# Physics 2425 Principles of Physics I

## Instructor

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## Course Description

### Content

Fundamental principles of physics, using calculus, for science, computer science, and engineering majors; the principles and applications of classical mechanics, including harmonic motion, physical systems and thermodynamics; experimental design, data collection and analysis, and preparation of laboratory reports; with emphasis on problem solving.

### Prerequisites

Completion of MATH 2413 - Calculus I is required before taking Physics 2425.

### Textbook

The textbook is *Matter & Interactions, 4th edition* by R. Chabay and B. Sherwood (John Wiley & Sons, 2015). Textbook Errata are at http://matterandinteractions.org/errata/.

### Course Overview

In this course we will be examining the nature of matter and its interactions. The variety of phenomena that we will be able to explain and understand is very wide, ranging from the orbit of a planet to the speed of sound in a solid. The ***main goal*** of the course is to have you engage in a process central to science: ***modeling a broad range of physical phenomena using a small set of powerful fundamental principles***.

### Approach

The course will emphasize rigorous problem-solving in physics using a student-centered active learning environment. Class sessions will require students to be responsive, to think, and to perform hands-on tasks. Key concepts of new material will be discussed in short lectures. Lab time will be interspersed with classroom discussion. If you devote a sufficient amount of time each day to studying physics, you will be in a position to attack physics problems efficiently, based on a clear understanding of the fundamental physical principles that underlie all successful analyses.

### Collaborative Work

This course encourages collaborative teamwork, a skill that is valued by most employers. As you study together, help your partners to get over confusions, ask each other questions, and critique each other's homework write-ups. Teach each other! You can learn a great deal by teaching. But remember that you are responsible for understanding all details of a problem solution.

### Study requirements

In addition to your time in class each week, you are expected to spend about 10 hours studying outside of class. If you typically spend less than 8 hours in outside study, you are unlikely to be able to learn the material. Less well prepared students may find they need to spend even more time than this. If you typically spend more than 12 hours in outside study, it is extremely important that you consult with me about ways to study more efficiently.

It is important to keep up with the class. New concepts introduced in this course build on earlier ones, so mastering key concepts is critical. If you get behind, seek help right away!

### Attendance policy

Attendance and effort are vital to success in this course. Class attendance keeps you well connected to the course, so that you know at all times what's going on, what are the most important points, etc., and gives you opportunities to ask questions and clear up confusions. Therefore, students are expected to be in attendance for every class session. However, everybody gets sick, has some emergency, needs to care for a friend or family member or similar stuff now and then. Therefore, all students will be allowed two excused absences, no documentation required. The third and fourth absences will be unexcused and after a fifth absence you will be dropped from the class. If you stop attending class and wish to avoid an "F" you must obtain an official drop form, have it signed, and take the completed form to the registrar's office before your fifth absence. See the current class schedule for the last day you can drop a class.

## Assignments

### WebAssign

Homework and reading assignments will be delivered and graded on WebAssign, a web-based homework system. WebAssign provides immediate feedback on the correctness of your answers and allows you to make another attempt on problems you initially miss. WebAssign access codes come packaged with a new textbook if purchased from the SPC bookstore or can be purchased online.

### Readings

A key component of the course is the textbook, in which you are asked to analyze phenomena, to work out small examples, to make some of the steps in derivations, etc. *Class discussion will not cover all of the assigned material; it is essential that you study the textbook carefully.* You should work all the checkpoint questions in each reading assignment and seek help on any that give you difficulty.

Class sessions will be devoted to *discussion* of ideas, clarifying points of confusion, and activities of various kinds that allow you to practice using the concepts you have read about in the text. The text thus provides the *background* for these activities. *Therefore, it is essential to read the appropriate sections in the textbook BEFORE coming to class.* Your time in class will be largely ineffective if you have not studied the appropriate text sections prior to coming to class.

A reading assignment will be due in WebAssign before the start of each class session.

### Homework

A WebAssign homework assignment will be due each week. For most problems in these assignments, you are allowed two free submissions per question part and a third submission that, if used, will incur a 25% penalty to your score on that part. It is therefore extremely important that you work each problem carefully on paper, in great detail, before submitting your answers. This practice is vital to learning the material and will also help you when reviewing the assignments before a test. Therefore, each student will maintain a portfolio of solved WebAssign problems. The portfolio should be maintained in a three ring binder and each problem should begin on a new sheet of loose leaf paper – no paper torn from a spiral notebook. After the assignment due date, some problems will be selected for detailed grading and the student will remove these selected problems from their portfolio and turn them in. Writing solutions provides practice in communicating your thinking process in a clear and precise way. Engineers (as well as professionals in other technical areas) actually spend a good amount of time working to communicate their ideas in a way that is comprehensible to others. Being able to write clearly is an important skill for an engineer. You will also find that writing good explanations of your thinking process will improve your understanding of the physics concepts you are studying. Communicating your thinking process on paper will require writing sentences and paragraphs in addition to equations and formulas. A well written solution will include verbal explanation stating what physics principles are used, appropriate well-labeled diagrams, symbolic solution before numerical values are substituted, and correct numerical result with correct number of significant figures and correct units. Students whose work is excessively messy or difficult to read may be required to produce typed solutions using a good word-processing package such as Microsoft Word or LaTeX.

