PHYS371: Classical Mechanics

Fall 2020: August 24–December 18

MWF 1:00 PM–1:50 PM, ~~STB225 and~~ Zoom-ed

Zoom meeting: https://hawaii.zoom.us/j/99448332047

ID: 994 4833 2047 *Passcode:* 3716324 ("371mech")

Version 4: December 11, 2020 (subject to change)

Professor:	Dr. Kathy Cooksey; STB 220; kcooksey@hawaii.edu; 808-932-7195
Office Hours:	M 9–10 AM, MW 2–3 PM, F 10–11 AM, and by appt.; in-person or Zoom
	Zoom meeting: https://hawaii.zoom.us/j/93811629543
	ID: 938 1162 9543 *Passcode:* 2665739 ("Cooksey")
Website:	Laulima PHYS-371-001 (HIL.14750.FA20)
Textbook:	*Analytical Mechanics*, 6th ed., by Fowles & Cassiday (ISBN 978-0030223174)

Course Description:

Intermediate-level kinematics and dynamics. Central force motion; rotations, noninertial frames, normal modes of vibrations; introduction to Lagrangian and Hamiltonian formalism.

Pre-requisite: PHYS170, PHYS272, and MATH300 (may be currently enrolled)

Learning Objectives:

- Broad course goals:
  1. Deepen understanding of mechanics, as learned in introductory physics.
  2. Increase complexity of physics included in mechanics problems.
  3. Be able to derive many other useful equations from a set of fundamental equations.
  4. Improve problem-solving skills, especially in how: (i) an approach is motivated; (ii) a solution is formatted; and (iii) the answer is verified to be reasonable, but also: dimensional analysis as a way of solving problems and"reverse engineering" equations; and clear diagrams (e.g., extended free-body diagrams) as a significant step in solving a problem efficiently.
- Specific content goals:
  1. Presenting a solution and thinking on one's feet is a highly transferrable skill.
  2. Manipulating equations algebraically/symbolically makes the resulting equation applicable to all situations with the same boundary conditions.
  3. Physical quantities have units that are used to understand the physical quantities, solve problems, and support intuition about the relative scales of physical quantities.

Email, Textbook, and Website:

- UHH considers email and Laulima an official form of communication; students are responsible for receiving and returning information in a timely manner.
- The professor will email students at their `hawaii.edu` accounts only.
- Students must have: reliable internet access;[1] a Zoom account and the necessary A/V equipment[2] to participate remotely; and a scanner or equivalent capability[3] to produce a PDF from hand-written work.

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[1] UH Hilo has increased Wi-Fi capacity to include all parking lots; see https://hilo.hawaii.edu/help/wifi/.

[2] Laptops are available for checkout at the UH Hilo library; see https://hilo.hawaii.edu/library/laptops.

[3] A smartphone and an app like CamScanner (https://www.camscanner.com/) can be used to produce legible PDFs.

- The required textbook is *Analytical Mechanics*, 6th ed., by Fowles & Cassiday (ISBN 978-0030223174). A more recent version may be used; the student is responsible for correlating the assigned reading to the updated textbook; the seventh edition is on reserve at the library.
- The Laulima[4] course website PHYS-371-001 (HIL.14750.FA20) will be the hub for all course information.

Class Rules:

- Students are responsible for their own learning, which includes preparing for class, submitting work, asking questions, and seeking additional help. The professor can only teach; only the student can learn.
  - College is the last time someone will ask you to do something hard and help you do it. The majority of college students use instructors' office hours.
  - Office hours are good times to get individualized help from the expert (i.e., the instructor), and office hours are part of the instructor's job.
- Students must respect and support their peers' learning, which means helping each other with difficult concepts but not just giving the answer.
- Students need to convey (either in person, by email, through an intermediary, or somehow) to the professor questions, comments, and concerns about the course.
- The professor will be receptive to and respectful of the students' needs and interests and must generally follow the class rules as detailed for the students (also see next section).
- Group work is encouraged in class and for homework assignments. However, all submitted work must be the original work of the student with reference to any problem-set partners.
- All references (e.g., websites, books other than the official course textbook, etc.) used to complete assignments must be cited, including numbers, techniques, facts, etc.
- Solutions to problems must show sufficient supporting work to receive full points. A complete solution includes: proper problem setup (e.g., state assumptions, define knowns and unknowns as variables, draw and label a figure); sufficient work to follow substitutions and reductions (typically symbolically first, then numeric substitution); and assessment of solution (units but also order of magnitude). See the Problem-Solving Strategy section below.
- The professor will take attendance each class even though attendance is not part of the grade (see Grading below). Any student who misses a week of class without communicating with the professor will be made inactive on Laulima, meaning s/he cannot access course materials until meeting with the professor.
- A non-smart-phone calculator is required for every class. Students should practice with the calculator they will use for tests and the final exam.
- *COVID-19 Online Instruction*—whole semester
  - Lectures will be live via Zoom. Students must have reliable internet access,[1] a Zoom account, and the necessary A/V equipment[2] to participate remotely (i.e., webcam, mic, and speakers or headphones).
  - Lectures will not be recorded. Students are encouraged to learn how to take quick screen shots (the online equivalent of taking a picture of the whiteboard).
  - If a student misses lecture, s/he should, in the following order: review any posted material; get the notes from a peer; and ask the professor any follow-up questions. (In addition to contacting the professor, see Grading section below.)

