05 Torque and Rotational Dynamics

Content Area: **Science**
Course(s): **AP Physics C**
Time Period: **Semester 1**
Length: **3 weeks**
Status: **Published**

Standards

SCI.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.
	Analyzing and Interpreting Data
SCI.HS.PS2.A	Forces and Motion
	Cause and Effect

AP Physics C Learning Objectives

Note: Learning Objectives are taken verbatim from the AP Physics C - Mechanics Course and Exam Description. The verb "describe" could refer to a variety of different methods of expression (e.g. words, diagrams, graphs, mathematical expressions), as appropriate.

Describe the rotation of a system with respect to time using angular displacement, angular velocity, and angular acceleration.

Describe the linear motion of a point on a rotating rigid system that corresponds to the rotational motion of that point, and vice versa.

Identify the torques exerted on a rigid system.

Describe the torques exerted on a rigid system.

Describe the rotational inertia of a rigid system relative to a given axis of rotation.

Describe the rotational inertia of a rigid system rotating about an axis that does not pass through the system's center of mass.

Describe the conditions under which a system's angular velocity remains constant.

Describe the conditions under which a system's angular velocity changes.

Enduring Understandings

Interactions produce changes in motion.

Forces characterize interactions between objects or systems.

There are relationships among the physical properties of angular velocity, angular position, and angular acceleration.

A net torque acting on a rigid body will produce rotational motion about a fixed axis.

When a physical system involves an extended rigid body, there are two conditions of equilibrium - a translational condition and a rotational condition.

Essential Questions

Why does a curveball take less time to reach the plate than a fastball?

Why is it easier to balance a bicycle when it's in motion?

Why are long wrenches more effective?

Why does it matter where a door handle is placed?

Knowledge and Skills

Topic 5.1 Rotational Kinematics

Knowledge:

- Angular displacement is the measurement of the angle, in radians, through which a point on a rigid system rotates about a specified axis.
- A rigid system is one that holds its shape but in which different points on the system move in different directions during rotation. A rigid system cannot be modeled as an object.
- One direction of angular displacement about an axis of rotation — clockwise or counterclockwise — is typically indicated as mathematically positive, with the other direction becoming mathematically negative.
- If the rotation of a system about an axis may be well described using the motion of the system's center of mass, the system may be treated as a single object. For example, the rotation of Earth about its axis may be considered negligible when considering the revolution of Earth about the center of mass of the Earth-Sun system.
- Angular velocity is the rate at which angular position changes with respect to time.
- Angular acceleration is the rate at which angular velocity changes with respect to time.
- 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.
- For constant angular acceleration, the mathematical relationships between angular displacement, angular velocity, and angular acceleration can be described with the following equations:

Graphs of angular displacement, angular velocity, and angular acceleration as functions of time can be used to find the relationships between those quantities.

Skills:

- Create qualitative sketches of graphs that represent features of a model or the behavior of the physical system.
- Calculate or estimate an unknown quantity with units from known quantities, by selecting and following a logical computational pathway.
- Predict new values or factors of change of physical quantities using functional dependence between variables.
- Apply an appropriate law, definition, theoretical relationship, or model to make a claim.

Topic 5.2 Connecting Linear and Rotational Motion

Knowledge:

- For a point at a distance r from a fixed axis of rotation, the linear distance s traveled by the point as the system rotates through an angle is given by the equation .
- Derived relationships of linear velocity and of the tangential component of acceleration to their respective angular quantities are given by the following equations:
- For a rigid system, all points within that system have the same angular velocity and angular acceleration.

Skills:

- Create qualitative sketches of graphs that represent features of a model or the behavior of the physical system.
- Derive a symbolic expression from known quantities by selecting and following a logical mathematical pathway.
- Compare physical quantities between two or more scenarios or at different times and/or locations within a single scenario.
- Apply an appropriate law, definition, theoretical relationship, or model to make a claim.