### Getting help with assignments

You should ask lots of questions in class to clear up any initial confusion you might have about a topic. I also encourage you to avail yourself of my help during office hours. You do not have to wait for my official office hours to get help; anytime I am in my office you are always welcome to come get help. If you fall behind for any reason, please let me know as soon as possible. The sooner I know about these situations, the better I can help you make up work. I will do what I can to help you complete the course satisfactorily.

## Laboratory

During lab you will typically work in groups of three students on the following three kinds of activities:

- Experiments, involving measurement and analysis of data according to fundamental principles.
- Computer modeling, involving constructing 3-D models of physical systems and their motion. This will involve the VPython programming language. No previous programming experience is needed – I will teach you the basic concepts needed. Some computer modeling activities may need to be finished outside of class.
- Group problem solving, involving work on large, complex problems. In lab you may begin work on a large problem to be completed outside class or the entire problem may be solved during class.

You must attend class during the day the lab is done in order to receive credit. If you have an excused absence, you will be excused from the lab you missed, and your lab average will be taken from your remaining labs. If you miss a lab, you should work with your classmates to be sure you understand the missed lab activities since these will be covered on tests.

## Tests

### Tests

Three tests will be given as shown on the course calendar. Each test (except test 1) will consist of two parts. The first part will cover the new material. The second part will be an optional chance to show improvement in your understanding of the material from the previous test. This optional part can be used to improve your previous test grade. These tests will be closed-book, but some relevant formulas and constants will be provided. If you have an excused absence, you will need to contact me to make up the missed test.

### Final exam

A comprehensive final exam will cover all of the course material. The final exam will be closed-book, but some relevant formulas and constants will be provided. It will be given during the scheduled final exam time as shown in the schedule of classes and on the course calendar.

## Grade calculation

Your final grade will be assigned based on your overall, weighted class average using the weighting scheme shown below:

| Weighting Scheme | | |
|---|---|---|
| Task | Code | Weight |
| Reading | R | 10% |
| Homework | H | 15% |
| Lab | L | 15% |
| Tests | T | 36% |
| Final | F | 24% |

The letter grades will be based on a fixed scale as follows:

A: 89.5 – 100    B: 79.5 – 89.5    C: 69.5 – 79.5    D: 59.5 – 69.5    F: below 59.5

If everyone in the class does well, grades are not curved downward. Everyone can get an A. There usually is a "gray area" between two letter grades for borderline cases (grades within 0.5 points of the break point). Earning the higher grade in these cases depends on your interactions in class and whether your test and homework performance shows improvement during the course of the semester.

## Miscellaneous information

In this class, the teacher will establish and support an environment that values and nurtures individual and group differences and encourages engagement and interaction. Understanding and respecting multiple experiences and perspectives will serve to challenge and stimulate all of us to learn about others, about the larger world and about ourselves. By promoting diversity and intellectual exchange, we will not only mirror society as it is, but also model society as it should and can be.

Students with disabilities, including but not limited to physical, psychiatric, or learning disabilities, who wish to request accommodations in this class should notify the Disability Services Office early in the semester so that the appropriate arrangements may be made. In accordance with federal law, a student requesting accommodations must provide acceptable documentation of his/her disability to the Disability Services Office. For more information, call or visit the Disability Services Office at Levelland (Student Health & Wellness Office) 806-716-2577, Reese Center (Building 8) & Lubbock Center 806-716-4675, or Plainview Center (Main Office) 806-716-4302 or 806-296-9611.

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Note to students with disabilities: If you have a disability-related need for reasonable academic adjustments in this course, provide the instructor with a letter of accommodation from the Disability Services Office. If you need immediate accommodations or physical access, please arrange to meet with the Disability Services Office before the next class meeting.

## Core Objectives Addressed in this course:

**Communication skills -** to include effective written, oral, and visual communication

**Critical Thinking skills -** to include creative thinking, innovation, inquiry and analysis, evaluation and synthesis of information

**Empirical and Quantitative skills -** to include the manipulation and analysis of numerical data or observable facts resulting in informed conclusions

**Teamwork skills -** to include the ability to consider different points of view and to work effectively with others to support a shared purpose or goal

## Broad Course Objectives

Learning objectives students should achieve after one year of introductory physics are listed below.

1. Students should develop a good functional understanding of physics.
   They should be able to:
   a. describe and explain physics concepts including knowing where and when they apply.
   b. apply physics concepts when solving problems and examining physical phenomena.
   c. apply concepts in new contexts (transfer).
   d. translate between multiple-representations of the same concept (for example: between words, equations, graphs, and diagrams).
   e. combine concepts when analyzing a situation.
   f. evaluate explanations of physical phenomena.

2. Students should begin developing expert-like problem solving skills.
   They should be able to:
   a. apply a small set of fundamental physical principles to a wide variety of physical situations.
   b. use these principles to satisfactorily solve standard textbook problems.
   c. model complicated physical systems by making approximations and idealizations in order to be able to apply fundamental principles.
   d. solve more challenging problems, including: context-rich ("Real World") problems, estimation problems, multi-step problems, multi-concept problems, problems requiring qualitative reasoning.
   e. evaluate other people's written solutions and solution plans.

