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### UNIT NARRATIVE

This unit begins with an teacher facilitated demonstration of an Anchoring Event along with the Essential Question (Day 01) chosen to give students an opportunity to be curious about a real-world event that requires physics momentum concepts to seamlessly explain. Students will then individually create initial models about how and why the Anchoring Event happens using their prior physics knowledge only. Several times during this unit students should use their Summary Tables to connect their learning from individual lessons back to the Anchoring Event and Essential Question. The unit concludes with students revising their original models using their Summary Tables and creating a Seamless Explanation of the Anchoring Event and Essential Question by participating in multiple rounds of writing with peer feedback. This structure is based on the Ambitious Science Teaching model.

*NOTE – There are two Anchoring Event Options included with this unit. The original anchoring event about throwing and catching a heavy ball while on a low friction human cart (or skateboard) and another anchoring event about explaining why a Newton’s Cradle acts the way that it does. Teachers should choose only one of the anchoring events.*

Students will then be introduced to the concept of momentum with a two day (Day 02-03) guided discovery lesson introducing the quantity of momentum and the concept of conservation of momentum. The teacher will demonstrate a series of collisions (Days 02-03) where students are asked to describe the quantity that remains constant during each collision and after several iterations of collisions and discussion, and addressing several misconceptions, students will arrive at the conclusion that the product of mass and velocity is conserved during collisions. Next students will have a day of practice using the momentum equation to make claims about scenarios using the momentum equation (Day 04), and a second day of practice using the conservation of momentum to make quantitative predictions about collision scenarios (Day 05). Both of these practice days will be primarily AP Classroom Topic Questions because they are the questions most aligned to the AP Exam and many require students to incorporate concepts from previous learning about Kinematics and Dynamics.

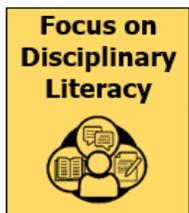
Next students will explore the different categories of two cart collisions (elastic, inelastic, and perfectly inelastic, explosion) by conducting an experiment to calculate the change in system momentum and change in kinetic energy for the system to confirm that the momentum of the system is ALWAYS conserved in collisions and investigate how the kinetic energy of the system changes during each type of collision (Day 06). The experiment can be facilitated using a PhET

simulation or using Vernier Dynamics tracks and carts along with motion sensors. Next students will practice making quantitative predictions about different types of collisions using both conservation of momentum and conservation of energy using primarily AP Classroom Topic Questions (Day 07).

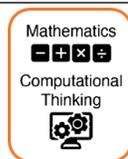
The second section of this unit focuses on the relationship between Impulse and Momentum. As an introduction to students will conduct an experiment with single cart collisions to measure to calculate the change in momentum of the cart and compare it with the Force-Time of the cart collisions (Day 08). Students will make claims about the relationship between the Force-time graph and the change in momentum and practice argumentation with peers until a class consensus has been reached and the teacher can fill in any remaining gaps in regard to the definition of Impulse and how it relates to momentum (Day 09). Next students will practice making quantitative predictions about change in momentum and Impulse using the Impulse-Momentum relationship using primarily AP Classroom Topic Questions (Day 10).

Then students will revise their initial models and ideas about the Anchoring Event and Essential Question to craft Seamless Explanations using all of the concepts they have learned about momentum.

**Teachers should assign the AP Classroom Progress Check as extra practice or review.**



In science, disciplinary literacy is synonymous with the science and engineering practices. The SEPs are the context through which all science concepts should be taught. In the lessons, you will find the Science and Engineering practices icons when the SEPs are being explicitly used by students.



[Physics Teams Join Link](#): This Teams is essential for teachers and contains both district resources and Physics Course Leader and Team contributions. All professional development meetings and trainings will be hosted in Professional Development Channel of this Team and teachers will need to join to appreciate the full support and hard work the Course Leaders put in to help support the Physics teacher family.

## UNPACKED STANDARDS

Below are the standards **taught** and **assessed** in this unit.

Topic		Learning Objective		Essential Knowledge	
4.1	Linear Momentum	4.1.A	Describe the linear momentum of an object or system.	4.1.A.1	Linear momentum is defined by the <b>equation</b> --> $p = mv$
				4.1.A.2	Momentum is a vector quantity and has the same direction as the velocity.
				4.1.A.3	Momentum can be used to analyze collisions and explosions.
					i. A collision is a model for an interaction where the forces exerted between the involved objects in the system are much larger than the net external force exerted on those objects during the interaction. ii. As only the initial and final states of a collision are analyzed, the object model may be used to analyze collisions. iii. An explosion is a model for an interaction in which forces internal to the system move objects within that system apart.
<b>BOUNDARY STATEMENT:</b> <i>Unless otherwise stated, the general term "momentum" will refer specifically to linear momentum.</i>					
4.2	Change in Momentum and Impulse	4.2.A	Describe the impulse delivered to an object or system.	4.2.A.1	The rate of change of momentum is equal to the net external force exerted on an object or system. <b>Relevant equation</b> --> $F_{net} = \frac{\Delta p}{\Delta t}$
				4.2.A.2	Impulse is defined as the product of the average force exerted on a system and the time interval during which that force is exerted on the system. <b>Relevant equation</b> --> $J = F_{avg}\Delta t$
				4.2.A.3	Impulse is a vector quantity and has the same direction as the net force exerted on the system.
				4.2.A.4	The impulse delivered to a system by a net external force is equal to the area under the curve of a graph of the net external force exerted on the system as a function of time.
				4.2.A.5	The net external force exerted on a system is equal to the slope of a graph of the momentum of the system as a function of time.
		4.2.B	Describe the impulse delivered to an object or system.	4.2.B.1	The rate of change of momentum is equal to the net external force exerted on an object or system. <b>Relevant equation</b> --> $F_{net} = \frac{\Delta p}{\Delta t}$
				4.2.B.2	Impulse is defined as the product of the average force exerted on a system and the time interval during which that force is exerted on the system. <b>Relevant equation</b> --> $J = F_{avg}\Delta t$
				4.2.B.3	Impulse is a vector quantity and has the same direction as the net force exerted on the system.

