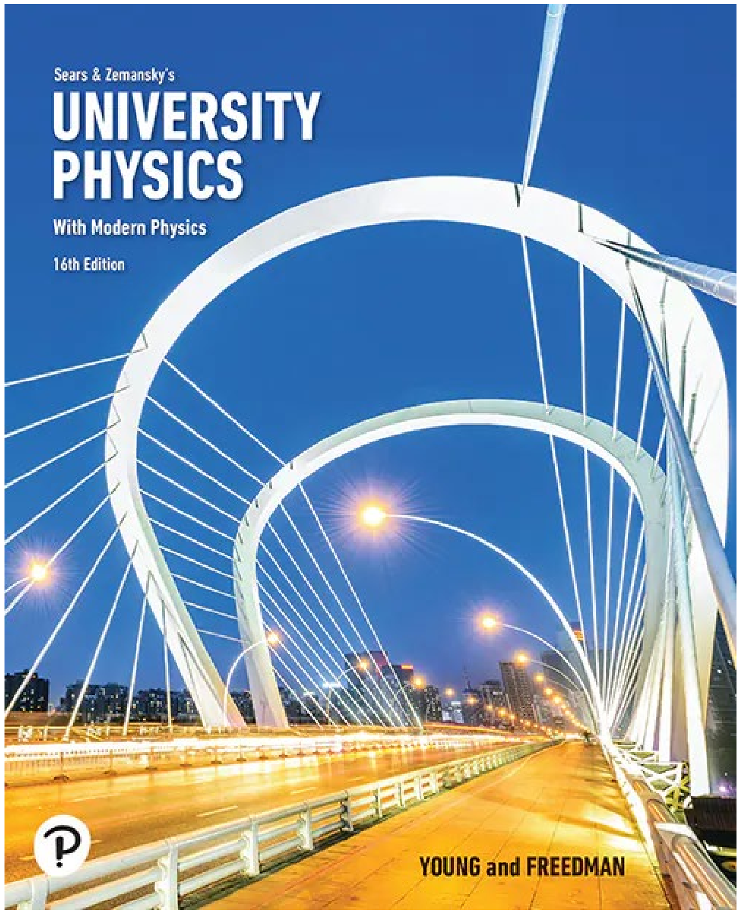
A Correlation of

University Physics

16th Edition



To the

AP® Physics C: Mechanics

Course Framework (Fall 2024)

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The units above reflect the College Board's AP® Physics C: Mechanics Course Framework.

Topic	Learning Objective	Essential Knowledge	University Physics 16e
1.1 Scalars and Vectors	1.1.A Describe a scalar or vector quantity using magnitude and direction, as appropriate.	1.1.A.1 Scalars are quantities described by magnitude only; vectors are quantities described by both magnitude and direction.	Section 1.7
		1.1.A.2 Vectors can be visually modeled as arrows with appropriate direction and lengths proportional to their magnitude.	Section 1.7
		1.1.A.3 Distance and speed are examples of scalar quantities, while position, displacement, velocity, and acceleration are examples of vector quantities.	Section 1.7
		1.1.A.4 Vectors can be expressed in unit vector notation or as a magnitude and a direction.	Sections 1.7, 1.8, 1.9
		1.1.A.5 In a given one-dimensional coordinate system, opposite directions are denoted by opposite signs.	Section 1.8
1.2 Displacement, Velocity, and Acceleration	1.2.A Describe a change in an object's position.	1.2.A.1 When using the object model, the size, shape, and internal configuration are ignored. The object may be treated as a single point with extensive properties such as mass and charge.	Section 2.1
		1.2.A.2 Displacement is the change in an object's position.	Section 2.1
	1.2.B Describe the average velocity and acceleration of an object.	1.2.B.1 Averages of velocity and acceleration are calculated considering the initial and final states of an object over an interval of time.	Sections 2.1, 2.3
		1.2.B.2 Average velocity is the displacement of an object divided by the interval of time in which that displacement occurs.	Section 2.1
		1.2.B.3 Average acceleration is the change in velocity divided by the interval of time in which that change in velocity occurs.	Section 2.3