3. Students should develop laboratory skills.
   They should be able to:
   a. interact (set up, calibrate, set zero, determine uncertainty, etc.) with an apparatus and make measurements.
   b. explain the physical principles underlying the operation of the apparatus, measurements, physical situation being studied and analysis of data.
   c. design, execute, analyze, and explain a scientific experiment to test a hypothesis.
   d. evaluate someone else's experimental design.

4. Students should develop technology skills.
   They should be able to:
   a. create simple computer models of physical situations.
   b. utilize a spreadsheet to graph and do curve fitting.
   c. find information on the web.
   d. use microcomputer, video, and web-based software and hardware for data collection and analysis.

5. Students should improve their communication, interpersonal, and questioning skills.
   They should be able to:
   a. express understanding in written and oral forms by explaining their reasoning to peers.
   b. demonstrate their knowledge and understanding of physics in written assignments.
   c. discuss experimental observations and findings.
   d. present a well-reasoned argument supported by observations and physical evidence.
   e. evaluate oral arguments, both their own and those espoused by others.
   f. function well in a group.
   g. evaluate the functioning of their group.

6. Students should retain and/or develop student cognitive attitudes and beliefs (expectations) that are favorable for learning physics with deep understanding.
   They should:
   a. believe that understanding physics means understanding the underlying concepts and principles instead of focusing on knowing and using equations.
   b. see physics as a coherent framework of ideas that can be used to understand many different physical situations.
   c. see what they are learning in the classroom as useful and strongly connected to the real world.
   d. be cognizant of the scientific process/approach and how to apply it.
   e. indicate a willingness to continue learning about physics and its applications.
   f. see themselves as part of a classroom community of learners.

## Physics 2425 Student Learning Objectives

Your success in the class is determined to a large extent by you being able to do the tasks shown below. You are responsible for all these outcomes, even those not discussed in class. It is your responsibility to ask someone (a classmate or the instructor) if you have questions.

1. Chapter 1 – Interactions and Motion
    - 1.1. I can give a brief overview of the structure of an atom. [1.1]
    - 1.2. I can recall and state the approximate radius of an atom and the approximate radius of a nucleus. [1.1]
    - 1.3. I can give a general overview of the atomic structure of solids, liquids, and gases. [1.1]
    - 1.4. I can explain the point particle model and use it when appropriate in problem solving. [1.1]
    - 1.5. I can identify when an object's motion indicates it is interacting with other objects and when its motion indicates no net interactions (Newton's 1$^{st}$ Law). [1.2 – 1.3]
    - 1.6. I can provide examples of physical quantities that are vectors and that are not vectors. [1.4]
    - 1.7. I properly use vector notation in all my problem solving. [1.4]
    - 1.8. I can perform all the vector mathematics discussed in section 1.4. [1.4]
    - 1.9. I can list the SI base units for mass, length, time, and charge. [1.5]
    - 1.10. I can make units conversions given the necessary conversion factors. [1.5]
    - 1.11. I can recall the definitions of average velocity and instantaneous velocity. [1.6,1.7]
    - 1.12. I can use the position update equation in problem solving. [1.7]
    - 1.13. I can use calculus to transform between position, velocity, and acceleration functions. [1.7]
    - 1.14. I can calculate the momentum of a particle at all speeds, using the nonrelativistic approximation when appropriate. [1.8, 1.10]
    - 1.15. I can draw an arrow to represent the momentum (or velocity) of an object at a specified location along its trajectory. [1.8]
    - 1.16. I can find the change in momentum of a particle both graphically and algebraically. [1.8]
    - 1.17. I can use an object's momentum together with the position update equation in problem solving. [1.9,1.10]
    - 1.18. I can state the default location of the origin and orientation of the Cartesian coordinate system in VPython. [1.11]
    - 1.19. I can translate the position update equation into VPython syntax. [1.11]
    - 1.20. I can explain the purpose of the "rate" statement in a VPython "while" loop. [1.11]
2. Chapter 2 – The Momentum Principle
    - 2.1. I clearly specify the system and surroundings for every problem I work. [2.1]
    - 2.2. I can state the momentum principle (Newton's 2$^{nd}$ Law) from memory, explain why it's a fundamental principle, and give the meaning of each term in the equation. [2.1]
    - 2.3. I can use the momentum principle to model situations involving large forces acting for short time intervals, estimating the magnitudes of the forces involved and/or the duration of the interaction. [2.2]
    - 2.4. I can use the momentum principle to reason qualitatively about the future motion of an object. [2.3]
    - 2.5. I can calculate the gravitational force the Earth exerts on an object near its surface. [2.4]
    - 2.6. I can use the momentum principle to iteratively predict the future motion of a particle experiencing a constant net force. [2.4]
    - 2.7. I can use the momentum principle to analytically predict the future motion of a particle experiencing a constant net force. [2.5]
    - 2.8. I can produce and interpret graphs of the position and velocity components vs. time for the special case of constant net force. [2.5]
    - 2.9. I can calculate the force a spring exerts on an object. [2.6]
    - 2.10. I can use the momentum principle to iteratively predict the future motion of a particle experiencing a varying net force. [2.6]
    - 2.11. I can explain why it is generally necessary to use numerical integration to predict the motion of an object. [2.6]
    - 2.12. I can give the necessary steps in the proper order to iteratively compute the motion of an object subject to a varying net force. [2.7]
    - 2.13. I can translate the momentum principle into appropriate VPython syntax. [2.7]
    - 2.14. I can translate the calculation of gravitational force near the earth's surface and the calculation of the spring force into VPython syntax. [2.7]
    - 2.15. I can write a VPython program to predict and display the motion of an object, such as a projectile with no air resistance, a fan cart on a track, or a block oscillating on a spring. [2.7]
3. Chapter 3 – The Fundamental Interactions
    - 3.1. I can specify the four fundamental types of interactions and give examples of each. [3.1, 3.8, 3.9]
    - 3.2. I can calculate the gravitational force exerted by one object on another. [3.2]
    - 3.3. I can calculate the approximate gravitational field strength at the surface of an astronomical object from the gravitational force law. [3.3]