				4.2.B.4.	The impulse delivered to a system by a net external force is equal to the area under the curve of a graph of the net external force exerted on the system as a function of time.	
				4.2.B.5	The net external force exerted on a system is equal to the slope of a graph of the momentum of the system as a function of time.	
4.3	Conservation of Linear Momentum	4.3.A	Describe the behavior of a system using conservation of linear momentum.	4.3.A.1	A collection of objects with individual momenta can be described as one system with one center-of-mass velocity. i. For a collection of objects, the velocity of a system's center of mass can be calculated <b>using the equation</b> $\vec{v}_{cm} = \frac{\Sigma \vec{p}_i}{\Sigma m_i} = \frac{\Sigma (m_i \vec{v}_i)}{\Delta m_i}$ ii. The velocity of a system's center of mass is constant in the absence of a net external force.	
				4.3.A.2	The total momentum of a system is the sum of the momenta of the system's constituent parts.	
				4.3.A.3	In the absence of net external forces, any change to the momentum of an object within a system must be balanced by an equivalent and opposite change of momentum elsewhere within the system. Any change to the momentum of a system is due to a transfer of momentum between the system and its surroundings.	
					i. The impulse exerted by one object on a second object is equal and opposite to the impulse exerted by the second object on the first. This is a direct result of Newton's third law. ii. A system may be selected so that the total momentum of that system is constant. iii. If the total momentum of a system changes, that change will be equivalent to the impulse exerted on the system. <b>Relevant equation</b> $\vec{J} = \Delta \vec{p}$	
					Correct application of conservation of momentum can be used to determine the velocity of a system immediately before and immediately after collisions or explosions.	
		<b>BOUNDARY STATEMENT:</b> <i>AP Physics 1 includes a quantitative and qualitative treatment of conservation of momentum in one dimension and a semiquantitative treatment of conservation of momentum in two dimensions. Exam questions involving solution of simultaneous equations are not included in AP Physics 1, but the AP Physics 1 Exam may include questions that assess whether students can set up the equations properly and reason about how changing a given mass, speed, or angle would affect other quantities. AP Physics 2 includes a full treatment of conservation of momentum in two dimensions for problems that include one unknown final velocity.</i>				
		4.3.B	Describe how the selection of a system determines whether the momentum of that system changes.	4.3.B.1	Momentum is conserved in all interactions.	
				4.3.B.2	If the net external force on the selected system is zero, the total momentum of the system is constant.	
				4.3.B.3	If the net external force on the selected system is nonzero, momentum is transferred between the system and the environment.	
		4.4	Elastic and Inelastic Collisions	4.4.A	The linear momentum of a system is conserved.	4.4.A.1
4.4.A.2	In an elastic collision, the final kinetic energies of each of the objects within the system may be different from their initial kinetic energies.					

				4.4.A.3	An inelastic collision between objects is one in which the total kinetic energy of the system decreases.
				4.4.A.4	In an inelastic collision, some of the initial kinetic energy is not restored to kinetic energy but is transformed by nonconservative forces into other forms of energy.
				4.4.A.5	In a perfectly inelastic collision, the objects stick together and move with the same velocity after the collision.

## KEY UNDERSTANDINGS AND QUESTIONS

Important big ideas and processes for the unit.

### Key Understandings

- Phenomena are events or processes (“things that happen”) that are observable or detectable**
- A scientific question is a question that may lead to a hypothesis and help us in answering the explanation for an observation or event**
- Momentum** is a quantity of motion of a moving body, calculated as the product of its mass and velocity
- Momentum** is a **vector** quantity
- The **total momentum** of a system is the vector sum of the momentum of each object in the system
- The **total momentum** of a system remains constant when there is zero net force acting on the system (**Conservation of Momentum**)
- The **center of mass** of a **system** will have a constant velocity during any collision when there is zero net force acting on the system (typically frictionless scenarios - **Conservation of Momentum**)
- The change in kinetic energy a system during a collision depends on the type of collision: elastic, inelastic, perfectly inelastic, and explosions.
- Elastic collisions** have no change in kinetic energy of the system (the kinetic energy of objects in the system can still change)
- Inelastic collisions** are ones where the total kinetic energy of the system decreases
- Perfectly inelastic collisions** are ones where the objects stick together and have the same final velocity
- Impulse** is the product of average Force x time
- Impulse** is calculated from a Force-Time graph by calculating the area under the curve
- Impulse-momentum relationship:** The change in momentum of an object is equal to the Impulse
- Force and time are inversely related for a constant change in momentum
- Models can/should be revised based on evidence from Unit Lessons**
- Making a Claim to explain the Anchoring Event and Essential Question**
- Identifying evidence from Unit Lessons relevant to Anchoring Event and Essential Question**
- Crafting a Seamless Explanation by connecting all relevant evidence to the claim using physics laws and principles**

### Key Questions

- What is momentum and how is it different than kinetic energy?
- When is momentum conserved during a collision?
- How does conservation of momentum help us make predictions about collisions?
- How does Kinetic Energy change during a collision?
- Why are some collisions likely to cause damage/injury and others are not?
- How do forces create changes in momentum of an object or a system of objects?
- How can the change in momentum of a system be predicted from the net force acting on the system?