		1.2.B.4 An object is accelerating if either the magnitude and/or direction of the object's velocity are changing.	Section 3.2
		1.2.B.5 Calculating average velocity or average acceleration over a very small time interval yields a value that is very close to the instantaneous velocity or instantaneous acceleration.	Sections 2.2, 2.3
	1.2.C Describe the instantaneous position, velocity, and acceleration of an object as a function of time.	1.2.C.1 As the time interval used to calculate the average value of a quantity approaches zero, the average value of that quantity approaches the value of the quantity at that instant, called the instantaneous value.	Sections 2.2, 2.3
		1.2.C.2 Time-dependent functions and instantaneous values of position, velocity, and acceleration can be determined using differentiation and integration.	Sections 2.2, 2.3, 2.6
1.3 Representing Motion	1.3.A Describe the position, velocity, and acceleration of an object using representations of that object's motion.	1.3.A.1 Motion can be represented by motion diagrams, figures, graphs, equations, and narrative descriptions.	Sections 2.1, 2,2, 2,3, 2.4, 2.5, 2.6
		1.3.A.2 For constant acceleration, three kinematic equations can be used to describe instantaneous linear motion in one dimension.	Section 2.4
		1.3.A.3 Near the surface of Earth, the vertical acceleration caused by the force of gravity is downward, constant, and has a measured value approximately equal to 10 m/s^2.	Section 2.5
		1.3.A.4 Graphs of position, velocity, and acceleration as functions of time can be used to find the relationships between those quantities.	Sections 2.1, 2,2, 2,3, 2.4, 2.5, 2.6

1.4 Reference Frames and Relative Motion	1.4.A Describe the reference frame of a given observer.	1.4.A.1 The choice of reference frame will determine the direction and magnitude of quantities measured by an observer in that reference frame.	Section 3.5
	1.4.B Describe the motion of objects as measured by observers in different inertial reference frames.	1.4.B.1 Measurements from a given reference frame may be converted to measurements from another reference frame.	Section 3.5
		1.4.B.2 The observed velocity of an object results from the combination of the object's velocity and the velocity of the observer's reference frame.	Section 3.5
1.5 Motion in Two or Three Dimensions	1.5.A Describe the motion of an object moving in two or three dimensions.	1.5.A.1 Motion in two or three dimensions can be analyzed using one-dimensional kinematic relationships if the motion is separated into components.	Sections 3.1, 3.2
		1.5.A.2 Velocity and acceleration may be different in each dimension and may be nonuniform.	Sections 3.1, 3.2
		1.5.A.3 Motion in one dimension may be changed without causing a change in a perpendicular dimension.	Sections 3.1, 3.2
		1.5.A.4 Projectile motion is a special case of two dimensional motion that has zero acceleration in one dimension and constant, nonzero acceleration in the second dimension.	Section 3.3

Topic	Learning Objective	Essential Knowledge	University Physics 16e
2.1 Systems and Center of Mass	2.1.A Describe the properties and interactions of a system.	2.1.A.1 System properties are determined by the interactions between objects within the system.	None
		2.1.A.2 If the properties or interactions of the constituent objects within a system are not important in modeling the behavior of the macroscopic system, the system can itself be treated as a single object.	None
		2.1.A.3 Systems may allow interactions between constituent parts of the system and the environment, which may result in the transfer of energy or mass.	None
		2.1.A.4 Individual objects within a chosen system may behave differently from each other as well as from the system as a whole.	None
		2.1.A.5 The internal structure of a system affects the analysis of that system.	None
		2.1.A.6 As variables external to a system are changed, the system's substructure may change.	None
	2.1.B Describe the location of a system's center of mass with respect to the system's constituent parts.	2.1.B.1 For objects or systems with symmetrical mass distributions, the center of mass is located on lines of symmetry.	Section 8.5
		2.1.B.2 The location of a system's center of mass along a given axis can be calculated.	Section 8.5
		2.1.B.3 For a nonuniform solid that can be considered as a collection of differential masses, the solid's center of mass can be calculated.	None
		2.1.B.4 A system can be modeled as a singular object that is located at the system's center of mass.	Section 8.5

2.2 Forces and Free-Body Diagrams	2.2.A Describe a force as an interaction between two objects or systems.	2.2.A.1 Forces are vector quantities that describe the interactions between objects or systems.	Section 4.1
		2.2.A.2 Contact forces describe the interaction of an object or system touching another object or system and are macroscopic effects of interatomic electric forces.	Section 4.1
	2.2.B Describe the forces exerted on an object or system using a free-body diagram.	2.2.B.1 Free-body diagrams are useful tools for visualizing forces being exerted on a single object or system and for determining the equations that represent a physical situation.	Section 4.6
		2.2.B.2 The free-body diagram of an object or system shows each of the forces exerted on the object or system by the environment.	Section 4.6
		2.2.B.3 Forces exerted on an object or system are represented as vectors originating from the representation of the center of mass, such as a dot. A system is treated as though all of its mass is located at the center of mass.	Section 4.6
		2.2.B.4 A coordinate system with one axis parallel to the direction of acceleration of the object or system simplifies the translation from free-body diagram to algebraic representation.	Section 5.2
2.3 Newton's Third Law	2.3.A Describe the interaction of two objects or systems using Newton's third law and a representation of paired forces exerted on each object or system.	2.3.A.1 Newton's third law describes the interaction of two objects or systems in terms of the paired forces that each exerts on the other.	Section 4.5
		2.3.A.2 Interactions between objects within a system (internal forces) do not influence the motion of a system's center of mass.	Section 4.3
		2.3.A.3 Tension is the macroscopic net result of forces that infinitesimal segments of a string, cable, chain, or similar system exert on each other in response to an external force.	None