3.4. I understand and can apply the property of reciprocity (Newton's 3rd Law) to forces between two objects carefully keeping track of the appropriate objects and forces. [3.4]
3.5. I can iteratively apply the momentum principle to predict the motion of gravitationally interacting objects. [3.5]
3.6. I can explain qualitatively when and why an object is speeding up or slowing down in an elliptical orbit, basing my discussion on the momentum principle. [3.5]
3.7. I can translate the calculation of the gravitational force into VPython syntax. [3.6]
3.8. I can write a VPython program to predict and display the motion of gravitationally interacting objects. [3.6]
3.9. I can calculate the electrical force exerted by one charged particle on another charged particle. [3.7]
3.10. I can explain what is meant by saying that momentum is a conserved quantity. [3.10]
3.11. I can calculate the total momentum of a system and relate it to the system's center-of-mass velocity. [3.10, 3.11]
3.12. I can use conservation of momentum to solve problems involving transfer of momentum between a system and its surroundings. [3.10, 3.12]
3.13. I can use conservation of momentum to solve problems involving an isolated system. [3.10, 3.12]
3.14. I can explain why only external forces must be included in the net force when applying the momentum principle to a multiparticle system. [3.11]
3.15. I can determine the center-of-mass of a multiparticle system. [3.11]
3.16. I can explain some of the limitations of the Newtonian Synthesis that arise with large multiparticle systems and that arise due to quantum mechanical effects. [3.13 – 3.15]

4. Chapter 4 – Contact Interactions
4.1. I can describe the features of the ball-spring model of a solid and enumerate the properties of atoms and the interatomic bond that suggest this is a good way to model a solid. [4.2]
4.2. I can explain qualitatively, in terms of a ball-spring model, how a solid can exert contact forces such as tension, friction, and normal forces. [4.1, 4.2, 4.3, 4.7, 4.8]
4.3. I can use a simple ball-spring model to determine the approximate length of an interatomic bond in a solid. [4.4]
4.4. I can determine the stiffness of various combinations of springs in terms of the stiffness of the individual springs. [4.5]
4.5. I can use the ball-spring model to determine the interatomic bond stiffness for a solid. [4.5, 4.6]
4.6. I can define stress and strain and relate them to Young's Modulus. I can use stress, strain, and Young's Modulus in problem solving. [4.6]
4.7. I can use appropriate measurements to determine Young's modulus for some material and then use the value of Young's modulus to determine the interatomic bond stiffness. [4.6]
4.8. I can apply the friction model in problem solving. [4.8]
4.9. I can describe what is meant by sound propagation in a solid using the ball-spring model. [4.9]
4.10. I can describe how to use an iterative scheme with the ball-spring model to determine the speed of sound in a solid. [4.9]
4.11. I can state the momentum principle in the derivative (or instantaneous) form and connect it to the previous update form, explaining the conditions for the update form to be valid. [4.10]
4.12. I can graphically find the rate of change of momentum at a given instant in an object's motion. [4.10]
4.13. I can connect the direction of the net force to the direction of the rate of change of the momentum and give examples illustrating that connection. [4.10]
4.14. Starting from the momentum principle, I can derive the differential equation that governs the motion of a simple harmonic oscillator. [4.11]
4.15. I can explain why a sinusoidal function is a reasonable guess as a solution to the differential equation for a simple harmonic oscillator. [4.11]
4.16. I can demonstrate that an appropriate sinusoidal function is a solution to the differential equation for a simple harmonic oscillator and determine how the angular frequency depends on the parameters of the oscillator. [4.11]
4.17. I can calculate the angular frequency, frequency, and period of a simple harmonic oscillator from the appropriate parameters of the oscillator. [4.11]
4.18. I can compare analytical and iterative solutions to the spring-mass oscillator, discussing advantages and limitations of each. [4.12]
4.19. I can calculate the speed of sound in a solid from the interatomic bond stiffness, interatomic spacing, and mass of the atom. [4.13]
4.20. I can explain pressure and buoyancy qualitatively in terms of molecular collisions. [4.14]
4.21. I can calculate the buoyant force on an object submersed in a fluid. [4.14]
4.22. I can calculate the force acting on a surface from the pressure of the surrounding fluid and the area of the surface. [4.14]