**ROADMAP**

<b>AT A Glance: Unit # 4 – Momentum</b>			
<b>Day</b>	<b>Date</b>	<b>Lesson</b>	<b>Lesson Notes</b>
1		Anchoring Event & Initial Modeling	
2		Conservation of Momentum Discovery 1	
3		Conservation of Momentum Discovery 2	
4		Practice – Momentum	
5		Practice –Conservation of Momentum	
6		Lab – KE Changes during Collisions	
7		Practice – Collisions	
8		One Car Collision Investigation 1	
9		One Car Collision Investigation 2	
10		Practice – Impulse-Momentum	
11		Anchoring Event–Seamless Explanations	
12		Flex/Review	Use the AP Classroom Unit 4: Momentum Progress check for review/practice.
13		<b>TX_SCI_APPhysics_S26_UE4</b>	<b>Scanning Deadline:</b>
14		Time Permitting – review the most missed MC and the entire FRQ using Success Day Lesson Plan	

Lesson	Objective(s) and Standard(s)	Instructional Notes	Resources
<p>Day 01</p> <p>Anchoring Event &amp; Modeling</p>	<p><b>STANDARD(s)</b>  <b>Topic 4.3: Conservation of Linear Momentum</b>            4.3.A Describe the behavior of a system using conservation of linear momentum.  <b>Topic 3.4: Conservation of Mechanical Energy</b>            3.4.B Describe the behavior of a system using conservation of mechanical energy principles.</p> <p><b>SWBAT:</b> create an initial explanatory model for the anchoring event</p> <p><b>DISCIPLINARY LITERACY FOCUS:</b></p> <div style="display: flex; justify-content: space-around;"> <div data-bbox="319 1008 457 1182" style="border: 1px solid red; border-radius: 10px; padding: 5px; text-align: center;">             Asking Questions            Defining Problems         </div> <div data-bbox="499 1008 638 1182" style="border: 1px solid blue; border-radius: 10px; padding: 5px; text-align: center;">             Developing and Using Models         </div> </div>	<p><b>KEY UNDERSTANDINGS CHECKLIST</b></p> <ul style="list-style-type: none"> <li><input type="checkbox"/> Phenomena are events or processes (“things that happen”) that are observable or detectable</li> <li><input type="checkbox"/> A scientific question is a question that may lead to a hypothesis and help us in answering the explanation for an observation or event</li> </ul> <p><b>LESSON CONTEXT FOR LESSON MASTERY</b>            This lesson introduces students to momentum through one of two possible anchor events. Students will be asked a question regarding an interactive, observable anchoring event. By playing with and making observations about the event, students form a hypothesis regarding the cause of the phenomenon. Their hypothesis will be tested and revised throughout the unit until a definitive conclusion is reached.</p> <p><b>LOOK-FORS</b> 🔍 (What to observe students doing or producing)</p> <ul style="list-style-type: none"> <li>• Recording qualitative and quantitative observations and data</li> <li>• Create a model with annotations, questions, and ideas</li> </ul> <p><b>LISTEN-FORS</b> 👂 (Examples of what students should be saying or explaining)</p> <ul style="list-style-type: none"> <li>• Using prior knowledge to justify a hypothesis</li> </ul> <p><b>COMMON MISCONCEPTIONS</b> ▶ (Historical/widespread misunderstandings)</p> <ul style="list-style-type: none"> <li>▪ Misconceptions will vary from student to student as this is their first exploration into momentum. The key is to NOT dissuade these misconceptions as they will be addressed as they arise throughout the unit.</li> </ul>	<p>Catching a ball on a skateboard</p> <p>Newton’s Cradle Behavior</p> <p><b>TEACHER CONTENT BACKGROUND RESOURCES</b></p> <ul style="list-style-type: none"> <li>• <a href="#">Ambitious Science Teaching Overview</a></li> </ul>

Lesson	Objective(s) and Standard(s)	Instructional Notes	Resources
<p style="text-align: center;"><b>Day 02</b></p> <p style="text-align: center;"><b>Momentum Discovery 1</b></p>	<p><b>STANDARD(s)</b>  <b>Topic 4.1: Linear Momentum</b>            4.1.A Describe the linear momentum of an object or system.</p> <p><b>Topic 4.3: Conservation of Linear Momentum</b>            4.3.A Describe the behavior of a system using conservation of linear momentum.</p> <p><b>SWBAT:</b> explain momentum conceptually and quantitatively by observing a series of cart collision demonstrations and describing what stays the same during each collision.</p>	<p><b>KEY UNDERSTANDINGS CHECKLIST</b></p> <ul style="list-style-type: none"> <li><input type="checkbox"/> The total momentum of a system remains constant when there is zero net force acting on the system (<b>Conservation of Momentum</b>)</li> <li><input type="checkbox"/> The change in kinetic energy a system during a collision depends on the type of collision: elastic, inelastic, perfectly inelastic, and explosions.</li> <li><input type="checkbox"/> <b>Elastic collisions</b> have no change in kinetic energy of the system (the kinetic energy of objects in the system can still change)</li> <li><input type="checkbox"/> <b>Inelastic collisions</b> are ones where the total kinetic energy of the system decreases</li> <li><input type="checkbox"/> <b>Perfectly inelastic collisions</b> are ones where the objects stick together and have the same final velocity</li> </ul> <p><b>LESSON CONTEXT FOR LESSON MASTERY</b>            This lesson gradually reveals the concept of momentum and conservation of momentum to students through teacher demonstration of a series of cart collisions. The collisions gradually become more complex, forcing students to refine their explanation for the underlying principle at work. This lesson introduces students to momentum bar graphs, which is an extremely useful model that can be applied to many lessons in the unit.</p>	<div style="border: 1px solid magenta; padding: 5px; margin-bottom: 10px;"> <p>Demonstration Materials:</p> <ul style="list-style-type: none"> <li>•1 Vernier Track</li> <li>•2 Vernier Carts</li> <li>•2 Vernier motion sensors</li> <li>•Various masses</li> </ul> </div> <p><b>TEACHER CONTENT BACKGROUND RESOURCES</b></p> <p><a href="#">Momentum Intro Video</a></p> <p><a href="#">Mathematical explanation of momentum</a> (first 5 min.)</p> <p><a href="#">Khan - Momentum</a></p> <p><a href="#">Khan Conservation of Momentum</a></p> <p><a href="#">PC - Momentum</a></p> <p><a href="#">PC – Conservation of Momentum</a></p>
<p style="text-align: center;"><b>Day 03</b></p> <p style="text-align: center;"><b>Momentum Discovery 2</b></p>	<p><b>DISCIPLINARY LITERACY FOCUS:</b></p> <div style="text-align: center; border: 1px solid magenta; padding: 5px; width: fit-content; margin: 10px auto;">  <p style="font-size: small;">Engaging in Argument from Evidence</p> </div>	<p><b>LOOK-FORS</b> 🔍 (What to observe students doing or producing)</p> <ul style="list-style-type: none"> <li>• Describing each collision using: words, free body diagrams, and bar graphs</li> <li>• Refining existing models based on current information</li> </ul> <p><b>LISTEN-FORS</b> 🗣️ (Examples of what students should be saying or explaining)</p> <ul style="list-style-type: none"> <li>• Students are describing what they see in the demonstration</li> <li>• Students are attempting to justify the phenomena using terms like “speed”, “velocity”, “mass”, and “direction”</li> </ul> <p><b>COMMON MISCONCEPTIONS</b> ▶ (Historical/widespread misunderstandings)</p> <ul style="list-style-type: none"> <li>▪ Misconceptions will vary from student to student as this is their first exploration into momentum. The key is to NOT dissuade these misconceptions as they will be addressed as they arise throughout the</li> </ul>	

