05 Torque and Rotational Dynamics

Content Area: **Science**
Course(s): **AP Physics 1**
Time Period: **Semester 2**
Length: **10 Periods**
Status: **Published**

Standards

SCI.HS.PS2.B	Types of Interactions
	Attraction and repulsion between electric charges at the atomic scale explain the structure, properties, and transformations of matter, as well as the contact forces between material objects.
	Patterns
	Constructing explanations and designing solutions in 9–12 builds on K–8 builds on K–8 experiences and progresses to explanations and designs that are supported by multiple and independent student-generated sources of evidence consistent with scientific ideas, principles, and theories.
	Apply scientific principles and evidence to provide an explanation of phenomena and solve design problems, taking into account possible unanticipated effects.
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.
SCI.HS.PS2.A	Forces and Motion
	Newton's second law accurately predicts changes in the motion of macroscopic objects.
	Cause and Effect
SCI.HS-PS2-4	Use mathematical representations of Newton's Law of Gravitation and Coulomb's Law to describe and predict the gravitational and electrostatic forces between objects.
	Scale, Proportion, and Quantity
	Using Mathematics and Computational Thinking
SCI.HS-ESS1-4	Use mathematical or computational representations to predict the motion of orbiting objects in the solar system.
SCI.HS.ESS1.B	Earth and the Solar System
	Analyzing and Interpreting Data

Enduring Understandings

All forces share certain common characteristics when considered by observers in inertial reference frames.

A force exerted on an object can cause a torque on that object.

Essential Questions

1. Why does it matter where a door handle is placed?
2. Why are long wrenches more effective?
3. What do mobiles have in common with the Grand Canyon Skywalk?
4. Why does a tightrope walker use a long pole?

Knowledge and Skills

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.
- Average angular velocity is the average rate at which angular position changes with respect to time.
- Average angular acceleration is the average rate at which the 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:

    $$\omega = \omega_0 + \alpha t$$

    $$\theta = \theta_0 + \omega t + \frac{1}{2}\alpha t^2$$

    $$\omega^2 = \omega_0^2 + 2\alpha(\theta - \theta_0)$$
  - 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 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

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 $\Delta\theta$ is given by the equation $\Delta s = r\Delta\theta$.

- Derived relationships of linear velocity and of the tangential component of acceleration to their respective angular quantities are given by the following equations:

  $s = r\theta$

  $v = r\omega$

  $aT = r\alpha$

- 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 a 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 locations in a single scenario.
- Apply an appropriate law, definition, theoretical relationship, or model to make a claim.

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

$$\tau = rT_{\perp} = rF\sin\theta$$

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.
- 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

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 I = mr2.
- 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: $I_{tot} = \sum_i I_i = \sum_i m_i r_i^2$

- 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: $I = I_{cm} + Md^2$

Skills

- Create quantitative graphs with appropriate scales and units, including plotting data.
- 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 locations in 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.

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 qualitative sketches of graphs that represent features of a model or the behavior of a physical system.
- Derive a symbolic expression from known quantities by selecting and following a logical mathematical pathway.
- Calculate or estimate an unknown quantity with units from known quantities, by selecting and following a logical computational pathway.
- Apply an appropriate law, definition, theoretical relationship, or model to make a claim

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 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 locations in a single scenario.
- Justify or support a claim using evidence from experimental data, physical representations, or physical principles or laws.

Transfer Goals

Patterns: Observed patterns in nature guide organization and classification and prompt questions about relationships and causes underlying them.

Cause and Effect: Events have causes, sometimes simple, sometimes multifaceted. Deciphering causal relationships, and the mechanisms by which they are mediated, is a major activity of science and engineering.

Scale, Proportion, and Quantity: In considering phenomena, it is critical to recognize what is relevant at different size, time, and energy scales, and to recognize proportional relationships between different quantities as scales change.

Systems and System Models: A system is an organized group of related objects or components; models can be used for understanding and predicting the behavior of systems.

Energy and Matter: Tracking energy and matter flows, into, out of, and within systems helps one understand their system's behavior.

Structure and Function: The way an object is shaped or structured determines many of its properties and functions.

Stability and Change: For both designed and natural systems, conditions that affect stability and factors that control rates of change are critical elements to consider and understand.

Assessments

https://docs.google.com/document/d/1wR7bQF-8AQoRrt0g4C3hKja0yjwDjC9_BiAmONWbTcl/edit?usp=sharing

Modifications

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