5. Chapter 5 – Determining Forces from Motion
5.1. I can divide the universe into a desired system and its surroundings, identify the forces acting on the system, and draw a correct free-body diagram for the system. [5.2]
5.2. I can use the momentum principle to find one or more unknown forces acting on an object in equilibrium. [5.3, 5.4]
5.3. I can use the momentum principle to find one or more unknown forces acting among multiple objects inside a system whose momentum may be changing. [5.5]
5.4. I can discuss when a net force acting on an object will result in a change in direction of motion. [5.6]
5.5. I can discuss qualitatively the factors that affect the curvature of the object's path. [5.6]

5.6. I can calculate the dot product of two vectors and can use the dot product to find the parts of the net force parallel and perpendicular to the momentum. [5.6]
5.7. I can translate the calculation of the parallel and perpendicular parts of the net force into VPython syntax. [5.6]
5.8. I can have VPython calculate and display the components of the net force acting parallel and perpendicular to the momentum of a moving object. [5.6]
5.9. I can use the product rule for derivatives to write the rate of change of momentum in two parts, one parallel to the momentum and one perpendicular to the momentum. [5.7]
5.10. I can split the derivative form of the momentum principle into two parts, parallel to and perpendicular to the momentum. [5.7]
5.11. I can calculate the magnitude of the rate of change of the momentum's direction in terms of instantaneous speed and kissing circle radius. [5.7]
5.12. I can determine the direction of the rate of change of the momentum at a turning point in an object's motion. [5.7]
5.13. I can apply the derivative form of the momentum principle using the parallel and perpendicular parts in problem solving. [5.7 – 5.10]
5.14. I can correctly explain the kinesthetic sensations and perceptions (including the sensation of weight or weightlessness) that often accompany curving motion by applying the momentum principle using an inertial reference frame. [5.9]

6. Chapter 6 – The Energy Principle
   6.1. I can explain what is meant by saying that energy is a conserved quantity. [6.1]
   6.2. I can state the energy principle from memory, explain why it's a fundamental principle, and give the meaning of each term in the equation. [6.1]
   6.3. I can calculate the total energy, rest energy, and kinetic energy of a particle at all speeds, using the nonrelativistic approximation for the kinetic energy when appropriate. [6.2]
   6.4. I can relate a particle's relativistic energy and momentum to its rest mass and use the equation in problem solving. [6.2]
   6.5. From a problem statement, I can create a diagram showing vector arrows for displacement and force, clearly indicating initial and final states and I can determine if the work done will be negative, positive, or zero. [6.3]
   6.6. I can identify cases when a force does zero work because the force remains perpendicular to the momentum or because no displacement occurs. [6.3]
   6.7. I can calculate the work done by both constant and nonconstant forces. [6.3]
   6.8. I can state the energy principle in both the difference form and update form from memory and use it to solve problems involving single particle systems. [6.4]
   6.9. I can apply the energy principle to solve problems involving a change in rest energy. [6.5]
   6.10. I can calculate the change in potential energy of a multiparticle system from the work done by the internal forces. [6.7, 6.8]
   6.11. I can find the component of a force along some direction from the negative gradient of the potential energy function in that direction. [6.8]
   6.12. I can determine the change in potential energy of the object/earth system when an object changes height near the earth's surface. [6.7]
   6.13. I can calculate the potential energy of two gravitationally interacting objects. [6.8]
   6.14. I can calculate the potential energy of two electrically interacting particles. [6.9]
   6.15. I can apply the energy principle to solve problems involving a multiparticle system. [6.7 – 6.10, 6.14]
   6.16. I can produce energy versus separation plots and use them to discuss conditions for a system to be either bound or unbound, to identify bound or unbound systems, and to identify limits on possible motion. [6.10]
   6.17. I can list the general properties that are true for potential energy and can deduce various consequences which result from these properties. [6.11]
   6.18. I can relate the mass of a multiparticle system to the masses of the constituent particles and the binding energy of the system and can solve problems involving changes in particle masses and binding energies. [6.12, 6.14]
   6.19. I can translate the calculation of energy quantities such as kinetic energy or potential energy into VPython syntax. [6.15]
   6.20. I can use VPython to calculate the energies of a system and plot energy versus time or energy versus separation graphs and use these graphs to check the accuracy of the computational model. [6.15]
7. Chapter 7 – Internal Energy
   7.1. I can calculate the potential energy of a stretched or compressed ideal spring. [7.2]
   7.2. I can draw a potential energy versus separation plot for a real spring and discuss how it differs from the potential energy of an ideal spring. [7.2]
   7.3. I can use the energy principle to solve problems which may include the potential energy of an ideal spring. [7.2]
   7.4. I can draw a graph of the Morse potential energy and draw conclusions from it about the interaction of two neutral atoms. [7.3]
   7.5. In the context of the ball-spring model for a solid, I can discuss why an ideal spring potential energy is a good approximation to the interatomic potential energy. [7.3]
   7.6. In the context of the ball-spring model for a solid, I can discuss the origin of the thermal energy of an extended object and can calculate changes in thermal energy corresponding to a temperature change. [7.4]