Lesson	Objective(s) and Standard(s)	Instructional Notes	Resources
<p>Day 04</p> <p>Practice - Momentum</p>	<p><b>STANDARD(s)</b>  <b>Topic 4.1: Linear Momentum</b>            4.1.A Describe the linear momentum of an object or system.</p> <p><b>SWBAT: Calculate</b> quantitative predictions using the momentum equation</p> <p><b>DISCIPLINARY LITERACY FOCUS:</b></p> <div data-bbox="394 646 533 815" style="border: 1px solid orange; border-radius: 10px; padding: 5px; text-align: center;"> <p>Mathematics</p>  <p>Computational Thinking</p>  </div>	<p><b>KEY UNDERSTANDINGS CHECKLIST</b></p> <ul style="list-style-type: none"> <li><input type="checkbox"/> <b>Momentum</b> is a quantity of motion of a moving body, calculated as the product of its mass and velocity</li> <li><input type="checkbox"/> <b>Momentum</b> is a vector quantity</li> </ul> <p><b>LESSON CONTEXT FOR LESSON MASTERY</b>            Students will work individually and in small groups to answer AP Classroom Topic Questions about Linear Momentum. Students were introduced to the concept of momentum in lessons 2-3 and answering these questions will help to anchor the definition of momentum as a vector and the product of mass times velocity. These questions also naturally spiral review of kinematics and dynamics concepts.</p> <p><b>LOOK-FORS</b> 🔍 (What to observe students doing or producing)</p> <ul style="list-style-type: none"> <li>• Students accurately describing momentum as a vector in the correct direction with the correct signs +/-.</li> </ul> <p><b>LISTEN-FORS</b> 🗣️ (Examples of what students should be saying or explaining)</p> <ul style="list-style-type: none"> <li>• Justifying claims using the equation for momentum</li> <li>• Describing the difference between positive and negative velocity as moving in opposite directions (or comparing to velocity)</li> </ul> <p><b>COMMON MISCONCEPTIONS</b> ▶️ (Historical/widespread misunderstandings)</p> <ul style="list-style-type: none"> <li>• Not treating momentum like a vector quantity (not taking the direction/sign of velocity into account)</li> </ul>	<p><b>TEACHER CONTENT BACKGROUND RESOURCES:</b>  <a href="#">Khan - Momentum</a>  <a href="#">PC - Momentum</a>            Defining and Calculating Momentum: AP Classroom Unit 4 Topic 4.1 Daily Video 1</p>
<p>Day 05</p> <p>Practice – Conservation of Momentum</p>	<p><b>STANDARD(s)</b>  <b>Topic 4.3: Conservation of Linear Momentum</b>            4.3.A Describe the behavior of a system using conservation of linear momentum.</p>	<p><b>KEY UNDERSTANDINGS CHECKLIST</b></p> <ul style="list-style-type: none"> <li><input type="checkbox"/> The total momentum of a system is the vector sum of the momentum of each object in the system</li> <li><input type="checkbox"/> The total momentum of a system remains constant when there is zero net force acting on the system (<b>Conservation of Momentum</b>)</li> </ul>	<p><b>TEACHER CONTENT BACKGROUND RESOURCES:</b>  <a href="#">Intro to Conservation of Momentum</a></p>

