**Topic 0-1 Learning Outcomes**

Upon the successful completion of Topic 0-1, you will be able to:

1. Discuss what physics is, and compare/contrast it with other disciplines.
2. Discuss the benefits of intrinsic vs extrinsic motivations.
3. Explain the purpose of each component of the course structure.
4. Determine where to get help learning physics.
5. Determine where to find answers about course logistics that may come up throughout the term.
6. Identify the relative strengths and weaknesses in your prerequisite math skills, and make plans for improving the weaker areas.

**Topic 1-1 Learning Outcomes**

Upon the successful completion of Topic 1-1, you will be able to:

1. Qualitatively describe what the center of mass of the object is and how it is useful for describing the kinematics of large objects.
2. Distinguish between translational and rotational motion.
3. Define and describe the kinematic quantities for translational motion: position, velocity, and acceleration.
4. Use the kinematic definitions (both derivative and integral forms) to calculate or describe the position, velocity and acceleration of an object graphically, with equations, and with words.
5. Describe the difference between the *x* component of the velocity and the speed.
6. Describe the difference between indefinite and definite integrals, and explain it's advantageous to use definite integrals in physics.
7. Connect the motion you observe in an experiment to a graphical representation of that same motion.
8. Perform experiments using an iOLab to measure the motion of an object with careful consideration of its operating principles and limitations.

**Topic 1-2 Learning Outcomes**

Upon the successful completion of Topic 1-2, you will be able to:

1. Determine whether a physical quantity should be described with a vector or a scalar.
2. Utilize proper notation when describing vectors, magnitudes, and components of vectors, and explain what can go wrong if you don't.
3. Draw a vector graphically and write an equation for it using unit vector notation.
4. Add, subtract, and scalar multiply vectors graphically and using unit vector notation.
5. Recognize when a set of vectors add to zero.
6. Calculate the magnitude of a vector and the angle it makes with respect to an axis from its components.
7. Calculate the components of a vector (with sign) in a rectangular coordinate system from the magnitude and angle with respect to an axis.
8. Take derivatives and integrals of vector functions expressed in unit vector notation in a rectangular coordinate system.
9. Calculate the position, velocity, and acceleration of the center of mass of a system comprised of a discrete set of objects.

**Topic 1-3 Learning Outcomes**

Upon the successful completion of Topic 1-3, you will be able to:

1. Describe when an object can be treated as undergoing simple projectile motion.
2. For an object undergoing simple projectile motion, determine the horizontal and vertical components of its acceleration vector.
3. Derive the equations for the horizontal and vertical components of the velocity and position functions for an object undergoing simple projectile motion.
4. Use time as the “linking” variable between the horizontal and vertical motions of an object moving in 2D.
5. Describe conceptually and mathematically how the parameters in a simple projectile motion problem influence the characteristics of the motion.
6. For an object undergoing a nonzero vertical displacement, describe what physical situations correspond to the two values of time that you derive using kinematics, and pick the value appropriate for the situation you are analyzing.
7. Identify important information in the descriptions of physical motion (e.g., maximum height implies the vertical component of the velocity is zero), and incorporate it into your solution to a problem.
8. Derive the equations for the horizontal and vertical components of the velocity and position functions for an object undergoing not-so-simple projectile motion with a given acceleration function.
9. Recognize when the horizontal and vertical motions of an object can and cannot be treated independently.

**Topic 1-4 Learning Outcomes**

Upon the successful completion of Topic 1-4, you will be able to:

1. Solve “multi-segment” problems by computing the velocity and/or position functions at all times.
2. Solve “chase” problems using the kinematic relationships for two or more objects with different types of motion.
3. Calculate average (vector) quantities using:
    a. the difference method with vector notation.
    b. the difference method with graphical representations.
    c. the integral method with vector notation.
4. Calculate average magnitudes using the integral method.
5. Describe the difference between calculating the magnitude of the average of a kinematic quantity and the average of the magnitude.