7.7. I can list various ways the internal energy of an extended multiparticle system can be classified, recognizing that fundamentally all the energy of a multiparticle system is due to rest energy, kinetic energy, and potential energy. [7.4]
7.8. I can describe qualitatively how a thermometer works and how an object's temperature correlates with its thermal energy. [7.4]
7.9. I can distinguish between thermal energy, temperature, and heat transfer. [7.5]
7.10. I can apply the energy principle in its most general form, including changes in internal energy of extended systems and transfers of energy by forces doing macroscopic work, transfers of energy due to temperature differences between the system and surroundings, as well as other energy transfer mechanisms. [7.5 – 7.10]
7.11. I can use power in solving problems with the energy principle. [7.6]
7.12. I can solve problems using the energy principle with differing choices of system and differing choices of reference frame. [7.8, 7.9]
7.13. I can use the momentum principle to qualitatively explain the motion of a falling object subject to a significant air resistance force. [7.10]
7.14. I can describe how air resistance depends on the density of the air, cross-sectional area of the moving object, and speed of the object and give a qualitative microscopic explanation for this behavior. [7.10]
7.15. I can translate expressions for air resistance, viscous friction, and sliding friction into VPython syntax and include these dissipative forces in computational models of motion. [7.11]

8. Chapter 8 – Energy Quantization
8.1. I can give the range of energies in eV for photons visible to the human eye and can describe in a general way the electromagnetic spectrum. [8.1]
8.2. I can calculate the electronic energy levels for a hydrogen atom and draw an energy level diagram for the hydrogen atom. [8.2]
8.3. I can describe emission and absorption processes and indicate them on an energy level diagram. [8.2]
8.4. I can apply the energy principle to solve problems involving emission or absorption of photons with corresponding changes in energy level as well as collisional excitation of atoms by electrons. [8.2]
8.5. I can calculate energies of photons in the emission or absorption spectrum given an energy level diagram. [8.2]
8.6. I can propose an energy level scheme for a system consistent with given observed energies of photons emitted from that excited system and use observed absorption spectrum data to distinguish between possible energy level schemes. [8.2]
8.7. I can describe in a qualitative way how temperature affects the fraction of atoms in a sample in the various possible energy states of the atom and the impact of this on the possibility of observing emission and/or absorption spectra. [8.3]
8.8. I can calculate the allowed energy levels for a quantum harmonic oscillator. [8.4]
8.9. I can describe in a qualitative way the energy band structure arising from the interplay of the electronic, vibrational, and rotational energies levels of a diatomic molecule. [8.5]
8.10. I can describe cases of other microscopic systems (nuclear, hadronic) that have discrete energy levels and can compare the typical energy level spacings of these various microscopic systems with the spacings of electronic, vibrational, and rotational energy levels in atomic and molecular systems. [8.6, 8.7]

9. Chapter 9 – Translational, Rotational, and Vibrational Energy
9.1. I can calculate the total kinetic energy, translational kinetic energy, and relative kinetic energy of a multiparticle system. [9.1]
9.2. I can calculate the gravitational potential energy of a system consisting of the earth and an extended object near the earth's surface. [9.1]
9.3. I can determine the moment of inertia for simple multiparticle systems. [9.2]
9.4. I can deduce the connection between the rotational speed of an extended rigid object and the linear speed of an atom located at some position in the object. [9.2]
9.5. I can calculate the rotational kinetic energy of an extended rigid object in terms of its moment of inertia and angular speed. [9.2]
9.6. I can use the energy principle to solve problems involving rotation (as well as perhaps translation) of an extended rigid object. [9.1, 9.2]
9.7. I can use integration to find the moment of inertia of an extended rigid object. [9.2]
9.8. I can use a point particle model of an extended object to apply the energy principle to the object. [9.3]
9.9. I can combine a point particle model and an extended object model in using the energy principle to solve problems involving deformable systems and complicated multiparticle systems. [9.3, 9.4]

10. Chapter 10 – Collisions
10.1. I can define what is meant by a collision and explain the conditions for the system's momentum and energy to be conserved during the collision. [10.1]
10.2. I can explain the difference between elastic and inelastic collisions. [10.2]
10.3. I can apply conservation of momentum and conservation of energy to 1D inelastic collisions. [10.3 – 10.4]
10.4. I can apply conservation of momentum and conservation of energy to 1D elastic collisions. [10.3 – 10.4]
10.5. I can use a change of reference frame in solving 1D collision problems. [10.5]
10.6. I can use conservation of momentum and conservation of energy to analyze scattering collisions, including collisions at relativistic momenta and energies. [10.6 – 10.11]

