energy at any point of the trajectory of an object undergoing SHM

2. Be able to describe that while the total mechanical energy of a SHO is constant, the energy of a SHO is constantly changing from potential to kinetic and vice versa

4. Damped oscillations

1. Be able to recognize when the motion of the real physical object can be described as a damped harmonic oscillator given:
   (a) the plot for position, or velocity, or acceleration
   (b) the mathematical expression for position, or velocity, or acceleration

2. Be able to infer all the descriptive parameters of the damped motion (γ, ω, etc) given:
   (a) the plot for position, or velocity, or acceleration
   (b) the mathematical expression for position, or velocity, or acceleration

3. Be able to infer from the graph or parameters of the motion if it is: underdamped, critically damped, or overdamped.
4. Be able to describe the motion (mathematically) of a real object undergoing damped oscillation
5. Be able to calculate the potential and kinetic energy at any point of the trajectory of an object undergoing damped oscillation
6. Be able to calculate the Q factor and relate its value to the characteristic behavior of the damped oscillator

5. Driven oscillators:

1. Be able to recognize and describe the motion of a real physical object undergoing driven oscillations
2. Be able to describe how the driven motion depends on the frequency of the driving force and the Q factor of the oscillator

Content level goals: WAVES

1. Wave definitions: Students should know the (definitions of the) parameters describing waves: wavelength, wave vector, frequency, period, phase, speed, intensity, energy, power
   1.1. Be able to estimate or calculate these parameters from graph
   1.2. Be able to estimate or calculate these parameters from mathematical descriptions (formulas) or description
   1.3. Be able to estimate or calculate these parameters from photographs or movies
2. Sound waves:
   2.1. Be able to describe in words how sound waves propagate through air
   2.2. Know the decibel (db) scale for sound intensity
   2.3. Be able to convert from db to W/m^2 and vice versa
   2.4. Be able to calculate the dependence of sound intensity on the distance from the source
3. Mechanical waves:
   3.1. Be able to identify the parameters defining the speed of mechanical wave
   3.2. Be able to calculate the speed of mechanical waves in various situations, e.g., inside a rod, in gas, along a string of varying density, etc.
4. Energy and Power in waves:
   4.1. Be able to explain how a wave can carry energy and power
   4.2. Be able to calculate the energy and power that a wave carries
5. Superposition of waves:
   5.1. Be able to describe AND predict quantitatively what happens when two waves (spatially) overlap
   5.2. Be able to calculate the result of superposition of waves
   5.3. Be able to distinguish between a propagating and standing wave based on the characteristics
6. Standing waves and musical instruments:
   6.1. Be able to calculate the parameters of a standing wave
   6.2. Be able to correlate the parameters of the mechanical waves like amplitude and frequency with the once generally used in acoustics like volume and pitch
   6.3. Be able to describe (comparatively) the situations which lead to the standing waves in bars, strings or air columns
   6.4. Be able to calculate the wavelength and frequencies corresponding to standing waves in bars, strings, and air columns
   6.5. Be able to recognize which situations lead to standing waves in bars, strings, and air columns
7. Beats:
   7.1. Be able to recognize the situations which lead to the observation of beats
   7.2. When two sound waves of different frequencies are combined students should be able to calculate the beat frequency of two waves.

7.3. Be able to calculate oscillation frequencies and from there calculate the beat frequency.

8. Doppler Effect

8.1. Be able to describe and calculate how the frequency of the wave reaching a recever depends on the velocity of the source and the receiver

8.1.1. for sound waves

8.1.2. for electromagnetic waves

9. Interference

9.1. Be able to quantitevely predict and calculate the wave patterns resulting from wave interference

Electricity and Magnetism + Wave Optics

Term 2 Week 1 Waves and Optics
Term 2 Week 2 Waves and Optics
Term 2 Week 3 Review of resistance, circuits, Emf and batteries, circuit analysis.
Term 2 Week 4 RC circuit analysis.
Term 2 Week 5 Inductors, LR, LCR circuits.
Term 2 Week 6 Alternating circuit analysis. LCR circuits.
Term 2 Week 7 Review electric force and fields, Gauss's law
Term 2 Week 8 Gauss's law and electric flux. Electric potential.
Term 2 Week 9 Electric potential (continued), calculate electric field from potential, capacitors.
Term 2 Week 10 Magnetic field, Lorentz force, and Cyclotron motion.
Term 2 Week 11 Biot–Savart law and Ampere's law.
Term 2 Week 12 Faraday's law.
Term 2 Week 13 Maxwell's equations, Electromagnetic waves.

