PHYS 1100: University Physics I (fall)

Calendar description: This calculus-based physics course is intended primarily for (astro)physics and chemistry majors and engineers. Topics include kinematics, Newtons laws of motion, conservation of energy and momentum, rotational dynamics, and Newton's law of gravitation. Emphasis is placed on problem solving skills.

Classes 3 hrs. and lab/tutorial 3 hrs. per week; 1 semester.

Note: Credit cannot be given to students who have already taken PHY 205.0 or 221.0

Contents

Overview

This is essentially a first calculus-based university course in mechanics. Its scope includes trajectories, Newton's Laws and free body diagrams, work and the conservation of energy, N-particle systems and the conservation of momentum, rotation, angular momentum, torques, simple problems in statics, and Newton's Law of Gravitation.

The lab portion of this course is described separately at PHYS 1100L. The instructors of the lab portion enjoy some autonomy in how the lab is conducted, but it is the instructor of the lecture portion of the course, hereafter the "lecturer", who is responsible for the overall course, assigns final grades to the students, and is judged by student evaluations. Therefore, the lab instructor(s) need to consult with the lecturer in how the lab is conducted, and where there is disagreement the view of the lecturer shall prevail.

Prerequisites

Nova Scotia grade 12 physics or equivalent

All concepts in physics introduced in this class are introduced as though for the first time. However, the pace of the course as well as the level of the problems attempted require students to have had a grade 12 background in physics before attempting this course.

Nova Scotia grade 12 precalculus math, or equivalent

Ordinary high school algebra, trigonometry, and vectors are assumed, though many students will have very shallow abilities in these subjects, particularly vectors. Almost all students with Nova Scotia grade 12 math will have been exposed to derivatives, and many can use them. However, very few students have had any instruction on integration.

Students should be enrolled in MATH 1210 at the same time as this course which will improve their comfort with derivatives as the term proceeds. Integration is not covered until the winter term (MATH 1211), and thus a half-lecture introducing integration will be needed when work done by a variable force is discussed in October.

The Math department has a placement exam into MATH 1200, and those who fail enroll instead into MATH 1090; essentially repeating grade 12 math. These students will not see derivatives until the winter and will not see integrals until the summer, long after they are needed in PHYS 1101, the follow-on to this course. These students are not discouraged from taking this course nor PHYS 1101, and may need extra help with the math.

Dependent courses

ASTR 1100 Introduction to Astrophysics

ASTR 1100 depends on this course primarily for a basic understanding in mechanics, and how a well-posed physics problem can be solved. Specifically, ASTR 1100 would benefit most from a good introduction to Newtonian gravitation, Kepler's Laws, and even a bit of fluid dynamics though, historically, these are the topics instructors of PHYS 1100 most often skip as they are pressed for time to cover what is needed in rotational dynamics.

PHYS 1101 University Physics II

PHYS 1101 depends on this course weakly, as the topics in 1101 (oscillations, waves, thermodynamics, and E&M) can all, in principle, be taught independently of a course in mechanics. However, the terms and nomenclature, problem solving skills, and level of sophistication students gain from PHYS 1100 are what make it possible for the instructor of PHYS 1101 to cover all the material of that course in one term.

PHYS 2301 Analytical Mechanics (indirectly)

PHYS 2301 will build directly on all topics covered in this course, including applying free body diagrams to solve dynamical problems, conservation laws, and rotational dynamics. The more thorough coverage students get at the HRW level, the better prepared they will be for the significantly more challenging problems posed in PHYS 2301.

Student Outcomes

The development of sound, systematic problem-solving skills is paramount, and will serve both our students and freshmen engineers (the vast majority of the class) well in any future physics classes they take.