[4]If you need Laulima help, click the Request Assistance link at any page on Laulima: `http://www.hawaii.edu/simp/laulima-feedback.php`. Or go to UH System Help Desk: `https://www.hawaii.edu/its/help-desk/`.

  - The professor wants to see the students so webcams must be on and students visible the majority of the time.
  - Students will be participating during lecture. To facilitate explanations, students should have spare paper and a dark pen or a whiteboard and marker on hand, so they can hold up equations or sketches to their webcam.

Good-to-Know about the Professor:

- She enjoys teaching and wants to be better at it, and she really cares about helping students be better. These aspects combined mean she is on the students' side; trust in that and knowledge that she is receptive to feedback will smooth over rough patches.
- She chooses teaching techniques based on physics-education research to support student learning as best as possible. This means she has one or more reasons for nearly every component of and action in a course. She'll gladly motivate these choices whenever necessary or asked.
  - The COVID-19 pandemic has led to the professor teaching online. She still endeavors to use best practices, even given the new constraints.
- Her primary goal is to help students improve *how* they learn with the logic that if students learn how to learn, they can master any content. The related goal is to focus on transferrable skills so that time and effort spent for the class yield benefits beyond the course and semester.
- Generally, she does not answer questions directly. A student making connections and constructing a solution her- or himself will ingrain the answer more effectively, and the professor facilitates the process by asking leading questions. Since the motivation is to help the students, they should embrace and engage with this process. (It is also a transferrable skill to discuss ideas and answer questions on the fly.)
- She designs quizzes, tests, and exams so that no one gets 100% and no one gets 0% because either score would not be useful in assessing what the students understand and how to help. The percentage reflects what the student knows of what s/he could have learned; the letter grade reflects what the student learned and how much s/he has improved.
  The rule-of-thumb is to score above the median (see Grading below). She has no interest in failing students who make good-faith effort in the class (e.g., good attendance, submit completed work, ask questions in and out of class).
- She thinks no single resource is comprehensive, so the expectation is that the student will have to work with the professor, her materials, the textbook, and the wealth of material available on the internet.
- The expectation is that a course requires 2–3 hr outside-of-class time per credit per week. Hence a 15-cr semester equals 30–45 hr per week (i.e., a full-time job).
- She generally responds to email 24-to-48 hours after receipt. If the matter is urgent, the student should call (office voicemail is automatically emailed) or stop by her office (her general weekly schedule is on her homepage: http://www2.hawaii.edu/~kcooksey).

General Course Outline (subject to change):

This is problem-solving course; there are no traditional lectures. The students will be asked to solve some subset of the problem set in class (facilitated by the professor and assisted by the whole class). For this, the students may use the textbook, the official Equation Sheet, and their notes. We wil be following the Problem-Solving Strategy below (i.e., "The Format").

Reading assignments are to be read for the *following week.* which is why the schedule below starts in Week 0. The chapter intro should be read whenever the first section is assigned; it is recommended the students review any related sections from their introductory mechanics course (e.g., PHYS170). The students are expected to come to class with questions about the assigned reading.

Problem sets (PS) are assigned every week and due as a module at class time ("HW#X"; see schedule below). One problem will be graded in detail for half the points; the rest will be checked for completeness (e.g., attempt, "The Format") for the other half. Problem sets are to be uploaded to Laulima:Drop Box as one or a few clear, organized, and clearly labeled PDF(s); a scanner or equivalent[3] is necessary. Feedback will be given on the PDF(s); this includes about the quality of submission, which must be addressed before the next problem-sets upload. The professor reserves the right to *not* grade unclear, disorganized, poorly labeled, or non-PDF solutions. There is a 24-hr late deadline, at a 25% penalty; the professor will grade mixed on-time+late submissions to maximize the student's points. Complete solutions will be posted after the late deadline.

> Note: grading of problem sets like homework is a compromise. The professor would normally have in-class quizzes on the problem sets (one problem given verbatim, only Equation Sheet allowed). However, given the likely difficulties with a online course and uncertainty induced by the pandemic, real-time professor-student interaction is precious, thus lecture will predominately be reserved for teaching—and, ideally, learning.

There are two take-home tests, on Wednesdays, when there will be no lecture. The tests are open book and open note, including the course's Laulima page (but *not* the rest of the internet); they will be posted on Laulima and due the same day, to be completed and submitted at the student's leisure. All content from a cutoff and earlier are fair game; the cutoff is determined by what content has been covered with the chance for feedback (hence the tests' titles and problem sets in square brackets). This pattern is designed so that the students have a chance to: (i) learn the material via reading, discussion, and problem sets; (ii) practice the content via problem sets; and (iii) receive feedback via discussion and/or posted solutions. Thus, there is a lag between material being the focus of "lecture" and when the material will be on a test. The cumulative final exam will have a format similar to the tests.

