06 Energy and Momentum of Rotating Systems

Content Area:	**Science**
Course(s):	
Time Period:	**Semester 2**
Length:	**5 weeks**
Status:	**Published**

Standards

SCI.HS.PS2.A	Forces and Motion
SCI.HS.PS2.B	Types of Interactions
SCI.HS.ESS1.B	Earth and the Solar System
SCI.HS-ESS1-4	Use mathematical or computational representations to predict the motion of orbiting objects in the solar system.
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-PS2-4	Use mathematical representations of Newton's Law of Gravitation and Coulomb's Law to describe and predict the gravitational and electrostatic forces between objects.
	Cause and Effect
	Scale, Proportion, and Quantity
	Analyzing and Interpreting Data
	Using Mathematics and Computational Thinking
	Patterns

Enduring Understandings

Rotational Kinematics

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

Torque and Angular Acceleration

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

Angular Momentum and Torque

A net torque exerted on a system by other objects or systems will change the angular momentum of the system.

Conservation of Angular Momentum

The angular momentum of a system is conserved.

Essential Questions

1. How does a system at rotational equilibrium compare to a system in translational equilibrium?
2. How does the choice of system and rotation point affect the forces that can cause a torque on an object or a system?
3. How can balanced forces cause rotation?
4. Why does it matter where the door handle is placed?
5. Why are long wrenches more effective?
6. How can an external net torque change the angular momentum of a system?
7. Why is a rotating bicycle wheel more stable than a stationary one?
8. § How does the conservation of angular momentum govern interactions between objects and systems?
9. Why do planets move faster when they travel closer to the sun?

Knowledge and Skills

Knowledge:

1. An observer in a reference frame can describe the motion of an object using such quantities as position, displacement, distance, velocity, speed, and acceleration.

a. Displacement, velocity, and acceleration are all vector quantities.

b. Displacement is change in position. Velocity is the rate of change of position with time. Acceleration is the rate of change of velocity with time. Changes in each property are expressed by subtracting initial values from final values.

c. A choice of reference frame determines the direction and the magnitude of each of these quantities.

d. There are three fundamental interactions or forces in nature: the gravitational force, the electroweak force, and the strong force. The fundamental forces determine both the structure of objects and the motion of objects.

e. In inertial reference frames, forces are detected by their influence on the motion (specifically the velocity) of an object. So force, like velocity, is a vector quantity. A force vector has magnitude and direction. When multiple forces are exerted on an object, the vector sum of these forces, referred to as the net force, causes a change in the motion of the object. The acceleration of the object is proportional to the net force.

f. The kinematic equations only apply to constant acceleration situations. Circular motion and projectile motion are both included. Circular motion is further covered in Unit 3.

g. For rotational motion, there are analogous quantities such as angular position, angular velocity, and angular acceleration.

h. This also includes situations where there is both a radial and tangential acceleration for an object moving in a circular path. For uniform circular motion of radius r, v is proportional to omega, ω (for a given r), and proportional to r (for a given omega, ω). Given a radius r and a period of rotation T, students derive and apply $v = (2\pi r)/T$.

2. Only the force component perpendicular to the line connecting the axis of rotation and the point of application of the force results in a torque about that axis.

a. The lever arm is the perpendicular distance from the axis of rotation or revolution to the line of application of the force.

b. The magnitude of the torque is the product of the magnitude of the lever arm and the magnitude of the force.

c. The net torque on a balanced system is zero.

3. The presence of a net torque along any axis will cause a rigid system to change its rotational motion or an object to change its rotational motion about that axis.

a. Rotational motion can be described in terms of angular displacement, angular velocity, and angular acceleration about a fixed axis.

b. Rotational motion of a point can be related to linear motion of the point using the distance of the point from the axis of rotation.

c. The angular acceleration of an object or a rigid system can be calculated from the net torque and the rotational inertia of the object or rigid system.

4. A torque exerted on an object can change the angular momentum of an object.

a. Angular momentum is a vector quantity, with its direction determined by a right-hand rule.

b. The magnitude of angular momentum of a point object about an axis can be calculated by multiplying the perpendicular distance from the axis of rotation to the line of motion by the magnitude of linear momentum.

c. The magnitude of angular momentum of an extended object can also be found by multiplying the rotational inertia by the angular velocity. Students do not need to know the equation for an object's rotational inertia, as it will be provided at the exam. They should have a qualitative sense of what factors affect rotational inertia—for example, why a hoop has more rotational inertia than a puck of the same mass and radius.

d. The change in angular momentum of an object is given by the product of the average torque and the time the torque is exerted.

