06 Energy and Momentum of Rotating Systems

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

Standards

SCI.HS-PS2-2	Use mathematical representations to support the claim that the total momentum of a system of objects is conserved when there is no net force on the system.
	Systems and System Models
SCI.HS.PS2.A	Forces and Motion
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.
	Using Mathematics and Computational Thinking
SCI.HS.PS3.A	Definitions of Energy
SCI.HS.PS3.B	Conservation of Energy and Energy Transfer
SCI.HS-PS3-5	Develop and use a model of two objects interacting through electric or magnetic fields to illustrate the forces between objects and the changes in energy of the objects due to the interaction.
	Developing and Using Models
SCI.HS.PS3.C	Relationship Between Energy and Forces
	Cause and Effect
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
	Scale, Proportion, and Quantity

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 rotational kinetic energy of a rigid system in terms of the rotational inertia and angular velocity of that rigid system.

Describe the work done on a rigid system by a given torque or collection of torques.

Describe the angular momentum of an object or rigid system.

Describe the angular impulse delivered to an object or rigid system by a torque.

Relate the change in angular momentum of an object or rigid system to the angular impulse given to that object or rigid system.

Describe the behavior of a system using conservation of angular momentum.

Describe how the selection of a system determines whether the angular momentum of that system changes.

Describe the kinetic energy of a system that has translational and rotational motion.

Describe the motion of a system that is rolling without slipping.

Describe the motion of a system that is rolling while slipping.

Describe the motions of a system consisting of two objects or systems interacting only via gravitational forces.

Enduring Understandings

Interactions produce changes in motion.

Forces characterize interactions between objects and systems.

Conservation laws constrain interactions.

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

In the absence of an external torque, the total angular momentum of a system can transfer from one object to another within the system without changing the total angular momentum of the system.

Essential Questions

What keeps a bicycle balanced?

Why do planets move faster when they travel closer to the sun?

What do satellites and projectiles have in common?

How would figure skating be different if angular momentum wasn't conserved?

Knowledge and Skills

Topic 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:

- 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 qualitative sketches of graphs that represent features of a model or the behavior of the physical system.
- 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.
- Justify or support a claim using evidence from experimental data, physical representations, or physical principles or laws.

Topic 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 the torque as a function of angular position.

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 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 .
- The angular momentum of an object about a given point is .
- 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 imparting it.
- 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 momenta of the object or rigid system.
- 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 Newton’s second law of motion for cases in which rotational inertia is constant.
- The net torque exerted on an object or rigid system 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 or rigid system 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 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.
- Justify or support a claim using evidence from experimental data, physical representations, or physical principles or laws.

Topic 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 rotational 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 farther 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 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.
- 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.

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

Topic 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 total energy of a system consisting of a satellite orbiting a central object in a circular path can be written in terms of the gravitational potential energy of that system or the kinetic energy of the satellite.
- 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 the physical system.
- Derive a symbolic expression from known quantities by selecting and following a logical mathematical pathway.
- Justify or support a claim using evidence from experimental data, physical representations, or physical principles or laws.

Transfer Goals

In Unit 6, students will apply their knowledge of energy and momentum to rotating systems. Similar to the approach used for translational energy and momentum concepts in Units 3 and 4, it is important that students have conceptual understanding of how angular momentum and rotational energy change due to external torque(s) on a system. Additionally, articulating the conditions under which the rotational energy and/or angular momentum of a system remains constant is foundational to working through more complex scenarios. Students will use the content and skills presented in both Units 5 and 6 to further study the motion of orbiting satellites and rolling without slipping in this unit.

Assessments

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

Modifications

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