Date	Topic	Activity
Week 0: Before semester begins	Independent mechanics review	Read: §§1.1–1.6, §§1.9–1.10, §§2.1–2.3, §§3.1–3.3, §4.3, §4.5, and any necessary PHYS170 sections Complete PS#1: Vectors Review
Week 1: M Aug 24, W Aug 26, F Aug 28	Fundamental Concepts I (PS#1 in-class)	Read: §§1.7–1.8, §§1.11–1.12, §2.4, §§4.1–4.2 Pre-quiz (for credit only; completed on Laulima, by end of day) Complete PS#2: Fundamental Concepts I
Week 2: M Aug 31, W Sep 2, F Sep 4	Fundamental Concepts II (PS#2 in-class)	Read: None Complete PS#3: Fundamental Concepts II
Week 3: W Sep 9, F Sep 11	*(M Sep 7: Labor Day)* Noninertial Frames I (PS#3 in-class)	Read: §§5.1–5.3 Complete PS#4: Noninertial Frames I
Week 4: M Sep 14, W Sep 16, F Sep 18	Noninertial Frames II (PS#4 in-class)	Read: §§5.4–5.6 *Due Wed. "HW#1": Fundamental Concepts [PS#1–3]* Complete PS#5: Noninertial Frames II
Week 5: M Sep 21, W Sep 23, F Sep 25	Central-Force Motion I (PS#5 in-class)	Read: §§6.1–6.6 Complete PS#6: Central-Force Motion I
Week 6: M Sep 28, W Sep 30, F Oct 2	Central-Force Motion II (PS#6 in-class)	Read: §§6.7–6.14 *Due Wed. "HW#2": Noninertial Frames [PS#4–5]* Complete PS#7: Central-Force Motion II
Week 7: M Oct 5, W Oct 7, F Oct 9	Rotational Motion I (PS#7 in-class)	Read: §§1.11–1.12 (again), §§5.2–5.6 (again), §§8.1–8.6, Khan Academy "Double integrals over non-rectangular regions"† Complete PS#8: Rotational Motion I
Week 8: M Oct 12, W Oct 14, F Oct 16	Rotational Motion II (PS#8 in-class)	Read: mathisfun.com "How to Multiply Matrices",‡ §§9.1–9.5 *Due Wed. "HW#3": Central-Force Motion [PS#6–7]* Complete PS#9: Rotational Motion II
Week 9: M Oct 19, W Oct 21, F Oct 23	Rotational Motion III (PS#9 in-class)	Read: §§9.6–9.10 Complete PS#10: Rotational Motion III Mid-term course evaluation (closes F Oct 30)
	Wed. Test #1: Fundamentals, Noninertial Frames, & Central-Force Motion [PS#1–7]	
Week 10: M Oct 26, W Oct 28, F Oct 30	Lagrangian & Hamiltonian I (PS#10 in-class)	Read: §§10.1–10.5 Complete PS#11: Lagrangian & Hamiltonian I
Week 11: M Nov 2, W Nov 4, F Nov 6	Lagrangian & Hamiltonian II (PS#11 in-class)	Read: §§10.5–10.7 *Due Wed. "HW#4": Rotational Motion [PS#8–10]* Complete PS#12: Lagrangian & Hamiltonian II
Week 12: M Nov 9, F Nov 13	Lagrangian & Hamiltonian III (PS#12 in-class) *(W Nov 11: Veteran's Day)*	Read: §§10.8–10.9 Complete PS#13: Lagrangian & Hamiltonian III
Week 13: M Nov 16, W Nov 18, F Nov 20	Lagrangian & Hamiltonian IV (PS#13 in-class)	Read: §§3.1–3.3 (again), §3.4, §3.6, §4.4, §5.6 (again), §8.4 (again) Complete PS#14: Oscillations Review
Week 14: M Nov 23, W Nov 25	Oscillations I (PS#14 in-class) *(F Nov 27: Thanksgiving break)*	Read: §§11.1–11.2 *Due Wed. "HW#5": Lagrangian & Hamiltonian [PS#11–13]* Complete PS#15: Oscillations I
Week 15: M Nov 30, W Dec 2, F Dec 4	Oscillations II (PS#15 in-class)	Read: §§11.3–11.5 Complete PS#16: Oscillations II
	Wed. Test #2: Rotational Motion, Lagrangian, & Hamiltonian [PS#8–13]	
Week 16: M Dec 7, W Dec 9	Oscillations III (PS#16 in-class)	Read: None *Due Wed. "HW#6": Oscillations [PS#14–15]* Post-quiz (for credit only; completed on Laulima, by end of day)
Week 17: W Dec 16	Final Exam (11:50 AM–1:50 PM—trust but verify)	

† Khan Academy "Double integrals over non-rectangular regions": https://www.khanacademy.org/math/multivariable-calculus/integrating-multivariable-functions/double-integrals-a/a/double-integrals-over-non-rectangular-regions.

‡ mathisfun.com "How to Multiply Matrices": https://www.mathsisfun.com/algebra/matrix-multiplying.html.

Reading Assignments: as mentioned previously, reading assignments are to be read for the *following week*. The section titles per week are given below; it's like a more detailed schedule.