**Topic 2-1 Learning Outcomes**

Upon the successful completion of Topic 2-1, you will be able to:

1. Define dynamics, and contrast it with kinematics.
2. Explain why a force can only arise as the result of two objects interacting, and label each force as a vector with two subscripts in the appropriate order.
3. Describe the eight forces we will typically work with in this class.
4. Compute the magnitude and state the direction of the weight force on an object (i.e., the gravitational force of Earth on an object near its surface).
5. Choose a system and determine which forces are internal and external to that system.
6. Draw a free body diagram for a system in the presence of external forces, and combine the forces to determine the net external force (magnitude and direction and/or components in a given coordinate system).
7. Identify Newton’s third law pairs.
8. Explain the difference between two forces being equal because of Newton’s third law and two forces that happen to be equal (in a particular situation) because of Newton’s second law.
9. For an object in contact with another, determine the directions of the normal forces between the two objects.
10. Solve dynamics problems with Newton’s second law.
11. Write the net force acting on an object using summation notation.

**Topic 2-2 Learning Outcomes**

Upon the successful completion of Topic 2-2, you will be able to:

1. Describe how a "contact force" can be broken up into two components (one parallel and one perpendicular to the contact surface), and state the names of those two components.
2. If an object is slipping with respect to another object, determine the magnitude and direction that kinetic friction is acting on each of the two objects.
3. If two objects are not slipping with respect to each other, determine the magnitude and direction that static friction is acting on each of the two objects (if it exists).
4. Compute the maximum force that static friction can obtain before two objects will slip with respect to each other.
5. Explain the difference between $f_{\mathrm{s,ab}}$ and $f_{\mathrm{s,ab,max}}$ and use them to determine whether or not two objects with slip with respect to each other.
6. Explain the factors influence your choice of coordinate system, and choose a coordinate system that provides the simplest solution path (e.g., upright, tilted).

**Topic 2-3 Learning Outcomes**

Upon the successful completion of Topic 2-3, you will be able to:

1. Construct a complete and well-presented solution to a given problem by applying the steps in the PHGN100 Problem Solving Process, even when you do not see at the outset what the solution will entail. Rather than following it blindly, be able to articulate the purpose of each step.
2. Define an inertial observer, and explain the implications of using a non-inertial observer.
3. Recognize “zero-acceleration intuition” situations, and use them to check your answers for systems that are accelerating.
4. Perform dimensional analysis on an algebraic solution, or unit analysis on a numerical solution, to check for potential errors.
5. Perform other “checks” on the reasonableness of a solution, such as: removing complicated effects, geometric limits, mass limits, and time limits.

**Topic 2-4 Learning Outcomes**

Upon the successful completion of Topic 2-4, you will be able to:

1. For scenarios involving multiple objects, solve for unknown forces or accelerations using multiple choices of systems with potentially different coordinate systems (i.e., "Kelso" problems, "Atwoods" problems, etc.).
2. Choose a series of subsystems that will give you enough (new) information to solve for your unknowns.
3. Describe the differences between "ideal" and "physical" pulleys.
4. Choose coordinate systems for multiple systems that allow you to write down consistent and correct forms of Newton's Second Law (e.g., choose the positive x-axis for each coordinate system to agree with the direction of motion).
5. Apply Newton's Second Law to a multi-object system such that the net force is equal to the total mass of the system multiplied by the acceleration of the center of mass.