Students completing PHYS 1100 should begin to develop the following skills:

1. gain a competency in units and unit conversions
2. accept different notation conventions
3. develop a systematic and consistent approach to problem solving (*e.g.*, free body diagrams), and learn to translate word problems into mathematical equations. Many students will cling to their "rules of thumb" and simplistic approaches learned in high school that don't work for the more complex problems encountered at university-level physics.
4. be able to visualise a problem and use diagrams effectively
5. be able to choose the more efficient of different but physically equivalent methodologies (*e.g.*, free body diagrams and conservation of energy)
6. apply differential calculus to physics problems

Typical problems students completing PHYS 1100 should be able to solve:

1. When should a projectile be launched so that it collides with a moving object?
2. Given two masses resting on the floor attached by a string passing over an ideal pulley, with what minimum force must one pull up on the pulley so that both masses are off the floor? (Atwood's machine)
3. Consider a student sitting in a chair. If the "action force" is the student's weight, what is the "reaction force" (and the answer is *not* 'the normal force exerted by the chair on the student'; see the segment "Notes to the instructor" below).
4. What is the normal force exerted by the track on a rolling ball as the ball reaches the top of a "loop-de-loop"?
5. A dog walks towards the shore along a flat raft floating on the surface of a calm lake. In terms of the raft's length, how much closer is the dog to the shore once it crosses the raft?

6. Two people sliding toward each other on an ice rink collide obliquely and hold on to each other. In which direction does the couple slide?

7. If you tug on the thread wrapped under a spool, does the spool roll away from or toward you? What is the acceleration?

Curriculum

In parentheses is an approximate number of lectures to spend on each topic.

In square brackets are the names of various demonstrations as they are listed in the department's demonstration catalogue that could be used for each major topic.

1. vectors (1) [Wooden vectors]
    - definition, vectors on an x-y plot, addition of vectors
    - polar $\leftrightarrow$ Cartesian representations
    - dot and cross products
2. Kinematics (2) [Shoot the monkey]
    - kinematical relations (constant acceleration) in vector form
    - trajectories, range, maximum height of projectile
    - circular motion
3. Forces (4) [Acceleration up inclined plane; Atwood's machine; Centripetal force: Swinging]
    - Newton's laws and inertial frames of reference
    - What does Newton's third law really mean?
    - Newton's second law and free body diagrams (FBD)
    - friction, centripetal acceleration
4. Work and energy (4)
    - definition of work (first example of the dot product)
    - variable forces (Hooke's law, work done by a spring)
    - work-kinetic theorem
    - conservative *vs.* non-conservative forces
    - potential energy
        - gravitational potential energy near the surface of the earth
        - potential energy of a Hooke's spring
    - conservation of energy (general, isolated, conservative systems)

- problems requiring both conservation of energy and FBDs

5. systems of particles (4) [Conservation of momentum: 1D & 2D collisions]
   - centre of mass
   - momentum, and the conservation of momentum
   - elastic and inelastic collisions, 1-D and 2-D

6. Rotational dynamics (6) [Moment of inertia: tubes; Moment of inertia: rolling down plane; Angular momentum: rotating stool; Angular momentum: bicycle wheel with optional motor; Tower of Lyre]
   - kinematics revisited
   - moment of inertia
   - torques (first example of a cross product)
   - Newton's second law, and FBDs in rotational dynamics
   - angular momentum, and the conservation of angular momentum
     - bicycle wheel
   - rolling motion
     - billiard ball problem
     - spool of thread problem
   - equilibrium (balancing forces and torques) of systems in which all forces and moment arms lie within the same plane

7. Gravitation (2)
   - Newton's law of gravity
   - forces from several point masses
   - potential energy
   - Kepler's Laws (optional)

Suggested texts

Halliday, Resnick, and Walker (second suggestion) has been used for years at SMU for both halves of University Physics (PHYS 1100 and PHYS 1101). Starting in 2007, HRW was replaced by Knight (first suggestion) and used for PHYS 1500 (Introduction to Modern Physics) as well, *with mixed reviews*.

This list of calculus-based first-year physics texts is by no means exhaustive, and is representative of those with which one or more faculty members in the department are familiar and would seriously consider using.