2.4 Newton's First Law	2.4.A Describe the conditions under which a system's velocity remains constant.	2.4.A.1 The net force on a system is the vector sum of all forces exerted on the system.	Section 4.1
		2.4.A.2 Translational equilibrium is the configuration of forces such that the net force exerted on a system is zero.	Section 4.2
		2.4.A.3 Newton's first law states that if the net force exerted on a system is zero, the velocity of that system will remain constant.	Section 4.2
		2.4.A.4 Forces may be balanced in one dimension but unbalanced in another. The system's velocity will change only in the direction of the unbalanced force.	Section 4.2
		2.4.A.5 An inertial reference frame is one from which an observer would verify Newton's first law of motion.	Section 4.2
2.5 Newton's Second Law	2.5.A Describe the conditions under which a system's velocity changes.	2.5.A.1 Unbalanced forces are a configuration of forces such that the net force exerted on a system is not equal to zero.	Section 4.3
		2.5.A.2 Newton's second law of motion states that the acceleration of a system's center of mass has a magnitude proportional to the magnitude of the net force exerted on the system and is in the same direction as that net force.	Section 8.5
		2.5.A.3 The velocity of a system's center of mass will only change if a nonzero net external force is exerted on that system.	Section 8.5

2.6 Gravitational Force	2.6.A Describe the gravitational interaction between two objects or systems with mass.	2.6.A.1 Newton's law of universal gravitation describes the gravitational force between two objects or systems as directly proportional to each of their masses and inversely proportional to the square of the distance between the systems' centers of mass.	Section 13.1
		2.6.A.2 A field models the effects of a noncontact force exerted on an object at various positions in space.	Sections 13.1, 21.4
		2.6.A.3 The gravitational force exerted by an astronomical body on a relatively small nearby object is called weight.	Sections 4.4, 13.2
	2.6.B Describe situations in which the gravitational force can be considered constant.	2.6.B.1 If the gravitational force between two systems' centers of mass has a negligible change as the relative position of the two systems changes, the gravitational force can be considered constant at all points between the initial and final positions of the systems.	Section 4.4
		2.6.B.2 Near the surface of the Earth, the strength of the gravitational field is 10 N/kg.	Sections 2,5, 4.4
	2.6.C Describe the conditions under which the magnitude of a system's apparent weight is different from the magnitude of the gravitational force exerted on that system.	2.6.C.1 The magnitude of the apparent weight of a system is the magnitude of the normal force exerted on the system.	Section 5.2
		2.6.C.2 If the system is accelerating, the apparent weight of the system is not equal to the magnitude of the gravitational force exerted on the system.	Section 5.2
		2.6.C.3 A system appears weightless when there are no forces exerted on the system or when the force of gravity is the only force exerted on the system.	Section 5.2
		2.6.C.4 The equivalence principle states that an observer in a noninertial reference frame is unable to distinguish between an object's apparent weight and the gravitational force exerted on the object by a gravitational field.	Section 37.9

	2.6.D Describe inertial and gravitational mass.	2.6.D.1 Objects have inertial mass, or inertia, a property that determines how much an object's motion resists changes when interacting with another object.	Section 4.3
		2.6.D.2 Gravitational mass is related to the force of attraction between two systems with mass.	Section 13.1
		2.6.D.3 Inertial mass and gravitational mass have been experimentally verified to be equivalent.	None
	2.6.E Describe the gravitational force exerted on an object by a uniform spherical distribution of mass.	2.6.E.1 The net gravitational force exerted on an object by a uniform spherical distribution of mass is the sum of the individual forces from small differential masses that comprise the distribution.	Section 13.6
		2.6.E.2 Newton's shell theorem describes the net gravitational force exerted on an object by a uniform spherical shell of mass.	Section 13.6
		2.6.E.3 The gravitational force exerted on an object within a uniform sphere can be shown to be proportional to the object's distance from the sphere's center.	Section 13.6
2.7 Kinetic and Static Friction	2.7.A Describe kinetic friction between two surfaces.	2.7.A.1 Kinetic friction occurs when two surfaces in contact move relative to each other.	Section 5.3
		2.7.A.2 The magnitude of the kinetic friction force exerted on an object is the product of the normal force the surface exerts on the object and the coefficient of kinetic friction.	Section 5.3
	2.7.B Describe static friction between two surfaces.	2.7.B.1 Static friction may occur between the contacting surfaces of two objects that are not moving relative to each other.	Section 5.3
		2.7.B.2 Static friction adopts the value and direction required to prevent an object from slipping or sliding on a surface.	Section 5.3

