Unit 5: Newtonian Mechanics – Systems of Particles, Linear Momentum

OBJECTIVES

We will continue to reinforce the all concepts explored previously.

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

Enduring Understanding 3.D: A force exerted on an object can change the momentum of the object.

Essential Knowledge 3.D.1: The change in momentum of an object is a vector in the direction of the net force exerted on the object.

Learning Objective 3.D.1.1: The student is able to justify the selection of data needed to determine the relationship between the direction of the force acting on an object and the change in momentum caused by that force.

Essential Knowledge 3.D.2: The change in momentum of an object occurs over a time interval.

a. The force that one object exerts on a second object changes the momentum of the second object (in the absence of other forces on the second object.)

b. The change in momentum of that object depends on the impulse, which is the product of the average force and the time interval during which the interaction occurred.

Learning Objective 3.D.2.1: The student is able to justify the selection of routines for the calculation of the relationships between changes in momentum of an object, average force, impulse, and time of interaction.

Learning Objective 3.D.2.2: The student is able to predict the change in momentum of an object from the average force exerted on the object and the interval of time during which the force is exerted.

Learning Objective 3.D.2.3: The student is able to analyze data to characterize the change in momentum of an object from the average force exerted on the object and the interval of time during which the force is exerted.

Learning Objective 3.D.2.4: The student is able to **design a plan** for collecting data to investigate the relationship between changes in momentum and the average force exerted on an object over time.

Enduring Understanding 3.E: A force exerted on an object can change the kinetic energy of the object.

* Everything we did in our energy unit related to this Enduring Understanding will be revisited in this unit.

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

Enduring Understanding 4.A: The acceleration of the center of mass of a system is related to the net force exerted on the system, where $\vec{a} = \frac{\vec{F}}{m}$.

Essential Knowledge 4.A.1: The linear motion of a system can be described by the displacement, velocity, and acceleration of its center of mass.

Learning Objective 4.A.1.1: The student is able to use representations of the center of mass of an isolated two-object system to analyze the motion of the system qualitatively and semiquantitatively.

Enduring Understanding 4.B: Interactions with other objects or systems can change the total linear momentum of a system.

Essential Knowledge 4.B.1: The change in linear momentum for a constant-mass system is the product of the mass of the system and the change in velocity of the center of mass.

Learning Objective 4.B.1.1: The student is able to calculate the change in linear momentum of a two-object system with constant mass in linear motion from a representation of the system (data, graphs, etc.)

Learning Objective 4.B.1.2: The student is able to analyze data to find the change in linear momentum for a constant-mass system using the product of the mass and the change in velocity of the center of mass.

Essential Knowledge 4.B.2: The change in linear momentum of the system is given by the product of the average force on that system and the time interval during which the force is exerted.

a. The units for momentum are the same as the units of the areas under the curve of a force versus time graph.

b. The changes in linear momentum and force are both vectors in the same direction.

Learning Objective 4.B.2.1: The student is able to apply mathematical routines to calculate the change in momentum of a system by analyzing the average force exerted over a certain time on the system.

Learning Objective 4.B.2.2: The student is able to perform analysis on data presented as a force-time graph and predict the change in momentum of a system.

Enduring Understanding 4.C: Interactions with other objects or systems can change the total energy of a system.

* Everything we did in our energy unit related to this Enduring Understanding will be revisited in this unit.

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.1: A system is an object or a collection of objects. The objects are treated as having no internal structure.

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 conserve quantity with its surroundings.

Learning Objective 5.A.2.1: The student is able to define open and closed/isolated systems for everyday situations and apply conservation concepts for energy, charge, and linear momentum to those situations.

Essential Knowledge 5.A.3: An interaction can be either a force exerted by objects outside the system or the transfer of some quantity with objects outside the system.

Essential Knowledge 5.A.4: The boundary between a system and its environment is a decision made by the person considering the situation in order to simplify or otherwise assist in analysis.

Enduring Understanding 5.D: The linear momentum of a system is conserved.

Essential Knowledge 5.D.1: : In a collision between objects, linear momentum is conserved. In an elastic collision, kinetic energy is the same before and after.

a. In an isolated system, the linear momentum is constant throughout the collision.

b. In an isolated system, the kinetic energy after an elastic collision is the same as the kinetic energy before the collision.

Learning Objective 5.D.1.1: The student is able to make qualitative predictions about natural phenomena based on conservation of linear momentum and restoration of kinetic energy in elastic collisions.

Learning Objective 5.D.1.2: The student is able to apply the principles of conservation of momentum and restoration of kinetic energy to reconcile a situation that appears to be isolated and elastic, but in which data indicate that linear momentum and kinetic energy are not the same after the interaction, by refining a scientific question to identify interactions that have not been considered. Students will be expected to solve qualitatively and/or quantitatively for one-dimensional situations and only qualitatively in two-dimensional situations.

Learning Objective 5.D.1.3: The student is able to apply mathematical routines appropriately to problems involving elastic collisions in one dimension and justify the selection of those mathematical routines based on conservation of momentum and restoration of kinetic energy.