    10.7. I can discuss the Rutherford scattering experiment, highlighting the postulated atomic structure at the time and the unexpected and dramatic results that resulted in a new understanding of atomic structure. [10.7, 10.8]
    10.8. I can write a VPython program that models the interaction of two objects with both objects moving, such as in a collision between charged particles as in the Rutherford scattering experiment. [10.7, 10.9]
    10.9. I can use a change of reference frame in solving 2D collision problems. [10.12]
11. Chapter 11 – Angular Momentum
    11.1. I can calculate the translational angular momentum of a particle relative to a specified location. [11.1]
    11.2. I can find the direction of the angular velocity vector for a rotating rigid object. [11.2]
    11.3. I can find the rotational angular momentum of a rotating rigid object in terms of its moment of inertia and its angular velocity vector. [11.2]
    11.4. I can relate the total, translational, and rotational angular momentum of a system to the translational motion of the system's center of mass and the motion of the system particles relative to the center of mass. [11.3]
    11.5. I can calculate the total angular momentum of a rotating and translating object or multiparticle system. [11.3]
    11.6. I can calculate the torque produced by a force relative to a specified location. [11.4]
    11.7. I can state the angular momentum principle from memory in the update form, derivative form, and conservation form as it applies to single particles as well as multiparticle systems.[11.5, 11.6]
    11.8. I can explain why only torques caused by external forces must be included in the net torque when applying the angular momentum principle to a multiparticle system. [11.6]
    11.9. I can use conservation of angular momentum to determine changes in rotational speed when a deformable system's moment of inertia changes while no external torques are acting on the system. [11.7]
    11.10. I can apply conservation of angular momentum to find changes in rotational speeds when a collision occurs. [11.7]
    11.11. I can apply the angular momentum principle to determine the period for a physical pendulum. [11.7]
    11.12. I can apply conservation of angular momentum to find the speed of an object orbiting in an elliptical path at various points in its motion. [11.7]
    11.13. I can calculate changes in rotational speed of simple objects subjected to a constant net torque parallel to or opposite the angular momentum of the system. [11.8]
    11.14. I can apply the angular momentum principle to systems in static equilibrium. [11.8]
    11.15. I can calculate the angle through which an object rotates when a constant net torque parallel to or opposite the angular momentum changes the object's rotational speed. [11.9]
    11.16. I can use the angular momentum principle to iteratively predict the rotational motion of a system in a computational model using VPython. [11.10]
    11.17. I can show that angular momentum quantization in the Bohr model for a hydrogen atom leads to the correct electronic energy levels for hydrogen. [11.11]
    11.18. I can discuss the predictions of quantum mechanics for rotational angular momentum (spin) of fundamental particles and some of the consequences of these predictions. [11.11]
    11.19. I can apply the angular momentum principle to analyze the precession of a gyroscope. [11.12]
12. Chapter 12 – Entropy: Limits on the Possible
    12.1. I can describe the Einstein model of a solid, determining the number of oscillators needed to model a block composed of a given number of atoms. [12.2]
    12.2. I can explain the difference between a microstate and a macrostate. [12.2]
    12.3. I can state the fundamental assumption of statistical mechanics from memory and describe its consequences for the Einstein model of a solid applied to two interacting blocks. [12.2, 12.3]
    12.4. I can determine the number of ways (microstates) to distribute a specified number of quanta of energy among a given number of oscillators in the Einstein model of a solid. [12.2]
    12.5. I can determine the number of microstates for any given macrostate of a system of two blocks in thermal contact. [12.2, 12.3]
    12.6. I can calculate the entropy of a block from the number of microstates. [12.3]
    12.7. I can calculate the entropy of each block and the total entropy of a two interacting block system for any given macrostate of the system. [12.3]
    12.8. I can identify the equilibrium macrostate of two blocks in thermal contact both from the number of microstates and from the entropy of the system. [12.3]
    12.9. I can explain the consequences of going from "nanoparticle" sized blocks to macroscopic sized blocks on the likelihood of significant fluctuations away from the equilibrium macrostate. [12.3]
    12.10. I can state from memory the second law of thermodynamics in terms of entropy changes and relate it to the Einstein model as applied to the two interacting block system. [12.4]
    12.11. I can relate the changes in entropy of a system and its surroundings to the reversibility or irreversibility of a process. [12.4]
    12.12. I can classify the temperature of a block as higher or lower in terms of how rapidly the entropy of the block changes with changing internal energy. [12.5]
    12.13. I can calculate the temperature of a block, using the Einstein model to determine the entropy change occurring when the internal energy changes by one quantum. [12.5]

12.14. I can calculate the entropy change which occurs when a small amount of energy is transferred to a system due to a temperature difference with the surroundings. [12.5]
12.15. I can explain why thermal equilibrium of two blocks occurs when they have the same temperature by referring to the way the entropy of the blocks change with transfers of energy from one block to the other. [12.5]
12.16. I can calculate the specific heat of a material at a given temperature using the Einstein model. [12.6]
12.17. I can use VPython to calculate the number of microstates of two interacting blocks as a function of energy distribution between the two blocks. [12.7]
12.18. I can use VPython to calculate the entropy of two interacting blocks as a function of energy distribution between the two blocks. [12.7]
12.19. I can use VPython to calculate the temperatures of two interacting blocks as a function of energy distribution between the two blocks. [12.7]
12.20. I can use VPython to calculate and display the heat capacity of a solid as a function of temperature. [12.7]
12.21. I can discuss how the Boltzmann distribution arises when considering a small system in contact with a large constant temperature reservoir. [12.8]
12.22. I can use the Boltzmann distribution to examine various results for ideal gases such as density of gas with altitude in the atmosphere, velocity and speed distribution in a gas, average translational kinetic energy dependence on temperature, and specific heat of gases. [12.8]