Lesson	Objective(s) and Standard(s)	Instructional Notes	Resources
	<p><b>SWBAT:</b> make quantitative predictions about collision scenarios by creating accurate momentum bar charts and conservation of momentum equations.</p> <p><b>DISCIPLINARY LITERACY FOCUS:</b></p> <div data-bbox="390 553 529 727" style="border: 1px solid orange; border-radius: 10px; padding: 5px; text-align: center;"> <p>Mathematics              Computational Thinking  </p> </div>	<p><input type="checkbox"/> The <b>center of mass</b> of a <b>system</b> will have a constant velocity during any collision when there is zero net force acting on the system (typically frictionless scenarios - <b>Conservation of Momentum</b>)</p> <p><b>LESSON CONTEXT FOR LESSON MASTERY</b>            This lesson has students apply the Conservation of Momentum to narrative problems by setting up momentum bar charts like those created in Lesson 2 – 3. This lesson reinforces the practicality of using the momentum bar charts in conjunction with C.o.M to make predictions.</p> <p><b>LOOK-FORS 🔍 (What to observe students doing or producing)</b></p> <ul style="list-style-type: none"> <li>• Creating bar charts that connect to the narrative: mass is appropriately scaled, direction of velocity is considered by the “height” of the bar chart as negative/positive</li> <li>• Creating mathematical models with C.o.M that tie with their bar chart</li> </ul> <p><b>LISTEN-FORS 👂 (Examples of what students should be saying or explaining)</b></p> <ul style="list-style-type: none"> <li>• Justifying features of their bar charts based on key wording from the narrative (ex: why their bar charts are wider based on mass values, why their bar charts are below x-axis due to direction of motion)</li> <li>• Using the principle of C.o.M to set up their math model</li> </ul> <p><b>COMMON MISCONCEPTIONS ▶ (Historical/widespread misunderstandings)</b></p> <ul style="list-style-type: none"> <li>▪ May forget to include direction in bar charts / equations (forgetting that momentum is a vector quantity)</li> </ul>	<p><a href="#">Khan – Conservation of Momentum</a></p> <p><a href="#">Khan-Bouncing fruit collision Example</a></p> <p><a href="#">Khan-System &amp; center of mass</a></p> <p><a href="#">PC – Conservation of Momentum</a></p> <p><a href="#">PC-Isolated Systems</a></p> <p><a href="#">PC-Using equations for algebraic problem solving</a></p> <p><a href="#">PC-Using equations as a Guide to Thinking</a></p> <p>Defining a System and Calculating Total Momentum: AP Classroom Topic 4.3 Daily Video 1</p>
<p><b>Day 06</b></p> <p><b>Lab - KE changes in collisions</b></p>	<p><b>STANDARD(s)</b>  <b>Topic 4.4: Inelastic and Elastic Collisions</b>            4.4.A The linear momentum of a system is conserved.</p>	<p><b>KEY UNDERSTANDINGS CHECKLIST</b></p> <p><input type="checkbox"/> The total momentum of a system remains constant when there is zero net force acting on the system (<b>Conservation of Momentum</b>)</p> <p><input type="checkbox"/> The change in kinetic energy a system during a collision depends on the type of collision: elastic, inelastic, perfectly inelastic, and explosions.</p> <p><input type="checkbox"/> <b>Elastic collisions</b> have no change in kinetic energy of the system (the kinetic energy of objects in the system can still change)</p>	

Lesson	Objective(s) and Standard(s)	Instructional Notes	Resources
	<p><b>SWBAT</b> describe the change in Kinetic Energy qualitatively and quantitatively for different types of collisions by performing experiments and analyzing data.</p> <p><b>DISCIPLINARY LITERACY FOCUS:</b></p>  <p>Planning and Carrying Out Investigations</p>	<p><input type="checkbox"/> <b>Inelastic collisions</b> are ones where the total kinetic energy of the system decreases</p> <p><input type="checkbox"/> <b>Perfectly inelastic collisions</b> are ones where the objects stick together and have the same final velocity</p> <p><b>LESSON CONTEXT FOR LESSON MASTERY</b></p> <p>This lesson has students experimentally calculate whether momentum is conserved in several different types of collisions. Students will also calculate the change in kinetic energy of the system during the collisions. This lesson connects back to Unit 3: Energy, by asking students to experimentally compare the kinetic energy before and after a collision. This lab activity can be completed virtually with a PhET simulation of IRL with the lab supplies listed.</p> <p><b>LOOK-FORS 🔍 (What to observe students doing or producing)</b></p> <ul style="list-style-type: none"> <li>Recording quantitative data: mass, velocity, momentum, kinetic energy</li> <li>Connecting the type of collision they see visually with the quantitative data collected: total kinetic energy before/after, total momentum before/after</li> </ul> <p><b>LISTEN-FORS 👂 (Examples of what students should be saying or explaining)</b></p> <ul style="list-style-type: none"> <li>Comparing the total momentum for each collision</li> <li>Comparing the total kinetic energy for each collision</li> <li>Justifying why momentum stays conserved</li> <li>Attempting to justify why kinetic energy may not stay conserved for a particular collision</li> </ul> <p><b>COMMON MISCONCEPTIONS ▶ (Historical/widespread misunderstandings)</b></p> <ul style="list-style-type: none"> <li>May misunderstand why the momentum of each object changes instead of staying the same before/after collision. They may be attempting to apply C.o.M to an individual object instead of the system</li> <li>May have difficulty explaining why total kinetic energy has reduced after a collision. They may be attempting to recall/apply C.o.E</li> </ul>	<p>Materials (per group):</p> <ul style="list-style-type: none"> <li>1 student computer</li> <li>1 Vernier Dynamics Track</li> <li>2 Vernier Carts</li> <li>2 Vernier motion sensors</li> <li>Vernier cart attachments</li> <li>Vernier Graphical Interface</li> </ul> <p><b>TEACHER CONTENT BACKGROUND RESOURCES</b></p> <p><a href="#">Khan – Elastic &amp; Inelastic Collisions</a></p> <p><a href="#">PC- Explosions</a></p> <p><a href="#">Demonstrating Collision Types</a> (Start at 4:15)</p> <p>Defining and Determining Types of Collisions: AP Classroom Topic 4.4 Daily Video 1</p>