Week 0 Review (PS#1)

- **§1.1** Introduction
- **§1.2** Measure of Space and Time. Units
- **§1.3** Notation, Formal Definitions and Rules of Vector Algebra
- **§1.4** The Scalar Product
- **§1.5** The Vector Product
- **§1.6** An Example of the Cross Product. Moment of Force
- **§1.9** Derivative of a Vector
- **§1.10** Position Vector of a Particle. Velocity and Acceleration in Rectangular Coordinates
- **§2.1** Newton's Laws of Motion. Historical Introduction
- **§2.2** Rectilinear Motion. Uniform Acceleration Under a Constant Force
- **§2.3** Forces That Depend on Position: The Concepts of Kinetics and Potential Energy
- **§3.1** Introduction [to Oscillations]
- **§3.2** Linear Restoring Force: Harmonic Motion
- **§3.3** Energy Considerations in Harmonic Motion
- **§4.3** Forces of the Separable Type: Projectile Motion
- **§4.5** Motion of Charged Particles in Electric and Magnetic Fields

Any necessary PHYS170 sections

Week 1 Fundamental Concepts I (PS#2)

- **§1.7** Triple Products
- **§1.8** Change of Coordinate System. The Transformation Matrix
- **§1.11** Velocity and Acceleration in Plane Polar Coordinates
- **§1.12** Velocity and Acceleration in Cylindrical and Spherical Coordinates
- **§2.4** Velocity-Dependent Forces. Fluid Resistance and Terminal Velocity
- **§4.1** Introduction [to General Motion of a Particle in Three Dimensions]: General Principles
- **§4.2** The Potential Energy Function in Three-Dimensional Motion: The Del Operator

Week 2 Fundamental Concepts II (PS#3)

None

Week 3 Noninertial Frames I (PS#4)

- **§5.1** Accelerated Coordinate Systems and Inertial Forces
- **§5.2** Rotating Coordinate Systems: Angular Velocity as a Vector Quantity
- **§5.3** Dynamics of a Particle in a Rotating Coordinate System

Week 4 Noninertial Frames II (PS#5)

- **§5.4** Effect of Earth's Rotation
- **§5.5** Motion of a Projectile in a Rotating Cylinder
- **§5.6** The Foucault Pendulum

Week 5 Central-Force Motion I (PS#6)

- **§6.1** Introduction [to Gravitation and Central Forces]
- **§6.2** Gravitational Force Between a Uniform Sphere and a Particle
- **§6.3** Kepler's Law of Planetary Motion
- **§6.4** Kepler's Second Law. Equal Areas: Conservation of Angular Momentum
- **§6.5** Kepler's First Law: The Law of Ellipses
- **§6.6** Kepler's Third Law: The Harmonic Law

Week 6 Central-Force Motion II (PS#7)

- **§6.7** Potential Energy in a Gravitational Field: Gravitational Potential
- **§6.8** Potential Energy in a General Central Field
- **§6.9** Energy Equation of an Orbit in a Central Field
- **§6.10** Orbital Energies in an Inverse-Square Field
- **§6.11** Limits of the Radial Motion: Effective Potential
- **§6.12** Motion in an Inverse-Square Repulsive Field: Scattering of Alpha Particles
- **§6.13** Nearly Circular Orbits in Central Fields: Stability
- **§6.14** Apsides and Apsidal Angles for Nearly Circular Orbits

Week 7 Rotational Motion I (PS#8)

- **§§1.11–1.12** again, from Week 1
- **§5.2–5.6** again, from Weeks 2–3
- **§8.1** Center of Mass of a Rigid Body
- **§8.2** Rotation of a Rigid Body About a Fixed Axis: Moment of Inertia
- **§8.3** Calculation of the Moment of Inertia
- **§8.4** The Physical Pendulum
- **§8.5** A General Theorem Concerning Angular Momentum
- **§8.6** Laminar Motion of a Rigid Body
- Khan Academy "Double integrals over non-rectangular regions"†

Week 8 Rotational Motion II (PS#9)

- mathisfun.com "How to Multiply Matrices"‡
- **§9.1** Rotation of a Rigid Body About an Arbitrary Axis: Moments and Products of Inertia—Angular Momentum and Kinetic Energy
- **§9.2** Principal Axes of a Rigid Body: Dynamics Balancing
- **§9.3** Euler's Equations of Motion of a Rigid Body
- **§9.4** Free Rotation of a Rigid Body: Geometric Description of the Motion
- **§9.5** Free Rotation of a Rigid Body with an Axis of Symmetry: Analytical Treatment

Week 9 Rotational Motion III (PS#10)

- **§9.6** Description of the Rotation of a Rigid Body Relative to a Fixed Coordinate System: The Eulerian Angles
- **§9.7** Gyroscopic Precession: Motion of a Top
- **§9.8** The Energy Equation and Nutation
- **§9.9** The Gyrocompass
- **§9.10** General Motion of a Rigid Body: Rolling Wheel

Week 10 Lagrangian & Hamiltonian I (PS#11)