Learning Objective 5.D.1.4: The student is able to design an experimental test of an application of the principle of the conservation of linear momentum, predict an outcome of the experiment using the principle, analyze data generated by that experiment whose uncertainties are expressed numerically, and evaluate the match between the prediction and the outcome.

Learning Objective 5.D.1.5: The student is able to classify a given collision situation as elastic or inelastic, justify the selection of conservation of linear momentum and restoration of kinetic energy as the appropriate principles for analyzing an elastic collision, solve for missing variables, and calculate their values.

Learning Objective 5.D.1.6: The student is able to make predictions of the dynamical properties of a system undergoing a collision by application of the principle of linear momentum conservation and the principle of the conservation of energy in situations in which an elastic collision may also be assumed.

Learning Objective 5.D.1.7: The student is able to classify a given collision situation as elastic or inelastic, justify the selection of conservation of linear momentum and restoration of kinetic energy as the appropriate principles for analyzing an elastic collision, solve for missing variables, and calculate their values.

Essential Knowledge 5.D.2: In a collision between objects, linear momentum is conserved. In an inelastic collision, kinetic energy is not the same before and after the collision.
a. In an isolated system, the linear momentum is constant throughout the collision.
b. In an isolated system, the kinetic energy after an inelastic collision is different from the kinetic energy before the collision.

> Learning Objective 5.D.2.1: The student is able to qualitatively predict, in terms of linear momentum and kinetic energy, how the outcome of a collision between two objects changes depending on whether the collision is elastic or inelastic.
> Learning Objective 5.D.2.2: The student is able to plan data collection strategies to test the law of conservation of momentum in a two-object collision that is elastic or inelastic and analyze the resulting data graphically.
> Learning Objective 5.D.2.3: The student is able to apply the conservation of linear momentum to a closed system of objects involved in an inelastic collision to predict the change in kinetic energy.
> Learning Objective 5.D.2.4: The student is able to analyze data that verify conservation of momentum in collisions with and without an external friction force.
> Learning Objective 5.D.2.5: The student is able to classify a given collision situation as elastic or inelastic, justify the selection of conservation of linear momentum as the appropriate solution method for an inelastic collision, recognize that there is a common final velocity for the colliding objects in the totally inelastic case, solve for missing variables, and calculate their values.
> Learning Objective 5.D.2.6: The student is able to apply the conservation of linear momentum to an isolated system of objects involved in an inelastic collision to predict the change in kinetic energy.

Essential Knowledge 5.D.3: The velocity of the center of mass of the system cannot be changed by an interaction within the system. [Physics 1: includes no calculations of centers of mass; the equation is not provided until Physics 2. However, without doing calculations, Physics 1 students are expected to be able to locate the center of mass of highly symmetric mass distributions, such as a uniform rod or cube of uniform density, or two spheres of equal mass.]
a. The center of mass of a system depends upon the masses and positions of the objects in the system. In an isolated system (a system with no external forces), the velocity of the center of mass does not change.
b. When objects in a system collide, the velocity of the center of mass of the system will not change unless an external force is exerted on the system.

> Learning Objective 5.D.3.1: The student is able to predict the velocity of the center of mass of a system when there is no interaction outside of the system but there is an interaction within the system (i.e., the student simply recognizes that interactions within a system do not affect the center of mass motion of the system and is able to determine that there is no external force).
> Learning Objective 5.D.3.2: The student is able to make predictions about the velocity of the center of mass for interactions within a defined one-dimensional system.

Learning Objective 5.D.3.3: The student is able to make predictions about the velocity of the center of mass for interactions within a defined two-dimensional system.

PROCEDURE:

1. Phase 1: Impulse-Momentum Theorem
   - Homework: CHECK FOOTNOTES…Chapter 7 Conceptual Questions 1, 3, 4-7 and Problems 1-3, 5[1], 6, 7, 8[2], 9, 10
2. Phase 2: Conservation of Momentum
   - Homework: CHECK FOOTNOTES…Chapter 7 Conceptual Questions 10-15, 20 and Problems 15, 16, 25[3], 29, 30, 34, 59 (conceptual only), 60 (conceptual only)
3. Phase 3: Energy in Collisions
   - Homework: Chapter 7 Conceptual Questions 8[4], 16, and Problems 27, 28, 32, 61 (both conceptual and problem), 62 (both conceptual and problem), 64 (conceptual only), and 65 (both conceptual and problem)

LABORATORY COMPONENT:

Lab: Impulse-Momentum Theorem

Lab: Conservation of Momentum

Lab: Qualitative Analysis of Elastic, Inelastic, and Totally Inelastic Collisions

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[1] After doing this problem, recalculate the impulse if the player caught the volleyball and brought it to a stop. Write a statement comparing the impulse required to stop something versus the impulse required to "bounce" it back the other way.

[2] Write a concluding statement comparing the impulse required to stop the puck versus the impulse required to "bounce" it back the other way.

[3] Write a statement describing in terms of momentum transfer and mass why Kevin slowed down when he grabbed his bro.

[4] Answer this semiquantitatively (i.e., using formulas but not numbers) to explain this as thoroughly as you can.