Week	TOPICS	LEARNING GOALS Students should be able to ...	TEXT Young / Freed man
1	Beats Standing waves (for Electromagnetism)	• Intensity and Power of Mechanical and non-mechanical waves • Examples of beats and standing waves • Superposition to create standing waves.	
2	Interference (for Electromagnetism) Thin film	• Phase differences and path differences • Phase shifts for reflected waves • Refractive index • Double slits, multiple slits, soap bubbles	
3	DC Circuits, Real Batteries, Kirchoff's Laws.	• distinguish terminal voltage from emf and relate it to the internal resistance of a battery use Ohm's Law to relate current through a resistor to the potential difference across it • determine the equivalent resistance for combinations of resistors and apply Kirchoff's laws to multiple loop circuits • describe energy transfer in a circuit and calculate the power dissipated	

4	Capacitors and Energy stored in Capacitors RC circuit analysis Capacitors circuits. RC Time Constant and RC circuits with multiple branches.	• determine the equivalent capacitance for combinations of capacitors • determine the energy stored in a capacitor • predict the time dependence of current, charge and potential difference for charging and discharging in an RC circuit. • calculate the time constant for multiple branch RC circuits, and explain what it represents • determine the energy stored for inductor • predict the time dependence of current, charge and potential difference for charging and discharging in an LR circuit. • calculate the time constant for multiple branch LR circuits, and explain what it represents • understand multiple branch LRC circuits, and explain their behavior	
5	Inductors, LRC circuits with supplies DC.	• determine the energy stored for inductor • predict the time dependence of current, charge and potential difference for charging and discharging in an LR circuit. • calculate the time constant for multiple branch LR circuits, and explain what it represents • understand multiple branch LRC circuits, and explain their behavior	

6	AC circuits. Multiple branch RLC ciruits.	• understand resistance, reactance and impedance • basic filters • analyze multiple branch *RLC* circuit and describe how a circuit works • predict the time dependence of current and voltage across componets in AC and DC circuits	
7	Coulomb's Law and Electric fields (chap. 21) overall goals: use Coulomb's law to calculate electric field for point and continuous charge distributions understand and describe an electric field	• list the steps for charging by inductance • recognize all the components of Coulomb's law and be able to use it to calculate the electric force between multiple charges • know the relationship between an electric field and an electric force • draw electric field vectors and lines • understand the principle of superposition • form the integrals for calculating the electric field using Coulomb's law, and recognize helpful symmetries e.g., line finite and infinite, ring, infinite plane, finite disk ... • calculate the torque and describe the motion of a dipole molecule in an electric field	21.1 21.2 21.3 21.4 21.4/6 21.5 21.5 21.7

8	Gauss's Law (chap. 22) overall goal: understand electric flux for closed and non-closed surfaces use Gauss's Law to determine the electric field produced by various charge distributions recognize the symmetry of problems and determine applying Gauss vs Coulomb law	• understand the concepts of electric flux, the net flow direction, and enclosed charge, and electric field on a surface • calculate the electric flux through different surfaces • recognize the importance of the directions of the and E- vectors • identify the mathematical difference between the expression for flux of a uniform and non-uniform field • understand all components of Gauss's Law • chose an appropriate Gaussian surface depending on symmetry • apply Gauss's law to various charge distributions, e.g., line, sphere, infinite plane, etc. • identify when to use Gauss's Law and when to use Coulomb's Law • describe the distribution of charge on a conductor • describe the electric field for different areas of a coaxial cable • Calculate edge effects using magnetic energy arguments	22.1 22.2 22.3/ 22.4 22.4 22.5