- **§10.1** Hamilton's Variational Principle. An Example
- **§10.2** Generalized Coordinates
- **§10.3** Calculating Kinetic and Potential Energies in Terms of Generalized Coordinates. An Example
- **§10.4** Lagrange's Equations of Motion for Conservative Systems
- **§10.5** Some Applications of Lagrange's Equations

Week 11 Lagrangian & Hamiltonian II (PS#12)

- **§10.6** Generalized Momenta. Ignorable Coordinates
- **§10.7** Forces of Constraint. Lagrange Multipliers

Week 12 Lagrangian & Hamiltonian III (PS#13)

- **§10.8** D'Alembert's Principle. Generalized Forces
- **§10.9** The Hamiltonian Function. Hamilton's Equation

Week 13 Oscillations Review (PS#14)

- **§§3.1–3.4** again, from Week 0
- **§3.6** Forced Harmonic Motion: Resonance
- **§4.4** The Harmonic Oscillator in Two and Three Dimensions
- **§5.6** again, from Week 3
- **§8.4** again, from Week 6

Week 14 Oscillations I (PS#15)

- **§11.1** Potential Energy and Equilibrium. Stability
- **§11.2** Oscillation of a System with One Degree of Freedom About a Position of Stable Equilibrium

Week 15 Oscillations II (PS#16)

- **§11.3** Coupled Harmonic Oscillators. Normal Coordinates
- **§11.4** General Theory of Vibrating Systems
- **§11.5** Vibration of a Loaded String or Linear Array of Coupled Harmonic Oscillators

Grading:

- The grade depends on the following categories: completing pre/post-quizzes (5%), problem sets (40%), tests (35%), and final exam (20%).
  - Problem sets, tests, and the final exam are to be uploaded to Laulima:Drop Box (or where instructed) as one or a few clear, organized, and clearly labeled PDF(s); a scanner or equivalent[3] is necessary. The professor reserves the right to *not* grade unclear, disorganized, poorly labeled, or non-PDF solutions.
  - The lowest problem-set grade will be dropped. There is a hard 24-hr late deadline, at a 25% penalty.
  - If a student notices an inconsistency in the professor's grading, s/he should ask; it might be a mistake or it might be a subtle point. Students are encouraged to ask questions about grading.
- Attendance is recorded but not part of the grade.
  - If a student must miss a class for a reasonable reason, s/he should email the professor before the start of class time.
  - If a student were unable to email in advance due to extreme circumstances, s/he should contact the professor as soon as possible. Such instances will be judged on a case-by-case basis.
    - In such (and similar) situations, the student is strongly encouraged to contact Student Services (info below). Student Services are liaisons between students and instructors, when Life adversely impacts Academics. If Student Services advocates on a student's behalf, the professor will work to accommodate any missed content and points.
  - If a student must miss a test or the final exam for a reasonable reason, please discuss the options with the professor as soon as possible.
    - Problem sets are never excused because their deadlines are known in advance and there is a late deadline.
    - If a student were excused from a test or exam, the graded work will not be included in her/his final grade.
    - If a student were excused from all points in a given category, the percentage of the other categories will be increased to fill the void.

- Cheating is not tolerated. Any question of cheating will be tested with an oral exam, to see whether the student understands the material. Cheating will result in a zero for the item in question and a report to the University. It may result in immediate failure of the course.
- The final letter grade will be given based on the class statistics (e.g., the 25^{th}, 50^{th}/median, 75^{th} percentiles). The goal is to score higher than the median on all graded work. The expectation is that final grades higher than the median will pass with at least a C and that the 25^{th} to 50^{th} percentiles will likely earn something in the C range.
  - The professor will give projected final letter grades after each test so the students know where they stand.

Problem-Solving Strategy (AKA "The Format"): This is the explicit format required for solutions to all quantitative problems. It is not required for conceptual problems (though may be useful).

Student's Name
Collaborator(s):

PHYS371 Problem Set #X

1. Problem title or very brief description

   Physics Category
   - Identify the broad category under which the problem falls because this reduces the set of concepts and equations that will be useful.
   - The broadest categories reflect the course modules (e.g., "kinematics" or "linear momentum") but being more specific can be useful (e.g., "kinematics (2D)", "force (equilibrium)", "energy (conservation)").

   Definitions
   - Define the variables to represent the known/given quantities (with units) and the unknown/target quantities.
   - Use informative symbols for the variables; subscripts are useful.
   - Often a diagram is a useful way to define the known and unknown variables.

   Algebraic Derivation
   - Write the basic equations on which the solution is based, in terms of the defined variables. There should be as many equations as unknowns.
   - Algebraically manipulate the equations to reduce and simplify.

   Numeric Substitution
   - If the problem requires a numeric answer, substitute into the reduced equation (while tracking units explicitly) and compute the result.

   Assessment
   - Check the units come out correctly (even if it's a non-numeric answer).
   - If it's a numeric answer, check the order-of-magnitude, else justify the derived equation scales reasonably with each variable.
   - Clearly justify that the final answer is reasonable. Units and order-of-magnitude/scaling are two "sanity checks" but also demonstrate understanding of expectation based on physics.
     - If result is not expected, discuss whether this is the point (e.g., learning, new intuition) or if it seems incorrect.
     - If the latter, then attempt to explain what is wrong (and earn back points).