# Calendar

Phys 2425.001 Spring 2018

| Week | Tuesday | | Thursday | |
|---|---|---|---|---|
| | Readings | Topics | Readings | Topics |
| 1 | 01/16 | Course Introduction; WebAssign Registration; Vectors | 01/18<br>**1.1 – 1.7** | Detecting Interactions: Newton's 1st Law; Position Update Equation<br>Lab – Motion of a Fan Cart on a Track |
| 2 | 01/23<br>**1.8 – 1.11** | Momentum; Change in Momentum; Using Momentum to Update Position<br>Lab – VP01: Intro to Computational Modeling | 01/25<br>**2.1 – 2.5** | The Momentum Principle (Newton's 2nd Law); Predicting Motion – Constant Net Force<br>Lab – VP02: Computational Models of Motion 1 |
| 3 | 01/31<br>**2.6 – 2.7** | Predicting Motion – Varying Net Force<br>Lab – VP03: Computational Models of Motion 2 | 02/01<br>**3.1 – 3.6** | Fundamental Interactions; Gravitational Force; Reciprocity (Newton's 3rd Law); Predicting the Motion of Gravitationally Interacting Objects<br>Lab – VP04: Calculating Gravitational Force |
| 4 | 02/06<br>**3.7 – 3.15** | Electric Force; Strong and Weak Interactions; Momentum Conservation; Momentum Principle for Multiparticle Systems; Collisions<br>Lab – VP05: A Space Voyage Part 1 | 02/08<br>**4.1 – 4.8** | Atomic Model of Contact Interactions: Tension Forces, Normal Forces, Frictional Forces<br>Lab – VP06: A Space Voyage Part 2 |
| 5 | 02/13 | **Test 1: Chapters 1 – 3** | 02/15<br>**4.9 – 4.14** | Speed of Sound in a Solid; Derivative Form of the Momentum Principle; Analytical Solution for a Spring-Mass System<br>Lab – Measurement Uncertainty |
| 6 | 02/20<br>**5.1 – 5.5** | Determining Unknown Forces Using the Derivative Form of the Momentum Principle<br>Lab – Test 1 Results and Assessment | 02/22<br>**5.6 – 5.10** | Applying the Derivative Form of the Momentum Principle to Curving Motion<br>Lab – Determining Spring Stiffness |
| 7 | 02/27 | Summary of Momentum Principle and Overview of Energy Principle<br>Lab – Problem Solving | 03/01<br>**6.1 – 6.6** | The Energy Principle applied to a Single Particle System<br>Lab – Mass/Spring Oscillator |
| 8 | 03/06<br>**6.7 – 6.11** | The Energy Principle applied to Multiparticle Systems; Gravitational Potential Energy; Electric Potential Energy<br>Lab – VP07: Spring/Mass Model Part 1 | 03/08<br>**6.12 – 6.15**<br>**7.1 – 7.3** | Nuclear Energy; Elastic Potential Energy of a Spring-Mass System; Potential Energy of Interacting Neutral Atoms<br>Lab – VP08: A Space Voyage Part 3 |
| 9 | 03/13 | Spring Break – No Class | 03/15 | Spring Break – No Class |
| 10 | 03/20<br>**7.4 – 7.11** | Energy Principle applied to Large Multiparticle Systems: Internal Energy, Microscopic Work (Heat Transfer); Energy Dissipation<br>Lab – Problem Solving | 03/22<br>**8.1 – 8.7** | Energy Quantization<br>Lab – VP09: Spring/Mass Model Part 2 |
| 11 | 03/27 | **Test 2: Chapters 4 – 7** | 03/29<br>**9.1 – 9.2** | Separation of Kinetic Energy in Multiparticle Systems into Translational, Rotational, and Vibrational Kinetic Energy; Moment of Inertia<br>Lab – Atomic and Molecular Spectra |
| 12 | 04/03<br>**9.3 – 9.4** | Modeling a System as a Point Particle and Modeling a System as an Extended Object; Detailed Model of Friction<br>Lab – Test 2 Results and Assessment | 04/05<br>**10.1 – 10.6** | Collisions – Applying both Momentum and Energy Principles Together<br>Lab – Jumping upward |
| 13 | 04/10<br>**10.7 – 10.12** | Rutherford's Discovery of the Nucleus; Relativistic Particle Collisions<br>Lab – Problem Solving | 04/12<br>**11.1 – 11.6** | Angular Momentum and the Angular Momentum Principle<br>Lab – VP10: Rutherford Scattering Model |
| 14 | 04/17<br>**11.7 – 11.10** | Combining All Three Fundamental Principles in Problem Solving<br>Lab – Problem Solving | 04/19<br>**11.11 – 11.12** | Angular Momentum Quantization; Gyroscopic Motion<br>Lab – Problem Solving |
| 15 | 04/24 | **Test 3: Chapters 8 – 11** | 04/26<br>**12.1 – 12.4, 12.7** | Fundamental Assumption of Statistical Mechanics; Entropy and the Second Law of Thermodynamics<br>Lab – VP11: Statistical Mechanics Part 1 |
| 16 | 05/01<br>**12.5 – 12.7** | Definition of Temperature ; Predicting the Specific Heat Capacity of Solids<br>Lab – Test 3 Results and Assessment | 05/03<br>**12.8 – 12.9** | The Boltzmann Distribution<br>Lab – VP12: Statistical Mechanics Part 2 |
| 17 | 05/08 | | 05/10 | **Final Exam – 8:00 to 10:00 am** |