**Topic 3-1 Learning Outcomes**

Upon the successful completion of Topic 3-1, you will be able to:

1. Define the kinematic quantities: angular position, angular velocity, and angular acceleration.
2. Apply the derivative forms of the kinematic definitions to relate the angular position, angular velocity, and angular acceleration of an object or set of objects graphically, with equations, and with words.
3. Apply the integral forms of the kinematic definitions to relate the angular position, angular velocity, and angular acceleration of an object or set of objects graphically, with equations, and with words.
4. Relate angular and linear quantities (position, velocity, and acceleration) via the radius of the motion.
5. For a particle translating in a circle, calculate centripetal acceleration from: the tangential velocity and radius, the angular velocity and radius, and the angular velocity and tangential velocity.
6. For a particle translating in a circle, calculate tangential acceleration from: the rate of change of the tangential velocity; and the rate of change of angular velocity and the radius.
7. For a particle undergoing uniform circular motion, relate the period, speed, angular speed, and radius of the motion.
8. Draw a free body diagram for a particle translating in a circle where the only forces acting on the object are due to physical interactions; determine the centripetal and tangential directions; and determine the direction the object is accelerating.
9. Apply the full version of the gravitational force law, rather than the approximation for objects near the surface of Earth, for “small” objects orbiting a massive body (e.g., a planet or sun).
10. Apply Newton’s Second Law of Translation to an object moving in a circle using the PHGN100 Problem Solving Process, paying particular attention to how you choose your coordinate system.

**Topic 3-2 Learning Outcomes**

Upon the successful completion of Topic 3-2, you will be able to:

1. Determine when a system will oscillate by identifying a net restoring force.
2. For a particle undergoing oscillatory motion, relate the period, frequency, and angular frequency of the motion.
3. Relate the force (magnitude and direction) exerted on a particle attached to a spring to the spring constant and displacement from the spring's rest length.
4. Relate the acceleration of a particle undergoing Simple Harmonic Motion (SHM) to the angular frequency of the motion and the object's displacement from the equilibrium position.
5. Use the initial conditions of an object undergoing SHM and kinematics to determine the correct position, velocity, and acceleration functions graphically and with equations.
6. Determine if a particle is undergoing SHM based on satisfying the criteria relating 1) the position and acceleration functions and 2) the amplitude and period.
7. Determine the angular frequency of a particle undergoing Simple Harmonic Motion by using Newton's second law to relate the position and acceleration functions.
8. Relate the amplitude, maximum magnitude of velocity, maximum magnitude of acceleration, and angular frequency for an object undergoing Simple Harmonic Motion.
9. Use a line of best fit from experimental data to determine a physical quantity.

**Topic 4-1 Learning Outcomes**

Upon the successful completion of Topic 4-1, you will be able to:

1. Calculate the magnitude and direction of the cross product of two vectors. You should be able to do this when the vectors are expressed in terms of magnitudes and angles (graphical method), and when they are expressed in unit vector notation (component method).
2. Compute the dot product of two vectors. You should be able to do this when the vectors are expressed in terms of magnitudes and angles (graphical method), and when they are expressed in unit vector notation (component method).
3. Recognize when the magnitude of the cross product of two vectors will be zero and when will be maximized.
4. Recognize when the dot product of two vectors will be positive, negative, or zero.
5. Compare and contrast the cross and dot products of two vectors.
6. Calculate line integrals of a vector over a given path.

**Topic 4-2 Learning Outcomes**

Upon the successful completion of Topic 4-2, you will be able to:

1. State Newton's 2nd Law for Rotation, and contrast it with Newton's 2nd Law for Translation.
2. For an extended object that is rotating, relate then angular and linear kinematic quantities that describe its motion and determine which ones are uniform over the extent of the object and which ones vary.
3. Describe how the moment of inertia of a rigid object would change when calculated about different axes.
4. For systems involving multiple extended objects rotation about a common axis, compute the total moment of inertia from the individual objects' moments of inertia.
5. Calculate the magnitude and direction of the torque due to a force about an axis of rotation. You should be able to do this when the vectors are expressed in terms of magnitudes and angles, and when they are expressed in unit vector notation.
6. Draw an extended free body diagram (EFBD) for an object in the presence of external forces and combine the torques about a given axis to determine the net external torque (magnitude and direction).
7. Determine where on an EFBD to represent a distributed force as a single force vector.