2. Problem title or very brief description

   Physics Category
   Definitions
   Algebraic Derivation
   Numeric Substitution
   Assessment

3. *...wash, rinse, repeat*

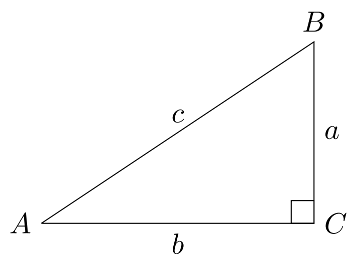
Content Not on Equation Sheet: Below are a combination of fundamental concepts in physics that must be learned (which is more than memorized) and relationships that can be derived from fundamental concepts and given equations. This is not a comprehensive list.

- This section (Content Not on Equation Sheet) of the PHYS170 Syllabus; see the latest version of PHYS170 Syllabus at: http://guavanator.uhh.hawaii.edu/~kcooksey/teaching/UHH/UHH.html. Some just may not be relevant (and maybe never was).

- The following content that was on the PHYS170 Equation Sheet (see link above) but not on the PHYS371 Equation Sheet; some just may not be relevant (and maybe never was):
  - Constants
    * Gravitational acceleration at Earth's surface: $g = 9.806\,\mathrm{m\,s^{-2}}$
  - Physics equations
    * Density: $\rho = \frac{M}{V}$
    * Kinematic equations (constant $\vec{\mathbf{a}}$):[5]
      $\vec{\mathbf{v}}(t) = \vec{\mathbf{v}}_0 + \vec{\mathbf{a}}t$
      $\vec{\mathbf{r}}(t) = \vec{\mathbf{r}}_0 + \vec{\mathbf{v}}_0 t + \frac{1}{2}\vec{\mathbf{a}}t^2$
      $v^2 = v_0^2 + 2a(r - r_0)$ (by component)
    * Magnitude of static friction: $f_\mathrm{s} \leq \mu_\mathrm{s} N$
    * Magnitude of kinetic friction: $f_\mathrm{k} = \mu_\mathrm{k} N$
    * Gravitational force: $\vec{\mathbf{F}}_{12}(r) = \frac{GM_1 M_2}{r^2}\,\hat{\mathbf{r}}_{12}$
    * Pressure: $P = \frac{F}{A}$, where F is force and A is area.
    * Ideal gas law (gas pressure): $PV = \mathcal{N}\,k_\mathrm{B}\,T$, where $\mathcal{N}$ is number of particles.
    * Temperature: $T_{(^\circ\mathrm{C})} = T_{(\mathrm{K})} - 273$ and $T_{(^\circ\mathrm{C})} = \frac{5}{9}\left(T_{(^\circ\mathrm{F})} - 32\right)$
    * Center of mass for particles: $\vec{\mathbf{r}}_\mathrm{CM} = \frac{1}{M_\mathrm{sys}}\sum_{n=1}^{\mathcal{N}} M_n \vec{\mathbf{r}}_n$
    * Moment of inertia for particles: $I = \sum_{n=1}^{\mathcal{N}} M_n r_n^2$.
    * Work-Energy Theorem:[5] $W_\mathrm{AB,net} = K_\mathrm{sys,B} - K_\mathrm{sys,A}$
    * Mass-energy equivalence: $E = Mc^2$
    * Kinetic energy of particle:[5] $K = \frac{1}{2}Mv^2$
    * Average KE of hot particles: $K_\mathrm{ave} \approx k_\mathrm{B}\,T$
    * Gravitational potential energy: $U(r) = -\frac{GM_1 M_2}{r}$
    * Potential energy of particle near Earth's surface: $U(y) = Mgy + \text{constant}$
    * Spring potential energy: $U(r) = \frac{1}{2}kr^2 + \text{constant}$
    * Period (T)-frequency (f) relation: $T = f^{-1}$
    * Wavelength (λ)-frequency relation: $v = \lambda f$

[5] Also applicable to fixed-axis rotating systems with appropriate substituions of $\vec{\boldsymbol{\theta}}$, $\vec{\boldsymbol{\omega}}$, $\vec{\boldsymbol{\alpha}}$, I, $\vec{\boldsymbol{\tau}}$, and/or $\vec{\mathbf{L}}$.

- General mathematics
  - Quadratic solution for $ax^2 + bx + c = 0$: $x = \dfrac{-b \pm \sqrt{b^2 - 4ac}}{2a}$
  - Vectors
    - Direction convention: $\vec{\mathbf{r}}_{12}$ points from 1 to 2
    - Unit vector $\hat{\mathbf{r}} = \dfrac{\vec{\mathbf{r}}}{r}$
  - Geometry & Trigonometry
    - Radian: $2\pi\,\text{rad} = 360°$
    - Circumference of a circle: $s = 2\pi r$
    - Area of a circle: $A = \pi r^2$
    - Area of a triangle: $A = \dfrac{1}{2}bh$
    - Area of a trapezoid: $A = \dfrac{1}{2}(a+b)h$
    - Surface area of a cylinder: $A = 2\pi rh + 2\pi r^2$
    - Volume of a cylinder: $V = \pi r^2 h$
    - Pythagorean theorem: $a^2 + b^2 = c^2$ and $\cos^2\theta + \sin^2\theta = 1$
    - Interior angles of a triangle: $\angle A + \angle B + \angle C = 180° = \pi\,\text{rad}$
    - $\sin(\angle A) = \dfrac{1}{\csc(\angle A)} = \cos(\angle B) = \dfrac{a}{c}$
    - $\cos(\angle A) = \dfrac{1}{\sec(\angle A)} = \sin(\angle B) = \dfrac{b}{c}$
    - $\tan(\angle A) = \dfrac{1}{\cot(\angle A)} = \cot(\angle B) = \dfrac{a}{b}$ (discontinuous function)