Physics for Scientists and Engineers: A Strategic Approach by Knight (Pearson, Addison Wesley; ISBN 0 8053 8960 1)

- replaced HRW at SMU beginning fall 2007 for its novel pedagogy based on a substantive body of “physics education research”.
- while calculus-based, it is considerably lower level than HRW, and much more verbose
- high-school-level treatment of angular momentum and entropy
- non-conventional order of topics in the 1st edition can make presentation repetitive: *e.g.*, conservation of energy introduced *before* work-kinetic theorem; Newton’s third law comes four chapters *after* the first two laws are introduced; an attempt is made to blur the distinction between kinematics and dynamics, waves comes four chapters after oscillations, *etc.*

Fundamentals of Physics by Halliday, Resnick, and Walker, 8th edition (Wiley; ISBN 978 0 471 75801 3)

- traditional text for many institutions including SMU from 1993–2007
- abandoned, in part, because of its frequent revisions and availability of solutions to virtually all its problems on the publisher’s website
- it is still the acknowledged text to which all other first-year calculus-based physics texts are compared.

Essential University Physics by Wolfson (Pearson, Addison Wesley; ISBN 0 8053 9212 2)

- Covers same material as HRW but is cheaper, is advertised to have fewer revisions, and much more succinct (2/3 the length)
- has a superb discussion of Newton’s third law

University Physics by Sears, Zemansky, Young, and Freedman (Addison Wesley)

Physics for Scientists and Engineers by Serway and Jewett (Thompson Brooks/Cole)

Notes to the instructor

1. PHYS 1100 and PHYS 1101 serve two primary purposes:

   - foundation courses for (astro)physics majors;
   - service courses for chemistry and the engineering programme.

   These two purposes are often at loggerheads—the level needed by our potential majors is often higher than that needed by the engineers.

   Historically, these courses have been taught at a level neither higher nor lower than necessary to provide a thorough treatment of Halliday, Resnick and Walker, where any and all problems in that text are fair game for assignments and, to a lesser extent, exams. In practise, this has meant teaching to the B/B+ students.

2. *Newton's third law.* When first year students, without any instruction on the subject, are asked "If the action force is your weight, what is the reaction force?", typically *none* can give the correct answer. When quizzed on this problem within a few days of being told the correct answer, about 25% of the students can reproduce it. Even when the correct answer is reviewed again, well under half of the students can reproduce it on the midterm, and even fewer on the final exam. Thus, some who "get it" by the midterm, go back to the wrong answer by the exam. Indeed, an informal survey of SMU graduate student TAs *and* faculty show that more than half of our potential first-year instructors cannot give the correct answer either.

   So entrenched is the wrong answer (the normal force of the ground) in our education system—no doubt, the answer taught in high school—that it seems to be virtually impossible to dislodge and replace it with the correct answer (the gravitational pull of the student on the earth). Evidently, Newton's third law warrants considerably more discussion in class than simply reviewing the phrase "For every action, there is an equal and opposite reaction" that most students can parrot off, even if they have no clue of what it means or how to apply it.

3. A 20-minute refresher on derivatives given in the second or third class is useful. 90% of first-year students show some competence with derivatives right from high school.

4. A half-lecture introduction on integration is needed in early October when work done by a variable force is introduced. Most students have little familiarity with integrals, but can be made to accept them (almost) as antiderivatives used to evaluate Riemann sums.

   Integrals can largely be ignored for the rest of the first term: centres of mass of extended objects can be restricted to symmetric objects; moments of inertia are given in tables; and gravitational forces from extended objects can be skipped.

5. The greatest mathematical difficulty students have is vectors. A quarter to half of the students will still make fatal vector errors on the final exam, yet most will tell you they understand vectors thoroughly.

6. Instructors for the three first-year courses [this, PHYS 1101 (University Physics II), and PHYS 1500 (Introduction to Modern Physics)] are strongly urged to discuss and agree upon a mutually suitable text in time for ordering texts for the fall.

7. The portion of course grade assigned to the laboratory portion (PHYS 1100L) should be between 20% and 30%.

8. It has been this department's policy that students repeating this course may be exempt from repeating the laboratory portion *if*:

   - the grade attained in the lab portion in the previous attempt of the course was a C− or better;

- the grade attained in the lab from the previous attempt of the course is used as the lab grade for the current attempt

Students exempted from repeating the lab portion should not, however, be exempted from repeating the tutorial portion of the course, should tutorials be part of the course.