Lesson	Objective(s) and Standard(s)	Instructional Notes	Resources
<p>Day 07</p> <p>Practice - Collisions</p>	<p><b>STANDARD(s)</b>  <b>Topic 4.4: Inelastic and Elastic Collisions</b>            4.4.A The linear momentum of a system is conserved.</p> <p><b>SWBAT:</b> describe collision scenarios as elastic or inelastic by calculating the change in kinetic energy of the system.</p> <p><b>DISCIPLINARY LITERACY FOCUS:</b></p> <div data-bbox="382 625 520 792" style="border: 1px solid orange; border-radius: 10px; padding: 5px; text-align: center;"> <p>Mathematics              Computational Thinking  </p> </div>	<p><b>KEY UNDERSTANDINGS CHECKLIST</b></p> <ul style="list-style-type: none"> <li><input type="checkbox"/> The total momentum of a system remains constant when there is zero net force acting on the system (<b>Conservation of Momentum</b>)</li> <li><input type="checkbox"/> The change in kinetic energy a system during a collision depends on the type of collision: elastic, inelastic, perfectly inelastic, explosion</li> <li><input type="checkbox"/> <b>Elastic collisions</b> have no change in kinetic energy of the system (the kinetic energy of objects in the system can still change)</li> <li><input type="checkbox"/> <b>Inelastic collisions</b> are ones where the total kinetic energy of the system decreases</li> <li><input type="checkbox"/> <b>Perfectly inelastic collisions</b> are ones where the objects stick together and have the same final velocity</li> </ul> <p><b>LESSON CONTEXT FOR LESSON MASTERY</b>            Students will answer the AP Classroom Topic Questions for Topic 4.4 – Collisions and provide justification for their answer choices.</p> <p><b>LOOK-FORS 🔍 (What to observe students doing or producing)</b></p> <ul style="list-style-type: none"> <li>• Recording quantitative data: mass, velocity, momentum, kinetic energy</li> <li>• Connecting the type of collision they see visually with the quantitative data collected: total kinetic energy before/after, total momentum before/after</li> </ul> <p><b>LISTEN-FORS 👂 (Examples of what students should be saying or explaining)</b></p> <ul style="list-style-type: none"> <li>• Comparing the total momentum for each collision</li> <li>• Comparing the total kinetic energy for each collision</li> <li>• Justifying why momentum stays conserved</li> <li>• Attempting to justify why kinetic energy may not stay conserved for a particular collision</li> </ul> <p><b>COMMON MISCONCEPTIONS ▶ (Historical/widespread misunderstandings)</b></p> <ul style="list-style-type: none"> <li>▪ May misunderstand why the momentum of each object changes instead of staying the same before/after collision. They may be attempting to apply C.o.M to an individual object instead of the system</li> </ul>	<p><b>TEACHER CONTENT BACKGROUND RESOURCES</b></p> <p><a href="#">Khan – Elastic &amp; Inelastic Collisions</a></p> <p><a href="#">PC- Explosions</a></p> <p><a href="#">Determining collision type through analysis</a> (start at 9:45)</p>

Lesson	Objective(s) and Standard(s)	Instructional Notes	Resources
		<p>May have difficulty explaining why total kinetic energy has reduced after a collision. They may be attempting to recall/apply C.o.E</p>	
<p><b>Day 08</b></p> <p><b>One Car Collision Investigation</b></p>	<p><b>STANDARD(s)</b>  <b>Topic 4.2: Change in Momentum and Impulse</b>  <b>4.2.A</b> Describe the impulse delivered to an object or system.  <b>4.2.B</b> Describe the relationship between the impulse exerted on an object or a system and the change in momentum of the object or system.</p> <p><b>SWBAT:</b> quantitatively describe the Impulse on a system as the product of average force and time</p>	<p><b>KEY UNDERSTANDINGS CHECKLIST</b></p> <ul style="list-style-type: none"> <li><input type="checkbox"/> <b>Impulse</b> is the product of average Force x time</li> <li><input type="checkbox"/> <b>Impulse</b> is calculated from a Force-Time graph by calculating the area under the curve</li> <li><input type="checkbox"/> <b>Impulse-momentum relationship:</b> The change in momentum of an object is equal to the Impulse</li> </ul> <p><b>LESSON CONTEXT FOR LESSON MASTERY</b></p> <p>This lesson connects to Unit 2: Dynamics and Unit 3: Energy by revisiting forces and connecting to a similar model: “Work-Energy Theorem”. Students are challenged to connect how external forces cause change to the system and how these changes can be analyzed / predicted. Students will work in groups to explore the relationship between the change in momentum of a single car collision and the Force-time graph of the collision and then participate in whole class discussion to compare observations and conclusions in order to come to a class consensus.</p>	<p><b>TEACHER CONTENT BACKGROUND RESOURCES</b></p> <p><a href="#">PC-Momentum Change &amp; Impulse</a></p> <p><a href="#">Khan-Impulse</a></p> <p>Definition of Impulse: AP Classroom Topic 4.2 Daily Video 1</p> <p>Relating Impulse to Force-Time Graphs: AP Classroom Topic 4.2 Daily Video 2</p>
<p><b>Day 09</b></p> <p><b>Impulse-Momentum Argumentation</b></p>	<p><b>SWBAT:</b> describe the change in momentum of a system by calculating the Impulse on the system (and vice versa)</p> <p><b>DISCIPLINARY LITERACY FOCUS:</b></p> <div style="display: flex; justify-content: space-around;">   </div>	<p><b>LOOK-FORS 🔍 (What to observe students doing or producing)</b></p> <ul style="list-style-type: none"> <li>• Recording meaningful qualitative and quantitative data about the demo and experimental investigation</li> <li>• Applying C.o.M and momentum bar charts to make predictions about an unknown variable</li> </ul> <p><b>LISTEN-FORS 🗣️ (Examples of what students should be saying or explaining)</b></p> <ul style="list-style-type: none"> <li>• Discussing a claim about the phenomena observed during the experimental investigation (ex: “the force-time graph helps explain why the total momentum changed because. . .”</li> </ul> <p><b>COMMON MISCONCEPTIONS ▶️ (Historical/widespread misunderstandings)</b></p>	