  - Calculus
    - $\dfrac{d}{dx}f(x) \equiv \lim_{\Delta x \to 0}\left(\dfrac{f(x+\Delta x) - f(x)}{\Delta x}\right)$
    - Chain rule: $\dfrac{d}{dx}f(y) = \dfrac{df(y)}{dy}\dfrac{dy}{dx}$
    - Product rule: $\dfrac{d}{dx}\big(f(x)g(x)\big) = f(x)\dfrac{dg(x)}{dx} + g(x)\dfrac{df(x)}{dx}$
    - $\dfrac{d}{dx}\left(x^n\right) = nx^{n-1}$
    - $\displaystyle\int_{x_0}^{x+\mathcal{N}\Delta x} f(x)dx \equiv \lim_{\Delta x \to 0}\left(\sum_{n=1}^{\mathcal{N}} f(x_0 + n\Delta x)\Delta x\right)$
    - $\displaystyle\int_{x_{\mathrm{A}}}^{x_{\mathrm{B}}} \frac{d}{dx}f(x) = f(x_{\mathrm{B}}) - f(x_{\mathrm{A}})$

- **Common prefixes**
  * Giga = 10^9 or billion; denoted as G.
  * Mega = 10^6 or million; denoted as M.
  * Kilo = 10^3 or thousand; denoted as k.
  * Centi = 10^{-2} or one-hundredth; denoted as c.
  * Milli = 10^{-3} or one-thousandth; denoted as m.
  * Micro = 10^{-6} or one-millionth; denoted as μ and sometimes called "micron" when applied to meters.
  * Nano = 10^{-9} or one-billionth; denoted as n.
  * Femto = 10^{-15} or one-quadrillionth; denoted as f.
- **Greek letters** (lower,upper case):

α, A	alpha	ν	nu
β, B	beta	ξ, Ξ	xi
γ, Γ	gamma	o, O	omicron
δ, Δ	delta	ϕ, Π	pi
$(\epsilon, \varepsilon), E$	epsilon	$(\rho, \varrho), P$	rho
$z\eta, Z$	zeta	σ, Σ	sigma
η, H	eta	τ, T	tau
$(\theta, \vartheta), \Theta$	theta	υ, Υ	upsilon
ι, I	iota	$(\phi, \varphi), \Phi$	phi
κ, K	kappa	χ, X	chi
λ, Λ	lambda	ψ, Ψ	psi
μ, M	mu	ω, Ω	omega

- Differences between PHYS371 Equation Sheet and PHYS170 Equation Sheet

$$K_{\text{rot}} = \frac{1}{2}I\omega^2 \quad \rightarrow \quad K_{\text{rot}} = \frac{1}{2}\vec{\boldsymbol{\omega}} \bullet \vec{\mathbf{L}} \text{ or } K_{\text{rot}} = \frac{1}{2}\vec{\boldsymbol{\omega}} \cdot \boldsymbol{I} \cdot \vec{\boldsymbol{\omega}} \text{ or } K_{\text{rot}} = \frac{1}{2}\tilde{\vec{\boldsymbol{\omega}}}\boldsymbol{I}\vec{\boldsymbol{\omega}}$$

$$\vec{\mathbf{L}} = I\vec{\boldsymbol{\omega}} \quad \rightarrow \quad \vec{\mathbf{L}} = \boldsymbol{I}\vec{\boldsymbol{\omega}} \text{ or } \vec{\mathbf{L}} = \boldsymbol{I} \cdot \vec{\boldsymbol{\omega}} \text{ (tensor mult.)}$$

$$I = \sum_{n=1}^{\mathcal{N}} M_n r_n^2 \quad \rightarrow \quad I = \int r^2 dm \text{ (but actually more complicated!) } I = \tilde{\vec{\mathbf{n}}}\boldsymbol{I}\vec{\mathbf{n}}$$

where $\vec{\mathbf{n}}$ is a unit vector in the direction of the axis:

$$\vec{\mathbf{n}} = \cos\alpha\,\hat{\mathbf{i}} + \cos\beta\,\hat{\mathbf{j}} + \cos\gamma\,\hat{\mathbf{k}} = \begin{bmatrix} \cos\alpha \\ \cos\beta \\ \cos\gamma \end{bmatrix}$$

(not on Equation Sheet).