**Topic 4-3 Learning Outcomes**

Upon the successful completion of Topic 4-3, you will be able to:

1. Construct a complete and well-presented solution to a given rotational dynamics or statics problem by applying the steps in the Dynamics Problem Solving Process, even when you do not see at the outset what the solution will entail.
2. Compare and contrast the concepts necessary to analyze static and dynamic situations.
3. Compare and contrast "ideal" and "physical" pulleys.
4. Use Newton's $2^{nd}$ Law for rotation and translation to determine the magnitude and direction of a pin force.

**Topic 4-4 Learning Outcomes**

Upon the successful completion of Topic 4-4, you will be able to:

1. Describe what an object rolling without slipping looks like, including the directions and magnitudes of the velocity vectors of various pieces of the rolling object.
2. Apply the rolling without slipping condition with the correct sign, and using the appropriate radius in a situation with multiple radii, as a step in the PHGN100 Problem Solving Process.
3. Determine if friction is necessary (and if it is, what its type and direction is) for an object to roll without slipping in a given context.
4. Use Newton's Second Law for Translation and Rotation, along with the rolling without slipping condition, to determine which direction an object will roll without slipping (or if it is impossible to roll without slipping).

**Topic 5-1 Learning Outcomes**

Upon the successful completion of Topic 5-1, you will be able to:

1. Define work and translational kinetic energy.
2. Calculate the work done by two-dimensional, external forces that do (e.g., spring) and do not (e.g., weight) vary as a function of position via direct integration.
3. Describe the differences between conservative and non-conservative forces.
4. Apply the work-energy theorem to a particular choice of system to determine:
    a. unknown works,
    b. changes in energy,
    c. or whether or not the energy of a system is constant.
5. Discuss the features of a problem that make it easier to approach with the work-energy theorem vs. Newton's Laws and kinematics, and vice versa.
6. Discuss the difference between conservation and constancy of energy.

**Topic 5-2 Learning Outcomes**

Upon the successful completion of Topic 5-2, you will be able to:

1. Define rotational kinetic energy and thermal energy.
2. Compute the work due to an external force or corresponding torque, without double-counting.
3. Identify the displacement over which a force acts when an object is both translating and rotating (i.e., rolling without slipping).
4. Use the “no slip” condition to compute the change in kinetic energy for an object that is rolling without slipping.
5. Calculate the change in thermal energy of a system consisting of two objects slipping with respect to each other using the work-energy theorem.
6. Recognize when you have enough information to calculate the change in thermal energy of a single object, or when you can only calculate the change in thermal energy of the complete system of interacting objects.

**Topic 5-3 Learning Outcomes**

Upon the successful completion of Topic 5-3, you will be able to:

1. Define potential energy.
2. Calculate the change in potential energy due to two-dimensional, internal, conservative forces that do (e.g., spring, gravity) and do not (e.g., weight) vary as a function of position via direct integration.
3. Recognize when a force does work, contributes to a change in potential energy, or does neither of these things.
4. Describe how different choices of systems/subsystems for a given problem influence terms in the work-energy theorem.
5. Construct a complete and well-presented solution to a given work-energy theorem problem by applying the steps in the PHGN100 Problem Solving Process, even when you do not see at the outset what the solution will entail.
6. Determine when individual terms in the work-energy theorem will be positive, negative, zero, approximately zero, or “do not apply” for a given process.

**Topic 6-1 Learning Outcomes**

Upon the successful completion of Topic 6-1, you will be able to:

1. Define impulse and linear momentum.
2. Calculate the impulse via direct integration for two-dimensional forces that do and do not vary as a function of time.
3. Relate average force to an impulse (or change in linear momentum) and a time interval.
4. Apply the Impulse-Momentum theorem to a particular choice of system to determine unknown impulses and/or changes in linear momenta.
5. Relate the linear momentum of a system to its translational kinetic energy and know the limitations of getting one from the other.
6. Discuss the features of a problem that make it easier to approach with the Impulse-Momentum Theorem vs. the Work-Energy Theorem, and vice versa.

