06 Energy and Momentum of Rotating Systems

Content Area: **Science**
Course(s): **AP Physics 1**
Time Period: **Semester 2**
Length: **6 Periods**
Status: **Published**

Standards

SCI.HS.PS2.A	Forces and Motion
SCI.HS.PS2.B	Types of Interactions
SCI.HS.PS3.A	Definitions of Energy
SCI.HS.PS3.B	Conservation of Energy and Energy Transfer
SCI.HS.PS3.C	Relationship Between Energy and Forces
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	Motion and Stability: Forces and Interactions
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.
SCI.HS-PS3-1	Create a computational model to calculate the change in the energy of one component in a system when the change in energy of the other component(s) and energy flows in and out of the system are known.
	If a system interacts with objects outside itself, the total momentum of the system can change; however, any such change is balanced by changes in the momentum of objects outside the system.
	Cause and Effect
	Scale, Proportion, and Quantity
	Patterns
	When two objects interacting through a field change relative position, the energy stored in the field is changed.
	Analyzing and Interpreting Data
	Using Mathematics and Computational Thinking

Enduring Understandings

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

The angular momentum of a system is conserved.

The Energy of a system is conserved.

Essential Questions

1. What keeps a bicycle balanced?
2. Why do planets move faster when they travel closer to the sun?
3. What do satellites and projectiles have in common?
4. What do ice skaters do with their arms when they want to spin faster? Why?

Knowledge and Skills

6.1 Rotational Kinetic Energy

Knowledge

- The rotational kinetic energy of an object or rigid system is related to the rotational inertia and angular velocity of the rigid system and is given by the equation

  $$K = \frac{1}{2} I\omega^2$$

  - The rotational inertia of an object about a fixed axis can be used to show that the rotational kinetic energy of that object is equivalent to its translational kinetic energy, which is its total kinetic energy.
  - The total kinetic energy of a rigid system is the sum of its rotational kinetic energy due to its rotation about its center of mass and the translational kinetic energy due to the linear motion of its center of mass.
- 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.
- Rotational kinetic energy is a scalar quantity.

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

6.2 Torque and Work

Knowledge

- A torque can transfer energy into or out of an object or rigid system if the torque is exerted over an angular displacement.
- 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.
- Work done on a rigid system by a given torque can be found from the area under the curve of a graph of torque as a function of angular position.

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 locations in a single scenario.
- 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.

6.3 Angular Momentum and Angular Impulse

Knowledge

- The magnitude of the angular momentum of a rigid system about a specific axis can be described with the equation $L = I\omega$.

- The magnitude of the angular momentum of an object about a given point is

  $L = rmv \sin\theta$

  - The selection of the axis about which an object is considered to rotate influences the determination of the angular momentum of that object.

  - The measured angular momentum of an object traveling in a straight line depends on the distance between the reference point and the object, the mass of the object, the speed of the object, and the angle between the radial distance and the velocity of the object.
- 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.
- Angular impulse has the same direction as the torque exerted on the object or system.
- 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.

- The magnitude of the change in angular momentum can be described by comparing the magnitudes of the final and initial angular momenta of the object or rigid system:

  $\Delta L = L - L0$

- 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.

    - The angular impulse exerted on an object or rigid system is equal to the change in angular momentum of that object or rigid system.

    - The rotational form of the impulse–momentum theorem is a direct result of the rotational form of Newton's second law of motion for cases in which rotational inertia is constant:
$$\tau_{net} = \frac{\Delta L}{\Delta t} = I\frac{\Delta \omega}{\Delta t} = I\alpha$$

- The net torque exerted on an object is equal to the slope of the graph of the angular momentum of an object as a function of time.
- The angular impulse delivered to an object 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.

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

6.4 Conservation of Angular Momentum

Knowledge

- 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 axis.

- Any change to a system's angular momentum must be due to an interaction between the system and its surroundings.

    - The angular impulse exerted by one object or system on a second object or system is equal and opposite to the angular impulse exerted by the second object or system on the first. This is a direct result of Newton's third law.

    - A system may be selected so that the total angular momentum of that system is constant.

    - The angular speed of a nonrigid system may change without the angular momentum of the system changing if the system changes shape by moving mass closer to or further from the rotational axis.

    - If the total angular momentum of a system changes, that change will be equivalent to the angular impulse exerted on the system.
- Angular momentum is conserved in all interactions.
- If the net external torque exerted on a selected object or rigid system is zero, the total angular

momentum of that system is constant.

- 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.

Skills

- Create quantitative graphs with appropriate scales and units, including plotting data.
- 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.
- Apply an appropriate law, definition, theoretical relationship, or model to make a claim.
- Justify or support a claim using evidence from experimental data, physical representations, or physical principles or laws.

6.5 Rolling

Knowledge

- The total kinetic energy of a system is the sum of the system's translational and rotational kinetic energies.

- While rolling without slipping, the translational motion of a system's center of mass is related to the rotational motion of the system itself with the equations:

  $\Delta xcm = r\Delta\theta$

  $vcm = r\omega$

  $acm = r\alpha$

- For ideal cases, rolling without slipping implies that the frictional force does not dissipate any energy from the rolling system.
- When slipping, the motion of a system's center of mass and the system's rotational motion cannot be directly related.
- 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.

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

6.6 Motion of Orbiting Satellites

Knowledge

- 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.

- The motion of satellites in orbits is constrained by conservation laws.

  - In circular orbits, the system's total mechanical energy, the system's gravitational potential energy, and the satellite's angular momentum and kinetic energy are constant.
  - In elliptical orbits, the system's total mechanical energy and the satellite's angular momentum are constant, but the system's gravitational potential energy and the satellite's kinetic energy can each change.
  - The gravitational potential energy of a system consisting of a satellite and a massive central object is defined to be zero when the satellite is an infinite distance from the central object.

- The escape velocity of a satellite is the satellite's velocity such that the mechanical energy of the satellite–central-object system is equal to zero.

  - When the only force exerted on a satellite is gravity from a central object, a satellite that reaches escape velocity will move away from the central body until its speed reaches zero at an infinite distance from the central body.
  - The escape velocity of a satellite from a central body of mass M can be derived using conservation of energy laws

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.
- 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_BiAmONWbTcI/edit?usp=sharing

Modifications

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