Lesson	Objective(s) and Standard(s)	Instructional Notes	Resources
		<ul style="list-style-type: none"> <li>May forget to include direction in bar charts / equations</li> </ul>	
<p><b>Day 10</b></p> <p><b>Practice - Impulse-Momentum</b></p>	<p><b>STANDARD(s)</b>  <b>Topic 4.2: Change in Momentum and Impulse</b>  <b>4.2.A</b> Describe the impulse delivered to an object or system.  <b>4.2.B</b> Describe the relationship between the impulse exerted on an object or a system and the change in momentum of the object or system.</p> <p><b>SWBAT</b> make quantitative predictions about collision scenarios by using the Impulse-Momentum relationship.</p> <p><b>DISCIPLINARY LITERACY FOCUS:</b></p> <div data-bbox="390 1203 527 1373" style="border: 1px solid orange; border-radius: 10px; padding: 5px; text-align: center;"> <p>Mathematics</p> <p>− + × ÷</p> <p>Computational Thinking</p>  </div>	<p><b>KEY UNDERSTANDINGS CHECKLIST</b></p> <ul style="list-style-type: none"> <li><input type="checkbox"/> <b>Impulse</b> is the product of average Force x time</li> <li><input type="checkbox"/> <b>Impulse</b> is calculated from a Force-Time graph by calculating the area under the curve</li> <li><input type="checkbox"/> <b>Impulse-momentum relationship:</b> The change in momentum of an object is equal to the Impulse</li> <li><input type="checkbox"/> Force and time are inversely related for a constant change in momentum</li> </ul> <p><b>LESSON CONTEXT FOR LESSON MASTERY</b>  At this point in the unit, the student has now covered all major topics for Momentum. In order to build a deeper conceptual understanding of the impulse-momentum relationship, this lesson asks students to utilize the relationship for both qualitative and quantitative problems. Conceptually understanding how to apply impulse-momentum is a fundamental skill necessary to make predictions about forces involved in collisions. Students will answer the AP Classroom Topic Questions for Topic 4.4 – Collisions and provide justification for their answer choices.</p> <p><b>LOOK-FORS</b> 🔍 (What to observe students doing or producing)</p> <ul style="list-style-type: none"> <li>Applying C.o.M and momentum bar charts to make predictions about an unknown variable</li> <li>Applying impulse-momentum to make predictions about an unknown variable</li> </ul> <p><b>LISTEN-FORS</b> 🗣️ (Examples of what students should be saying or explaining)</p> <ul style="list-style-type: none"> <li>Justifying a claim by referring back to either C.o.M or impulse-momentum</li> </ul> <p><b>COMMON MISCONCEPTIONS</b> ▶️ (Historical/widespread misunderstandings)</p>	<p><b>TEACHER CONTENT BACKGROUND RESOURCES</b></p> <p><a href="#">Khan-Impulse &amp; Momentum Example</a></p> <p><a href="#">Khan-Force-time graphs</a></p> <p>Applying Impulse-Momentum Relationship: AP Classroom Topic 4.2 Daily Video 3</p>

Lesson	Objective(s) and Standard(s)	Instructional Notes	Resources
		<ul style="list-style-type: none"> <li>• May forget to include accurate direction/sign in bar charts / equations</li> <li>• May assume that different sized objects experience different forces in a collision (reinforce Newton's 3<sup>rd</sup> Law!)</li> </ul>	
<p>Day 11</p> <p><b>Anchoring Event Seamless Explanation</b></p>	<p><b>STANDARD(s)</b></p> <p><b>Topic 4.3: Conservation of Linear Momentum</b></p> <p>4.3.A Describe the behavior of a system using conservation of linear momentum.</p> <p><b>Topic 3.4: Conservation of Mechanical Energy</b></p> <p>3.4.B Describe the behavior of a system using conservation of mechanical energy principles.</p> <p><b>SWBAT:</b> write a seamless explanation for the Anchoring Event and Essential Question</p>	<p><b>KEY UNDERSTANDINGS CHECKLIST</b></p> <ul style="list-style-type: none"> <li><input type="checkbox"/> Models can/should be revised based on evidence from Unit Lessons</li> <li><input type="checkbox"/> Making a Claim to explain the Anchoring Event and Essential Question</li> <li><input type="checkbox"/> Identifying evidence from Unit Lessons relevant to Anchoring Event and Essential Question</li> <li><input type="checkbox"/> Crafting a Seamless Explanation by connecting all relevant evidence to the claim using physics laws and principles</li> </ul> <p><b>LESSON CONTEXT FOR LESSON MASTERY</b></p> <p>Students use graphic organizers and reviewing summary tables to create a seamless explanation of the anchoring event. Students are given time to have whole group discussion and draw evidence from multiple sources to answer an essential question from the anchoring event. Being able to answer essential questions using discussion and evidence is a foundational skill for both Physics and other science courses.</p> <p><b>LOOK-FORS</b> 🔍 (What to observe students doing or producing)</p> <ul style="list-style-type: none"> <li>• Citing evidence from their summary tables</li> <li>• Including scientific reasoning to connect the evidence with the Claim</li> </ul>	<p>Skateboard Ball Throw</p> <p>Newton's Cradle</p> <p><b>TEACHER CONTENT BACKGROUND RESOURCES</b></p> <ul style="list-style-type: none"> <li>• <a href="#">Ambitious Science Teaching Overview</a></li> </ul>