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		2.7.B.3 The coefficient of static friction is typically greater than the coefficient of kinetic friction for a given pair of surfaces.	Section 5.3
2.8 Spring Forces	2.8.A Describe the force exerted on an object by an ideal spring.	2.8.A.1 An ideal spring has negligible mass and exerts a force that is proportional to the change in its length as measured from its relaxed length. A nonideal spring either has nonnegligible mass or exerts a force that is not proportional to the change in its length as measured from its relaxed length.	Sections 6.3, 14.1, 14.2
		2.8.A.2 The magnitude of the force exerted by an ideal spring on an object is given by Hooke's law.	Sections 6.3, 14.1, 14.2
		2.8.A.3 The force exerted on an object by a spring is always directed towards the equilibrium position of the object–spring system.	Sections 6.3, 14.1, 14.2
	2.8.B Describe the equivalent spring constant of a combination of springs exerting forces on an object.	2.8.B.1 A collection of springs that exert forces on an object may behave as though they were a single spring with an equivalent spring constant.	None
2.9 Resistive Forces	2.9.A Describe the motion of an object subject to a resistive force.	2.9.A.1 A resistive force is defined as a velocity-dependent force in the opposite direction of an object's velocity.	Section 5.3
		2.9.A.2 Applying Newton's second law to an object upon which a resistive force is exerted results in a differential equation for velocity.	Section 5.3
		2.9.A.3 Terminal velocity is defined as the maximum speed achieved by an object moving under the influence of a constant force and a resistive force that are exerted on the object in opposite directions. The terminal condition is reached when the net force exerted on the object is zero.	Section 5.3

2.10 Circular Motion	2.10.A Describe the motion of an object traveling in a circular path.	2.10.A.1 Centripetal acceleration is the component of an object's acceleration directed toward the center of the object's circular path.	Section 3.4
		2.10.A.2 Centripetal acceleration can result from a single force, more than one force, or components of forces that are exerted on an object in circular motion.	Section 5.4
		2.10.A.3 Tangential acceleration is the rate at which an object's speed changes and is directed tangent to the object's circular path.	Section 3.4
		2.10.A.4 The net acceleration of an object moving in a circle is the vector sum of the centripetal acceleration and tangential acceleration.	Section 3.4
		2.10.A.5 The revolution of an object traveling in a circular path at a constant speed (uniform circular motion) can be described using period and frequency.	Section 3.4
	2.10.B Describe circular orbits using Kepler's third law.	2.10.B.1 For a satellite in circular orbit around a central body, the satellite's centripetal acceleration is caused only by gravitational attraction. The period and radius of the circular orbit are related to the mass of the central body.	Section 13.5

Topic	Learning Objective	Essential Knowledge	University Physics 16e
3.1 Translational Kinetic Energy	3.1.A Describe the translational kinetic energy of an object in terms of the object's mass and speed.	3.1.A.1 An object's translational kinetic energy is equal to one-half of the product of the object's mass and its speed squared.	Section 6.2
		3.1.A.2 Translational kinetic energy is a scalar quantity.	Section 6.2
		3.1.A.3 Different observers may measure different values of the translational kinetic energy of an object, depending on the observer's frame of reference.	Section 6.2
3.2 Work	3.2.A Describe the work done on an object or system by a given force or collection of forces.	3.2.A.1 Work is the amount of energy transferred into or out of a system by a force exerted on that system over a distance.	Section 6.1
		3.2.A.2 Work is a scalar quantity that may be positive, negative, or zero.	Section 6.1
		3.2.A.3 The work done on an object by a variable force is calculated using the line integral of the force evaluated from the initial to the final positions.	Section 6.3
		3.2.A.4 The work–energy theorem states that the change in an object's kinetic energy is equal to the sum of the work being done by all forces exerted on the object.	Section 6.2
		3.2.A.5 Work is equal to the area under the curve of a graph of the parallel component of the force as a function of displacement.	Section 6.3