**Topic 6-2 Learning Outcomes**

Upon the successful completion of Topic 6-2, you will be able to:

1. Discuss the difference between constancy and conservation of linear momentum.
2. Describe the conditions under which the linear momenta of a system is approximately constant (e.g., in collisions and explosions).
3. Use constancy of linear momentum (where applicable, see above) to determine the initial or final momenta of a system of colliding (or interacting) objects.
4. Describe what it means for a collision to be elastic, inelastic, and perfectly inelastic.
5. Determine whether a collision is elastic, inelastic, or perfectly inelastic from information about the initial and final momenta of the particles involved in the collision.
6. Given a one-dimensional elastic collision, apply the impulse-momentum theorem and the one-dimensional elastic collision condition to determine unknown velocities or masses.

**Topic 6-3 Learning Outcomes**

Upon the successful completion of Topic 6-3, you will be able to:

1. Discuss the difference between constancy and conservation of angular momentum.
2. Define and calculate the angular momentum for a particle with respect to a point and for a rigid body rotating about an axis of symmetry.
3. Relate average torque to an angular impulse (or change in angular momentum) and a time interval.
4. Describe the conditions under which the angular momenta of a system is approximately constant (e.g., in “angular collisions”).
5. Use constancy of angular momentum (where applicable, see above) to determine the initial or final angular momenta of a system of colliding (or interacting) objects.
6. Relate the angular momentum of a system to its rotational kinetic energy and know the limitations of getting one from the other.

**Topic 7-1 Learning Outcomes**

Upon the successful completion of Topic 7-1, you will be able to:

1. Define potential energy function and compare/contrast it with the change in potential energy.
2. Use the graph of potential energy as a function of position to qualitatively and quantitatively determine the subsequent motion of an object and any turning points, if given initial conditions.
3. Determine the force given a corresponding potential energy function, and determine the potential energy function given a corresponding force.
4. Given a potential energy function, calculate the equilibrium positions and characterize their stability.
5. Recognize situations when it would be beneficial to analyze a graph of a potential energy function.

**Topic 7-2 Learning Outcomes**

Upon the successful completion of Topic 7-2, you will be able to:

1. Calculate the total mass, moment of inertia, and position of the center of mass for a set of discrete objects.
2. Determine how to slice up a uniform or nonuniform object such that the slices are stacked along the direction in which the mass density varies, making the density for each slice uniform.
3. Write an explicit expression for the differential mass element $dm$ of a slice in terms of $dl$, $dA$, or $dV$ and the density of the object.
4. For a given differential mass element $dm$ and rotation axis, determine the corresponding $dI$.
5. Using $dm$, calculate an objects total mass, moment of inertia about a specified axis, and position of the center of mass by taking the appropriate integrals (or recognizing that certain integrals will be zero due to symmetry).

**Topic 7-3 Learning Outcomes**

Upon the successful completion of Topic 7-3, you will be able to:

1. Calculate the vector $\vec{r}_{ab}$, its magnitude, and its corresponding unit vector from their definitions.
2. Explain what Newton's Universal Law of Gravitation means and why the two versions of it are equivalent.
3. Calculate the net gravitational force (both magnitude and direction) exerted on a point-like object with mass due to one or several other point-like objects with mass using both versions of Newton's Universal Law of Gravitation.
4. Calculate the net gravitational force (both magnitude and direction) exerted on a point-like object with mass due to an extended object with mass using calculus.
5. Calculate the net gravitational field (both magnitude and direction) at a point in space due to one or several point-like objects with mass.
6. Calculate the net gravitational field (both magnitude and direction) at a point in space due to an extended object with mass using calculus.
7. Use symmetry arguments to simplify your calculations for the net gravitational force on an object or the net gravitational field at a point.