9	Electric Potential (chap. 23) overall goal: understand and calculate the electric potential energy for various charge distributions understanding equipotential surfaces using the potential gradient to calculate the electric field go between potential, potential energy, force, and electric field quantities	• understand what an electric potential energy is for multiple charges systems • realize the connection between work and electric potential energy; compare the force of gravity with the electric force • define and calculate the electric potential (V); mathematically set up the potential for a single point charge, multiple point charges, and a continuous charge distribution • differentiate between the properties of the electric field and the electric potential, particularly in a conductor • graphically express the electric potential • visualize the electric potential by equipotential surfaces • to calculate the electric field from the electric potential gradient, and recognize when this is the best approach • identify the relationships between potential, potential energy, force, and electric field quantities • Calculate edge effects using electric field energy arguments	23.1 23.2/ 23.3 23.3 23.4 23.5
10	Sources of Magnetic Fields Biot–Savart law	• Magnetic Field • Gauss' law for Magnetic Field • Lorentz Force, application to cyclotron, force on wire. • use Biot–Savart law to calculate magnetic field of short wire, loop, solenoids	
11	Ampere's Law	• Ampere's Law for geometries of high symmetry • sketch the magnetic fields due to permanent magnets and current loops using Biot–Savart law and superposition of magnetic fields. • Calculate edge effects using magnetic field energy arguments	

12	Faraday's law Maxwell's Equations	• How Lenz's Law and Eddy Currents are a consequence of Faraday's law. • Applications of Faraday's law to electromagnetic braking and energy production. • Show how displacement current leads to Maxwell's equations • Geometric optics and Maxwell's equations	
13	Electric and Magnetic fields interact with matter. Maxwell's Equations, Electromagnetic Waves.	• Describe radiation pressure • Explain how electric and magnetic fields are interdependent and give examples of how they can exist without source charges or currents	

PHYS 153 Learning Goals for lab

The PHYS 153 lab will help you to recognize that science and engineering are not simply a static body of concepts and mathematics, but rather are fundamentally based on empirical observation and experimentation. The motivation for this lab course is not only to reinforce what is taught in lectures and tutorials, but also to leave you with the skills and attitudes that will be of value to you as an engineer.

Over the course of this lab, you will learn to make physical measurements and to use the measurement results in conjunction with relevant theoretical model equations to deduce important system parameters. You will gain an appreciation for various sources of uncertainty in individual measurements, and the quantities that are derived from combining a number of independent measurements. When extracting a final estimate for a system parameter from a given experiment, you will become able to distinguish between the uncertainties arising from measurements and the fundamental limitations of a given apparatus (compared to the idealized behaviour the apparatus is meant to mimic).

You will also learn a variety of technical skills including: the use of particular equipment; fitting measured data sets with model equations; keeping thorough laboratory notes; a variety of computer skills and statistical methods; and, the ability to communicate results and ideas.

These broad, course-level learning goals will be achieved by working through worksheets and on three relatively simple experiments (isothermal compression, acoustic waves, and RC circuits) that deal with concepts covered in the PHYS 153 lectures.

Designing an Experimental Procedure

Through examples, you will first learn the generic approach to determining what measurements need to be made, and what data manipulations are required in order to empirically determine some unknown quantity.

Making Measurements

You will learn how to take measurements. Taking measurements properly involves a range of skills and attitudes, beyond simply learning how to use specific equipment and follow basic procedures. The emphasis will be on the most broadly applicable skills.

Statistics and Data

You will learn some of the basic statistical treatments of data. This includes understanding how and when to apply certain calculations, and also the development of your ability to make evaluations of your data based on these calculations.

Relating Data to Model Equations

You will also learn an essential step in the association of empirical measurements with theory. This includes building an awareness of how data sets can differ from one another, the acquisition of some technical skills, and the ability to make connections between discrete data and mathematical functions.

Higher level skills and attitudes

Finally, you will develop some beneficial habits of the mind. These are meta-skills that might be considered the next level in your ability to handle an experiment.