3.3 Potential Energy	3.3.A Describe the potential energy of a system.	3.3.A.1 A system composed of two or more objects has potential energy if the objects within that system only interact with each other through conservative forces.	Section 7.3
		3.3.A.2 Potential energy is a scalar quantity associated with the position of objects within a system.	Sections 7.1, 7.2
		3.3.A.3 The definition of zero potential energy for a given system is a decision made by the observer considering the situation to simplify or otherwise assist in analysis.	Section 7.1
		3.3.A.4 For conservative forces, the change in a system's potential energy is equal to the negative of the line integral of the force exerted on the system evaluated from the initial to the final positions.	Section 7.3
		3.3.A.5 The conservative forces exerted on a system in a single dimension can be determined using the slope of the system's potential energy with respect to position in that dimension; these forces point in the direction of decreasing potential energy.	Section 7.4
		3.3.A.6 Graphs of a system's potential energy as a function of its position can be useful in determining physical properties of that system.	Sections 7.4, 7.5
		3.3.A.7 The potential energy of common physical systems can be described using the physical properties of that system.	Sections 7.4, 7.5
		3.3.A.8 The total potential energy of a system containing more than two objects is the sum of the potential energy of each pair of objects within the system.	Section 23.1

3.4 Conservation of Energy	3.4.A Describe the energies present in a system.	3.4.A.1 A system composed of only a single object can only have kinetic energy.	Section 6.2
		3.4.A.2 A system that contains objects that interact via conservative forces or that can change its shape reversibly may have both kinetic and potential energies.	Section 7.3
	3.4.B Describe the behavior of a system using conservation of mechanical energy principles.	3.4.B.1 Mechanical energy is the sum of a system's kinetic and potential energies.	Section 7.3
		3.4.B.2 Any change to a type of energy within a system must be balanced by an equivalent change of other types of energies within the system or by a transfer of energy between the system and its surroundings.	Section 7.3
		3.4.B.3 A system may be selected so that the total energy of that system is constant.	Section 7.3
		3.4.B.4 If the total energy of a system changes, that change will be equivalent to the energy transferred into or out of the system.	Section 7.3
	3.4.C Describe how the selection of a system determines whether the energy of that system changes.	3.4.C.1 Energy is conserved in all interactions.	Section 7.3
		3.4.C.2 If the work done on a selected system is zero and there are no nonconservative interactions within the system, the total mechanical energy of the system is constant.	Section 7.3
		3.4.C.3 If the work done on a selected system is nonzero, energy is transferred between the system and the environment.	Section 7.3

3.5 Power	3.5.A Describe the transfer of energy into, out of, or within a system in terms of power.	3.5.A.1 Power is the rate at which energy changes with respect to time, either by transfer into or out of a system or by conversion from one type to another within a system.	Section 6.4
		3.5.A.2 Average power is the amount of energy being transferred or converted, divided by the time it took for that transfer or conversion to occur.	Section 6.4
		3.5.A.3 Because work is the change in energy of an object or system due to a force, average power is the total work done, divided by the time during which that work was done.	Section 6.4
		3.5.A.4 The instantaneous power delivered to an object by a force is equal to the derivative of the work done by the force with respect to time.	Section 6.4
		3.5.A.5 The instantaneous power delivered to an object by the component of a constant force parallel to the object's velocity is equal to the product of the parallel component of the force exerted on the object and the speed of the object.	Section 6.4

Topic	Learning Objective	Essential Knowledge	University Physics 16e
4.1 Linear Momentum	4.1.A Describe the linear momentum of an object or system.	4.1.A.1 Linear momentum is equal to the product of mass and velocity.	Section 8.1
		4.1.A.2 Momentum is a vector quantity and has the same direction as the velocity.	Section 8.1
		4.1.A.3 Momentum can be used to analyze collisions and explosions.	Sections 8.1, 8.3, 8.4
4.2 Change in Momentum and Impulse	4.2.A Describe the impulse delivered to an object or system.	4.2.A.1 The rate of change of a system's momentum is equal to the net external force exerted on that system.	Section 8.1
		4.2.A.2 Impulse is defined as the integral of a force exerted on an object or system over a time interval.	Section 8.1
		4.2.A.3 Impulse is a vector quantity and has the same direction as the net force exerted on the system.	Section 8.1
		4.2.A.4 The impulse delivered to a system by a net external force is equal to the area under the curve of a graph of the net external force exerted on the system as a function of time.	Section 8.1
		4.2.A.5 The net external force exerted on a system is equal to the slope of a graph of the momentum of the system as a function of time.	Section 8.1
	4.2.B Describe the relationship between the impulse exerted on an object or a system and the change in momentum of the object or system.	4.2.B.1 Change in momentum is the difference between a system's final momentum and its initial momentum.	Section 8.1
		4.2.B.2 The impulse–momentum theorem relates the impulse delivered to an object and the object's change in momentum.	Section 8.1