Topic 5.3 Torque

Knowledge:

- 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.
- The lever arm is the perpendicular distance from the axis of rotation to the line of action of the exerted force.
- Torques can be described using force diagrams.
- Force diagrams are similar to free-body diagrams and are used to analyze the torques exerted on a rigid system.
- 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.
- The torque exerted on a rigid system about a chosen pivot point by a given force is described by
- The cross-product between two vectors, A and B, results in a vector quantity of magnitude
- The direction of the vector resulting from the cross-product of vectors A and B is perpendicular to both vectors A and B and therefore is normal to the plane defined by vectors A and B.
- The direction of the vector resulting from the cross-product of vectors A and B can be qualitatively determined by applying the appropriate right-hand rule.

Skills:

- Create diagrams, tables, charts, or schematics to represent physical situations.
- Calculate or estimate an unknown quantity with units from known quantities, by selecting and following a logical computational pathway.
- Compare physical quantities between two or more scenarios or at different times and/or locations within a single scenario.
- Justify or support a claim using evidence from experimental data, physical representations, or physical principles or laws.

Topic 5.4 Rotational Inertia

Knowledge:

- 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.
- The rotational inertia of an object rotating a perpendicular distance r from an axis is described by the equation .
- 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.
- For a solid that can be considered as a collection of differential masses, dm, the solid's rotational inertia can be calculated using the equation, , where r is the perpendicular distance from dm to the axis of rotation.
- 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.
- 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: .

Skills:

- Create quantitative graphs with appropriate scales and units, including plotting data.
- Derive a symbolic expression from known quantities by selecting and following a logical mathematical pathway.
- Compare physical quantities between two or more scenarios or at different times and/or locations within a single scenario.
- Create experimental procedures that are appropriate for a given scientific question.
- Apply an appropriate law, definition, theoretical relationship, or model to make a claim.

Topic 5.5 Rotational Equilibrium and Newton's First Law in Rotational Form

Knowledge:

- A system may exhibit rotational equilibrium (constant angular velocity) without being in translational equilibrium, and vice versa.
- Free-body and force diagrams describe the nature of the forces and torques exerted on an object or rigid system.
- Rotational equilibrium is a configuration of torques such that the net torque exerted on the system is zero.
- The rotational analog 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.
- 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.

Skills:

- Create diagrams, tables, charts, or schematics to represent physical situations.
- Derive a symbolic expression from known quantities by selecting and following a logical mathematical pathway.
- Compare physical quantities between two or more scenarios or at different times and/or locations within a single scenario.
- Apply an appropriate law, definition, theoretical relationship, or model to make a claim.

Topic 5.6 Newton's Second Law in Rotational Form

Knowledge:

- Angular velocity changes when the net torque exerted on the object or system is not equal to zero.
- 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.
- To fully describe a rotating rigid system, linear and rotational analyses may need to be performed independently.

Skills:

- Create quantitative graphs with appropriate scales and units, including plotting data.
- Derive a symbolic expression from known quantities by selecting and following a logical mathematical pathway.
- Predict new values or factors of change of physical quantities using functional dependence between variables.
- Create experimental procedures that are appropriate for a given scientific question.
- Justify or support a claim using evidence from experimental data, physical representations, or physical principles or laws.

Transfer Goals

Unit 5 reinforces the Unit 2 ideas of force and linear motion by introducing students to the rotational analogs of torque and rotational motion. Although these topics present more complex scenarios, the tools of analysis remain the same: The content and models explored in the first four units of AP Physics C: Mechanics set the foundation for Units 5 and 6. During their study of torque and rotational motion, students will be introduced to different ways of modeling forces. Throughout Units 5 and 6, students will compare and connect their understanding of linear and rotational motion, dynamics, energy, and momentum to develop holistic models to evaluate physical phenomena.

Assessments

https://docs.google.com/document/d/1wR7bQF-8AQoRrt0g4C3hKja0yjwDjC9_BiAmONWbTcI/edit?usp=sharing

Modifications

https://docs.google.com/document/d/1ODqaPP69YkcFiyG72fIT8XsUIe3K1VSG7nxuc4CpCec/edit?usp=sharing