5. Torque, angular velocity, angular acceleration, and angular momentum are vectors and can be characterized as positive or negative depending on whether they give rise to or correspond to counterclockwise or clockwise rotation with respect to an axis

6. The angular momentum of a system may change due to interactions with other objects or systems.

a. The angular momentum of a system with respect to an axis of rotation is the sum of the angular momenta, with respect to that axis, of the objects that make up the system.

b. The angular momentum of an object about a fixed axis can be found by multiplying the momentum of the particle by the perpendicular distance from the axis to the line of motion of the object.

c. Alternatively, the angular momentum of a system can be found from the product of the system's rotational inertia and its angular velocity. Students do not need to know the equation for an object's rotational inertia, as it will be provided at the exam. They should have a qualitative sense that rotational inertia is larger when the mass is farther from the axis of rotation.Alternatively, the angular momentum of a system can be found from the product of the system's rotational inertia and its angular velocity. Students do not need to know the equation for an object's rotational inertia, as it will be provided at the exam. They should have a qualitative sense that rotational inertia is larger when the mass is farther from the axis of rotation.

7. The change in angular momentum is given by the product of the average torque and the time interval during which the torque is exerted.

8. If the net external torque exerted on the system is zero, the angular momentum of the system does not change.

9. The angular momentum of a system is determined by the locations and velocities of the objects that make up the system. The rotational inertia of an object or a system depends on the distribution of mass within the object or system. Changes in the radius of a system or in the distribution of mass within the system result in changes in the system's rotational inertia, and hence in its angular velocity and linear speed for a given angular momentum. Examples include elliptical orbits in an Earth-satellite system. Mathematical expressions for the moments of inertia will be provided where needed. Students will not be expected to know the parallel axis theorem. Students do not need to know the equation for an object's rotational inertia, as it will be provided at the exam. They should have a qualitative sense that rotational inertia is larger when the mass is farther from the axis of rotation.

Skills :

1. Express the motion of an object using narrative, mathematical, and graphical representations.
2. Use representations of the relationship between force and torque
3. Compare the torques on an object caused by various forces.
4. Estimate the torque on an object caused by various forces in comparison with other situations.
5. Design an experiment and analyze data testing a question about torques in a balanced rigid system.
6. Calculate torques on a two-dimensional system in static equilibrium by examining a representation or model (such as a diagram or physical construction).
7. Predict the behavior of rotational collision situations by the same processes that are used to analyze linear collision situations using an analogy between impulse and change of linear momentum and angular impulse and change of angular momentum
8. In an unfamiliar context or using representations beyond equations, justify the selection of a mathematical routine to solve for the change in angular momentum of an object caused by torques exerted on the object
9. Plan data-collection and analysis strategies designed to test the relationship between torques exerted on an object and the change in angular momentum of that object.
10. Predict the behavior of rotational collision situations by the same processes that are used to analyze

linear collision situations using an analogy between impulse and change of linear momentum and angular impulse and change of angular momentum

11. In an unfamiliar context or using representations beyond equations, justify the selection of a mathematical routine to solve for the change in angular momentum of an object caused by torques exerted on the object.
12. Plan data-collection and analysis strategies designed to test the relationship between torques exerted on an object and the change in angular momentum of that object
13. Describe a representation and use it to analyze a situation in which several forces exerted on a rotating system of rigidly connected objects change the angular velocity and angular momentum of the system.
14. Plan data-collection strategies designed to establish that torque, angular velocity, angular acceleration, and angular momentum can be predicted accurately when the variables are treated as being clockwise or counterclockwise with respect to a well-defined axis of rotation, and refine the research question based on the examination of data.
15. Describe a model of a rotational system and use that model to analyze a situation in which angular momentum changes due to interaction with other objects or systems.
16. Plan a data-collection and analysis strategy to determine the change in angular momentum of a system and relate it to interactions with other objects and systems.
17. Use appropriate mathematical routines to calculate values for initial or final angular momentum, or change in angular momentum of a system, or average torque or time during which the torque is exerted in analyzing a situation involving torque and angular momentum.
18. Plan a data-collection strategy designed to test the relationship between the change in angular momentum of a system and the product of the average torque applied to the system and the time interval during which the torque is exerted.
19. Make qualitative predictions about the angular momentum of a system for a situation in which there is no net external torque
20. Make calculations of quantities related to the angular momentum of a system when the net external torque on the system is zero.
21. Describe or calculate the angular momentum and rotational inertia of a system in terms of the locations and velocities of objects that make up the system. Use qualitative reasoning with compound objects and perform calculations with a fixed set of extended objects and point masses.

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_BiAmONWbTcI/edit?usp=sharing

Modifications

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