4.3 Conservation of Linear Momentum	4.3.A Describe the behavior of a system using conservation of linear momentum.	4.3.A.1 A collection of objects with individual momenta can be described as one system with one center-of-mass velocity.	Section 8.5
		4.3.A.2 The total momentum of a system is the sum of the momenta of the system's constituent parts.	Section 8.2
		4.3.A.3 In the absence of net external forces, any change to the momentum of an object within a system must be balanced by an equivalent and opposite change of momentum elsewhere within the system. Any change to the momentum of a system is due to a transfer of momentum between the system and its surroundings.	Section 8.2
		4.3.A.4 Correct application of conservation of momentum can be used to determine the velocity of a system immediately before and immediately after collisions or explosions.	Sections 8.2, 8.3
	4.3.B Describe how the selection of a system determines whether the momentum of that system changes.	4.3.B.1 Momentum is conserved in all interactions.	Section 8.2
		4.3.B.2 If the net external force on the selected system is zero, the total momentum of the system is constant.	Section 8.2
		4.3.B.3 If the net external force on the selected system is nonzero, momentum is transferred between the system and the environment.	Section 8.2

4.4 Elastic and Inelastic Collisions	4.4.A Describe whether an interaction between objects is elastic or inelastic.	4.4.A.1 An elastic collision between objects is one in which the initial kinetic energy of the system is equal to the final kinetic energy of the system.	Sections 8.3, 8.4
		4.4.A.2 In an elastic collision, the final kinetic energies of each of the objects within the system may be different from their initial kinetic energies.	Sections 8.3, 8.4
		4.4.A.3 An inelastic collision between objects is one in which the total kinetic energy of the system decreases.	Section 8.3
		4.4.A.4 In an inelastic collision, some of the initial kinetic energy is not restored to kinetic energy but is transformed by nonconservative forces into other forms of energy.	Section 8.3
		4.4.A.5 In a perfectly inelastic collision, the objects stick together and move with the same velocity after the collision.	Section 8.3

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5.1 Rotational Kinematics	5.1.A Describe the rotation of a system with respect to time using angular displacement, angular velocity, and angular acceleration.	5.1.A.1 Angular displacement is the measurement of the angle, in radians, through which a point on a rigid system rotates about a specified axis.	Section 9.1
		5.1.A.2 Angular velocity is the rate at which angular position changes with respect to time.	Section 9.1
		5.1.A.3 Angular acceleration is the rate at which angular velocity changes with respect to time.	Section 9.1
		5.1.A.4 Angular displacement, angular velocity, and angular acceleration around one axis are analogous to linear displacement, velocity, and acceleration in one dimension and demonstrate the same mathematical relationships.	Section 9.2
5.2 Connecting Linear and Rotational Motion	5.2.A Describe the linear motion of a point on a rotating rigid system that corresponds to the rotational motion of that point, and vice versa.	5.2.A.1 For a point at a distance from a fixed axis of rotation, the linear distance traveled by the point as the system rotates is equal to the product of the distance from the axis of rotation and the angle through which the system rotates.	Section 9.3
		5.2.A.2 Derived relationships of linear velocity and of the tangential component of acceleration to their respective angular quantities are given.	Section 9.3
		5.2.A.3 For a rigid system, all points within that system have the same angular velocity and angular acceleration.	Section 9.1

5.3 Torque	5.3.A Identify the torques exerted on a rigid system.	5.3.A.1 Torque results only from the force component perpendicular to the position vector from the axis of rotation to the point of application of the force.	Section 10.1
		5.3.A.2 The lever arm is the perpendicular distance from the axis of rotation to the line of action of the exerted force.	Section 10.1
	5.3.B Describe the torques exerted on a rigid system.	5.3.B.1 Torques can be described using force diagrams.	Section 10.1
		5.3.B.2 The torque exerted on a rigid system about a chosen pivot point by a given force is equal to the cross-product of the position where the force is applied and the force.	Section 10.1
5.4 Rotational Inertia	5.4.A Describe the rotational inertia of a rigid system relative to a given axis of rotation.	5.4.A.1 Rotational inertia measures a rigid system's resistance to changes in rotation and is related to the mass of the system and the distribution of that mass relative to the axis of rotation.	Section 9.4
		5.4.A.2 The rotational inertia of an object rotating a perpendicular distance r from an axis is described by the equation $I = mr^2$.	Section 9.4
		5.4.A.3 The total rotational inertia of a collection of objects about an axis is the sum of the rotational inertias of each object about that axis.	Section 9.4
		5.4.A.4 For a solid that can be considered as a collection of differential masses, dm, the solid's rotational inertia can be calculated using the integral of $r^2 dm$, where r is the perpendicular distance from dm to the axis of rotation.	Section 9.6

