Unit 4: Newtonian Mechanics – Circular and Rotational Motion

OBJECTIVES

We will continue to reinforce the concepts explored previously.

There are no AP Physics 1 or AP Physics 2 learning objectives that focus *solely* on some of the topics (namely circular motion) covered in this unit. However, the topics we will cover appear on the formula sheet and are embedded within the following learning objectives.

Big Idea 3: The interactions of an object with other objects can be described by forces.

Enduring Understanding 3.F: A force exerted on an object can cause a torque on that object.

> Essential Knowledge 3.F.1: 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 ilne 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.
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> > Learning Objective 3.F.1.1: The student is able to use representations of the relationship between force and torque.
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> > Learning Objective 3.F.1.2: The student is able to compare the torques on an object caused by various forces.
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> > Learning Objective 3.F.1.3: The student is able to estimate the torque on an object caused by various forces in comparison to other situations.
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> > Learning Objective 3.F.1.4: The student is able to design an experiment and analyze data testing a question about torques in a balanced rigid system.
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> > Learning Objective 3.F.1.5: The student is able to calculate torques on a two-dimensional system in static equilibrium by examining a representation or model (such as a diagram or physical construction.)
>
> Essential Knowledge 3.F.2: 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 rigid system can be calculated from the net torque and the rotational inertia of the object or rigid system.
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> > Learning Objective 3.F.2.1: The student is able to make predictions about the change in the angular velocity about an axis for an object when forces exerted on the object cause a torque about that axis.
> >
> > Learning Objective 3.F.2.2.: The student is able to plan data collection and analysis strategies designed to test the relationship between a torque exerted on an object and the change in angular velocity of that object about an axis.

Essential Knowledge 3.F.3: A torque exerted on ana 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.

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.

Learning Objective 3.F.3.1: The student is able to 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.

Linear Objective 3.F.3.2: In an unfamiliar context or using representations beyond equations, the student is able to 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.

Learning Objective 3.F.3.3: The student is able to 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.

Big Idea 4: Interactions between systems can result in changes in those systems.

Enduring Understanding 4.D: A net torque exerted on a system by other objects or systems will change the angular momentum of the system.

Essential Knowledge 4.D.1: Torque, angular velocity, angular acceleration, and angular momentum are vectors and can be characterized as positive or negative depending upon whether they give rise to or correspond to counterclockwise or clockwise rotation with respect to an axis.

Learning Objective 4.D.1.1: The student is able to 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.

Learning Objective 4.D.1.2: The student is able to **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.

Essential Knowledge 4.D.2: 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.

Learning Objective 4.D.2.1: The student is able to 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.

Learning Objective 4.D.2.2: The student is able to 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.

Essential Knowledge 4.D.3: The change in angular momentum is given by the product of the average torque and the time interval during which the torque is exerted.

Learning Objective 4.D.3.1: The student is able to 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.

Learning Objective 4.D.3.2: The student is able to 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.

Big Idea 5: Changes that occur as a result of interactions are constrained by conservation laws.

Enduring Understanding 5.A: Certain quantities are conserved, in the sense that the changes of those quantities in a given system are always equal to the transfer of that quantity to or from the system by all possible interactions with other systems.

Essential Knowledge 5.A.2: For all systems under all circumstances, energy, charge, linear momentum, and angular momentum are conserved. For an isolated or a closed system, conserved quantities are constant. An open system is one that exchanges any conserved quantity with its surroundings.

Enduring Understanding 5.E.: The angular momentum of a system is conserved.

Essential Knowledge 5.E.1: If the net external torque exerted on the system is zero, the angular momentum of the system does not change.

Learning Objective 5.E.1.1: The student is able to make qualitative predictions about the angular momentum of a system for a situation in which there is no net external torque.

Learning Objective 5.E.1.2: The student is able to make calculations of quantities related to the angular momentum of a system when the net external torque on the system is zero.

Essential Knowledge 5.E.2: 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 system depends upon 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 should 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.

Learning Objective 5.E.2.1: The student is able to 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. Students are expected to do qualitative reasoning with compound objects. Students are expected to do calculations with a fixed set of extended objects and point masses.

PROCEDURE:

1. Phase 1: Uniform Circular Motion
    - Notes: Roman numeral I
    - Lab: Uniform Circular Motion
    - Homework 1: Chapter 5 Conceptual Questions 1-6, 8, 9, 11, 12, 14, 15 and Problems 1, 3, 5, 6, 13, 14, 20, 21, 27, 29, 36, 37, 56 (CQ & problem), 57 (CQ only), 58 (CQ only), and 61 (CQ only)
2. Phase 2: Rotational Motion – Torque
    - Notes: Roman numeral IIA and IIB
    - Lab: Rotational Equilibrium
    - Homework 2: Chapter 9 Conceptual Questions 1, 2, 5, 6, 8, 10, 14, 17, 24 and Problems 1-5, 7, 9, 15, 20, 64, 73 (CQ only)
3. Phase 3: Rotational Motion – Kinematics
    - Notes: Roman numeral IIC
    - Homework 3: Chapter 8 Conceptual Questions 3-9, 11-14 and Problems 2-5, 16, 17, 19, 29, 33 (a only), 39, 40, 46, 48, and (for the following, CQ only) 71, 72, 74
4. Phase 4: Rotational Motion – Dynamics (torque, angular acceleration, moment of inertia, angular momentum)
    - Notes: Roman numeral IID and IIE
    - Lab: Angular Torque and Angular Momentum
    - Homework: Chapter 9 Conceptual Questions 15, 18-23 and Problems 29-31, 43, 46, 52, and (for the following, CQ only) 76, 77, 78, 80

LABORATORY COMPONENT:

- Lab: Uniform Circular Motion
- Lab: Rotational Equilibrium
- Lab: Angular Torque and Angular Momentum