- Tensor multiplication ($\boldsymbol{\cdot}$, different from regular multiplication $\cdot$ and dot/scalar product $\bullet$)

- Matrix/tensor moment of inertia:

$$\begin{aligned} \boldsymbol{I} &= (I_{xx} + I_{xy} + I_{xz})\,\hat{\mathbf{i}} + (I_{yy} + I_{yx} + I_{yz})\,\hat{\mathbf{j}} + (I_{zz} + I_{zy} + I_{zx})\,\hat{\mathbf{k}} \\ &= \sum_{u\,\text{comp.}} \left(I_{xu}\,\hat{\mathbf{i}} + I_{yu}\,\hat{\mathbf{j}} + I_{zu}\,\hat{\mathbf{k}} \right) \\ &= \begin{bmatrix} I_{xx} & I_{xy} & I_{xz} \\ I_{yx} & I_{yy} & I_{yz} \\ I_{zx} & I_{zy} & I_{zz} \end{bmatrix} \end{aligned}$$

- What we really need to consider for advanced mechanics:

$$\begin{aligned} \text{Torque: } d\vec{\boldsymbol{\tau}} &= d(\vec{\mathbf{r}} \times \vec{\mathbf{F}}) \\ \text{Angular Mom.: } d\vec{\mathbf{L}} &= d(\vec{\mathbf{r}} \times \vec{\mathbf{p}}) \end{aligned}$$

like how, for PHYS272 content, the electric field of an extended source is integrated from:

$$d\vec{\mathbf{E}} = \frac{1}{4\pi\varepsilon_0}\frac{dq}{r^2}\,\hat{\mathbf{r}}$$

Campus-wide Information

UH Hilo COVID-19 Pandemic Information: https://hilo.hawaii.edu/covid19/
Disability Support: Any student with a documented disability who would like to request accommodation should contact the Disability Services Office—Student Services Center, E230; 932-7623 (V), 932-7002 (TTY), uds@hawaii.edu—as early in the semester as possible.
Advising: Advising is a very important resource designed to help students complete the requirements of the University and their individual majors. Students should consult with their advisor at least once a semester to decide on courses, check progress towards graduation, and discuss career options and other educational opportunities provided by UH Hilo. Advising is a shared responsibility, but students have final responsibility for meeting degree requirements.
Kilohana Academic Success Center: The KASC provides academic support opportunities for all UH Hilo students that foster their development into independent, self-motivated learners. Students who visit Kilohana have access to subject-specific and academic skills tutoring from UHH students selected for their academic achievement and dedication to helping others succeed. Kilohana is located on the lower level of the Mookini Library and on the web at http://hilo.hawaii.edu/kilohana/.
Human Rights: The University of Hawaiʻi at Hilo prohibits discrimination in its education programs based on race, national origin, color, creed, religion, sex, age, disability, veteran status, sexual orientation, gender identity or associational preference. If at any time during class you feel uncomfortable about what is being talked about, or feel that your human rights have been violated, please feel free to leave the room. However, the professor asks that you confer with her as soon as possible about what happened so that appropriate action can be taken if necessary to avoid future problems. If you are uncomfortable speaking with the professor about your concern, please contact Kalei Rapoza (kaleihii@hawaii.edu), Interim EEO/AA Director, at 932-7626.
UH Hilo Title IX Policy: The University of Hawaii is committed to providing a learning, working and living environment that promotes personal integrity, civility, and mutual respect and is free of all forms of sex discrimination and gender-based violence, including sexual assault, sexual harassment, gender-based harassment, domestic violence, dating violence, and stalking. If you or someone you know is experiencing any of these, the University has staff and resources on your campus to support and assist you. Staff can also direct you to resources that are in the community. Here are some of your options:

> If you wish to remain anonymous, speak with someone confidentially, or would like to receive information and support in a confidential setting, contact: • UH Hilo Counseling Services: SSC, room E-203, 932-7465; • UH Hilo Medical Services: Campus Center, room 212, 932-7369; and/or • Hawaiʻi Island YWCA, 935-0677.
>
> If you wish to report an incident of sex discrimination or gender-based violence including sexual assault, sexual harassment, gender-based harassment, domestic violence, dating violence, or stalking as well as receive information and support,† contact: • Libby Bailey, Title IX Coordinator, 932-7818, libby.bailey@hawaii.edu; • Jennifer Stotter, Director of the Office of Equal Opportunity & Deputy Title IX Coordinator, 932-7641, jstotter@hawaii.edu; and/or • Kalei Rapoza, Interim Director of Human Resources, 932-7626, kaleihii@hawaii.edu.
>
> †Please note that you do not have to file a report with the University to receive institutional support or assistance.

As a member of the University faculty, the professor is required to immediately report any incidence of sex discrimination or gender-based violence to the campus Title IX Coordinator. Although the Title IX Coordinator and professor cannot guarantee confidentiality, the student will still have options about how the case will be handled. The goal is to make sure the student is aware of the range of options available and has access to the necessary resources and support. For more information regarding sex discrimination and gender-based violence, the University's Title IX resources and the University's Policy, Interim EP 1.204, go to: http://www.hawaii.edu/titleix.
Student Conduct: Students are expected to follow the University of Hawaiʻi at Hilo Student Code of Conduct available at the following URL: http://www.uhh.hawaii.edu/catalog/student-conduct-code.html.