	5.4.B Describe the rotational inertia of a rigid system rotating about an axis that does not pass through the system's center of mass.	5.4.B.1 A rigid system's rotational inertia in a given plane is at a minimum when the rotational axis passes through the system's center of mass. 5.4.B.2 The parallel axis theorem relates the rotational inertia of a rigid system about any axis that is parallel to an axis through its center of mass.	Section 9.5 Section 9.5
5.5 Rotational Equilibrium and Newton's First Law in Rotational Form	5.5.A Describe the conditions under which a system's angular velocity remains constant.	5.5.A.1 A system may exhibit rotational equilibrium (constant angular velocity) without being in translational equilibrium, and vice versa. 5.5.A.2 A rotational corollary to Newton's second law states that if the torques exerted on a rigid system are not balanced, the system's angular velocity must be changing.	Sections 11.1, 11.3 Sections 11.1, 11.3
5.6 Newton's Second Law in Rotational Form	5.6.A Describe the conditions under which a system's angular velocity changes.	5.6.A.1 Angular velocity changes when the net torque exerted on the object or system is not equal to zero. 5.6.A.2 The rate at which the angular velocity of a rigid system changes is directly proportional to the net torque exerted on the rigid system and is in the same direction. The angular acceleration of the rigid system is inversely proportional to the rotational inertia of the rigid system. 5.6.A.3 To fully describe a rotating rigid system, linear and rotational analyses may need to be performed independently.	Section 10.2 Section 10.2 Section 10.2

Topic	Learning Objective	Essential Knowledge	University Physics 16e
6.1 Rotational Kinetic Energy	6.1.A Describe the rotational kinetic energy of a rigid system in terms of the rotational inertia and angular speed of that rigid system.	6.1.A.1 The rotational kinetic energy of an object or rigid system is equal to is equal to one-half of the product of the rotational inertia and angular speed squared.	Section 9.4
		6.1.A.2 A rigid system can have rotational kinetic energy while its center of mass is at rest due to the individual points within the rigid system having linear speed and, therefore, kinetic energy.	Section 9.4
		6.1.A.3 Rotational kinetic energy is a scalar quantity.	Section 9.4
6.2 Torque and Work	6.2.A Describe the work done on a rigid system by a given torque or collection of torques.	6.2.A.1 A torque can transfer energy into or out of an object or rigid system if the torque is exerted over an angular displacement.	Section 10.4
		6.2.A.2 The amount of work done on a rigid system by a torque is related to the magnitude of that torque and the angular displacement through which the rigid system rotates during the interval in which that torque is exerted.	Section 10.4
		6.2.A.3 Work done on a rigid system by a given torque can be found from the area under the curve of a graph of the torque as a function of angular position.	Section 10.4
6.3 Angular Momentum and Angular Impulse	6.3.A Describe the angular momentum of an object or rigid system.	6.3.A.1 The magnitude of the angular momentum of a rigid system about a specific axis is equal to the product of the rotational inertia and angular speed.	Section 10.5
		6.3.A.2 The angular momentum of an object about a given point is equal to the cross-product of the position and the linear momentum.	Section 10.5

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	6.3.B Describe the angular impulse delivered to an object or rigid system by a torque.	6.3.B.1 Angular impulse is defined as the product of the torque exerted on an object or rigid system and the time interval during which the torque is exerted.	None
		6.3.B.2 Angular impulse has the same direction as the torque imparting it.	None
		6.3.B.3 The angular impulse delivered to an object or rigid system by a torque can be found from the area under the curve of a graph of the torque as a function of time.	None
	6.3.C Relate the change in angular momentum of an object or rigid system to the angular impulse given to that object or rigid system.	6.3.C.1 The magnitude of the change in angular momentum can be described by comparing the magnitudes of the final and initial momenta of the object or rigid system.	Section 10.5
		6.3.C.2 A rotational form of the impulse–momentum theorem relates the angular impulse delivered to an object or rigid system and the change in angular momentum of that object or rigid system.	None
		6.3.C.3 The net torque exerted on an object or rigid system is equal to the slope of the graph of the angular momentum of an object as a function of time.	Section 10.5
		6.3.C.4 The angular impulse delivered to an object or rigid system is equal to the area under the curve of a graph of the net external torque exerted on an object as a function of time.	None
6.4 Conservation of Angular Momentum	6.4.A Describe the behavior of a system using conservation of angular momentum.	6.4.A.1 The total angular momentum of a system about a rotational axis is the sum of the angular momenta of the system's constituent parts about that rotational axis.	Section 10.5
		6.4.A.2 Any change to a system's angular momentum must be due to an interaction between the system and its surroundings.	Section 10.5

