Introduction: Rotational Statics & Dynamics

Unit: Rotational Statics & Dynamics

Topics covered in this chapter:

Centripetal Force 351
Rotational Inertia 356
Torque 364
Solving Linear & Rotational Force/Torque Problems 373

In this chapter you will learn about different kinds of forces and how they relate.

- *Centripetal Force* describes the forces experienced by an object moving in a circle.
- *Rotational Inertia,* and *Torque* describe the relationship between forces and rotation.
- *Solving Linear & Rotational Force/Torque Problems* discusses situations where torque is converted to linear motion and *vice versa*.

AP® This unit is part of *Unit 2: Force and Translational Dynamics* and *Unit 5: Torque and Rotational Dynamics* from the 2024 AP® Physics 1 Course and Exam Description.

Standards addressed in this chapter:

NGSS Standards/MA Curriculum Frameworks (2016):

HS-PS2-1. Analyze data to support the claim that Newton's second law of motion describes the mathematical relationship among the net force on a macroscopic object, its mass, and its acceleration.

HS-PS2-10(MA). Use free-body force diagrams, algebraic expressions, and Newton's laws of motion to predict changes to velocity and acceleration for an object moving in one dimension in various situations.

AP® **AP® Physics 1 Learning Objectives/Essential Knowledge (2024):**

2.9.A: Describe the motion of an object traveling in a circular path.

2.9.A.1: Centripetal acceleration is the component of an object's acceleration directed toward the center of the object's circular path.

2.9.A.1.i: The magnitude of centripetal acceleration for an object moving in a circular path is the ratio of the object's tangential speed squared to the radius of the circular path.

2.9.A.1.ii: Centripetal acceleration is directed toward the center of an object's circular path.

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2.9.A.2: Centripetal acceleration can result from a single force, more than one force, or components of forces exerted on an object in circular motion.

2.9.A.2.i.: At the top of a vertical, circular loop, an object requires a minimum speed to maintain circular motion. At this point, and with this minimum speed, the gravitational force is the only force that causes the centripetal acceleration.

2.9.A.2.ii: Components of the static friction force and the normal force can contribute to the net force producing centripetal acceleration of an object traveling in a circle on a banked surface.

2.9.A.2.iii: A component of tension contributes to the net force producing centripetal acceleration experienced by a conical pendulum.

2.9.A.3: Tangential acceleration is the rate at which an object's speed changes and is directed tangent to the object's circular path.

2.9.A.4: The net acceleration of an object moving in a circle is the vector sum of the centripetal acceleration and tangential acceleration.

2.9.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.

2.9.A.5.i: The time to complete one full circular path, one full rotation, or a full cycle of oscillatory motion is defined as period, *T*.

2.9.A.5.ii: The rate at which an object is completing revolutions is defined as frequency, $f = \frac{1}{T}$.

2.9.A.5.iii: For an object traveling at a constant speed in a circular path, the period is given by the derived equation $T = \frac{2\pi r}{v}$.

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.

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.

5.3.B: Describe the torques exerted on a rigid system.

5.3.B.1: Torques can be described using force diagrams.

5.3.B.1.i: Force diagrams are similar to free-body diagrams and are used to analyze the torques exerted on a rigid system.

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5.3.B.1.ii: Similar to free-body diagrams, force diagrams represent the relative magnitude and direction of the forces exerted on a rigid system. Force diagrams also depict the location at which those forces are exerted relative to the axis of rotation.

5.3.B.2: The magnitude of the torque exerted on a rigid system by a force is described by the following equation, where is the angle between the force vector and the position vector from the axis of rotation to the point of application of the force.

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.

5.4.A.2: The rotational inertia of an object rotating a perpendicular distance r from an axis is described by the equation $I = mr^2$.

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: $I_{tot} = \sum I_i = \sum m_i r_i^2$

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 uses the following equation to relate the rotational inertia of a rigid system about any axis that is parallel to an axis through its center of mass: $I' = I_{cm} + Md^2$.

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.1.i: Free-body and force diagrams describe the nature of the forces and torques exerted on an object or rigid system.

5.5.A.1.ii: Rotational equilibrium is a configuration of torques such that the net torque exerted on the system is zero.

5.5.A.1.iii: The rotational analogue of Newton's first law is that a system will have a constant angular velocity only if the net torque exerted on the system is zero.

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.

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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.

Skills learned & applied in this chapter:

- Solving chains of equations.
- Using geometry and trigonometry to combine forces (vectors).

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