	6.4.B Describe how the selection of a system determines whether the angular momentum of that system changes.	6.4.B.1 Angular momentum is conserved in all interactions.	Section 10.6
		6.4.B.2 If the net external torque exerted on a selected object or rigid system is zero, the total angular momentum of that system is constant.	Section 10.6
		6.4.B.3 If the net external torque exerted on a selected object or rigid system is nonzero, angular momentum is transferred between the system and the environment.	Section 10.6
6.5 Rolling	6.5.A Describe the kinetic energy of a system that has translational and rotational motion.	6.5.A.1 The total kinetic energy of a system is the sum of the system's translational and rotational kinetic energies.	Section 10.3
	6.5.B Describe the motion of a system that is rolling without slipping.	6.5.B.1 While rolling without slipping, the translational motion of a system's center of mass is related to the rotational motion of the system itself.	Section 10.3
		6.5.B.2 For ideal cases, rolling without slipping implies that the frictional force does not dissipate any energy from the rolling system.	Section 10.3
	6.5.C Describe the motion of a system that is rolling while slipping.	6.5.C.1 When slipping, the motion of a system's center of mass and the system's rotational motion cannot be directly related.	Section 10.3
		6.5.C.2 When a rotating system is slipping relative to another surface, the point of application of the force of kinetic friction exerted on the system moves with respect to the surface, so the force of kinetic friction will dissipate energy from the system.	None

6.6 Motion of Orbiting Satellites	6.6.A Describe the motions of a system consisting of two objects interacting only via gravitational forces.	6.6.A.1 In a system consisting only of a massive central object and an orbiting satellite with mass that is negligible in comparison to the central object's mass, the motion of the central object itself is negligible.	Section 13.5
		6.6.A.2 The motion of satellites in orbits is constrained by conservation laws.	Section 13.4
		6.6.A.3 The total energy of a system consisting of a satellite orbiting a central object in a circular path can be written in terms of the gravitational potential energy of that system or the kinetic energy of the satellite.	Section 13.4
		6.6.A.4 The escape speed of a satellite is the satellite's speed such that the mechanical energy of the satellite–central-object system is equal to zero.	Section 13.3

Topic	**Learning Objective**	**Essential Knowledge**	**University Physics 16e**
7.1 Defining Simple Harmonic Motion (SHM)	7.1.A Describe simple harmonic motion.	7.1.A.1 Simple harmonic motion is a special case of periodic motion.	Section 14.2
		7.1.A.2 SHM results when the magnitude of the restoring force exerted on an object is proportional to that object's displacement from its equilibrium position.	Section 14.2
7.2 Frequency and Period of SHM	7.2.A Describe the frequency and period of an object exhibiting SHM.	7.2.A.1 The period of SHM is related to the frequency and angular frequency by the equation $T = 2\pi/\omega = 1/f$.	Sections 14.1, 14.2
7.3 Representing and Analyzing SHM	7.3.A Describe the displacement, velocity, and acceleration of an object exhibiting SHM.	7.3.A.1 For an object exhibiting SHM, the displacement of that object measured from its equilibrium position can be represented by the equations $x = A\cos(2\pi ft)$ or $x = A\sin(2\pi ft)$.	Section 14.2
		7.3.A.2 The position as a function of time for an object exhibiting SHM is a solution of the second-order differential equation derived from the application of Newton's second law.	Section 14.2
		7.3.A.3 Characteristics of SHM, such as velocity and acceleration, can be determined by or derived from the equation $x = A\cos(\omega t + \varphi)$.	Section 14.2
		7.3.A.4 In the presence of a sinusoidal external force, a system may exhibit resonance.	Section 14.8
		7.3.A.5 Changing the amplitude of a system exhibiting SHM will not change its period.	Section 14.2
		7.3.A.6 Properties of SHM can be determined and analyzed using graphical representations.	Section 14.2

7.4 Energy of Simple Harmonic Oscillators	7.4.A Describe the mechanical energy of a system exhibiting SHM.	7.4.A.1 The total energy of a system exhibiting SHM is the sum of the system's kinetic and potential energies.	Section 14.3
		7.4.A.2 Conservation of energy indicates that the total energy of a system exhibiting SHM is constant.	Section 14.3
		7.4.A.3 The kinetic energy of a system exhibiting SHM is at a maximum when the system's potential energy is at a minimum.	Section 14.3
		7.4.A.4 The potential energy of a system exhibiting SHM is at a maximum when the system's kinetic energy is at a minimum.	Section 14.3
7.5 Simple and Physical Pendulums	7.5.A Describe the properties of a physical pendulum.	7.5.A.1 A physical pendulum is a rigid body that undergoes oscillation about a fixed axis.	Section 14.6
		7.5.A.2 For small amplitudes of motion, the period of a physical pendulum is derived from the application of Newton's second law in rotational form.	Section 14.6
		7.5.A.3 A simple pendulum is a special case of physical pendulums in which the hanging object can be modeled as a point mass at a distance from the pivot point.	Section 14.5
		7.5.A.4 A torsion pendulum is a case of SHM where the restoring torque is proportional to the angular displacement of a rotating system.	Section 14.4

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