Lesson	Objective(s) and Standard(s)	Instructional Notes	Resources
	<p><b>DISCIPLINARY LITERACY FOCUS:</b></p> 	<p><b>LISTEN-FORS</b> 🗣️: (Examples of what students should be saying or explaining)</p> <ul style="list-style-type: none"> <li>• Providing feedback to partners using the Accountable Talk Moves for Scholars and asking clarifying questions</li> </ul> <p><b>COMMON MISCONCEPTIONS</b> ▶️ (Historical/widespread misunderstandings)</p> <ul style="list-style-type: none"> <li>• May assume that different sized objects experience different forces in a collision (reinforce Newton's 3<sup>rd</sup> Law!)</li> </ul>	
<p><b>Day 12</b></p> <p><b>Flex – Practice - Review</b></p>	<p>Review or Extra Practice: Students can take part of the College Board Unit 4: Momentum Progress Check in AP Classroom.</p> <ul style="list-style-type: none"> <li>• Section 1: MCQ – good mix of conservation of momentum and Impulse-momentum questions <ul style="list-style-type: none"> <li>○ 18 MC questions with AP Exam timing (2 min/MC question) = 36 minutes</li> </ul> </li> <li>• OR, choose one of the FRQ options below (based on student gaps identified from previous Unit Exams and Semester Exam) <ul style="list-style-type: none"> <li>○ FRQ 1 – Deriving Equations for a Perfectly Inelastic Collision <ul style="list-style-type: none"> <li>▪ Mathematical Routines (MR)   10 points   20 min</li> </ul> </li> <li>○ FRQ 2 – LOTS of spiral review - Analyzing Motion graphs &amp; Creating FBD <ul style="list-style-type: none"> <li>▪ Translation Between Representations (TBR)   12 points   24-25 min</li> </ul> </li> <li>○ FRQ 3 – Find and unknown mass using collision experiment <ul style="list-style-type: none"> <li>▪ Experimental Design &amp; Analysis (LAB)   10 points   25 min</li> </ul> </li> <li>○ FRQ 4 – Perfectly inelastic collision becomes projectile motion <ul style="list-style-type: none"> <li>▪ Qualitative/Quantitative Translation (QQT)   8 points   16 min</li> </ul> </li> </ul> </li> </ul> <p><b>Provide time for student to review and correct their answers to the Progress Check</b></p> <ul style="list-style-type: none"> <li>• MCQ - Provide justification for the correct answers AND incorrect answers. How do we know if each answer choice is correct or incorrect?</li> <li>• Use AP Classroom rubric to peer and/or self-grade FRQ following the Success Day plan</li> </ul>		<div style="border: 1px solid pink; padding: 5px;"> <p><b>Consider Having students attempt the Progress Check including 1 FRQ for HW and spending this instructional day reviewing answers and correcting student misconceptions.</b></p> </div>
<p><b>Day 13</b></p>		<p style="text-align: center;"><b>TX_SCI_APPhysics_S26_UE4</b></p> <p style="text-align: center;"><b>All students should have access to the AP Physics Equation Table for all Exams!</b></p>	 <p>ap-physics-1-Equation Table - 2024.pdf</p>
<p><b>Day 14</b></p>		<p style="text-align: center;"><b>Success Day Lesson Plan (time permitting)</b></p>	

## VERTICAL STANDARDS for Texas

This section details the **progression** of key student standards in the courses **before** this course. This will help you understand what **prior knowledge skills to build upon**.

***These vertical standards are EXACTLY the same as Unit 3: Energy. Not every vertical standard applies but most of the energy and Work concepts are still relevant for momentum.***

5 <sup>th</sup> Grade Science	6/7 Grade Hybrid Science	8 <sup>th</sup> Grade Science
<p><b>3-5(7) Force, motion, and energy. The student knows the nature of forces and the patterns of their interactions. The student is expected to:</b></p> <p>5.7A investigate and explain how equal and unequal forces acting on an object cause patterns of motion and transfer of energy.</p> <p><b>3-5(8) Force, motion, and energy. The student knows that energy is everywhere and can be observed in cycles, patterns, and systems. The student is expected to:</b></p> <p>5(8)(A) investigate and describe the transformation of energy in systems such as energy in a flashlight battery that changes from chemical energy to electrical energy to light energy;</p> <p>5(8)(B) demonstrate that electrical energy in complete circuits can be transformed into motion, light, sound, or thermal energy and identify the requirements for a functioning electrical circuit; and</p>	<p><b>6(8) Force, motion, and energy. The student knows that the total energy in systems is conserved through energy transfers and transformations. The student is expected to:</b></p> <p>6(8)(A) compare and contrast gravitational, elastic, and chemical potential energies with kinetic energy;</p> <p>6(8)(B) describe how energy is conserved through transfers and transformations in systems such as electrical circuits, food webs, amusement park rides, or photosynthesis; and</p> <p><b>7(8) Force, motion, and energy. The student understands the behavior of thermal energy as it flows into and out of systems. The student is expected to:</b></p> <p>7(8)(A) investigate methods of thermal energy transfer into and out of systems, including conduction, convection, and radiation;</p> <p>7(8)(B) investigate how thermal energy moves in a predictable pattern from warmer to cooler until all substances within the system reach thermal equilibrium; and</p> <p>7(8)(C) explain the relationship between temperature and the kinetic energy of the particles within a substance.</p>	<p>None</p>

## VOCABULARY GLOSSARY

Domain-specific words and definitions for this unit.

Key Content Vocabulary				
<p><b>Momentum Bar Charts</b> – a visual model of the momentum of a system at two different positions/times</p> <p><b>Momentum (p)</b> (linear) – the product of mass and velocity of an object. Represented as p in formula.</p> $p = mv$ <p><b>Change in Momentum (<math>\Delta p</math>)</b> – The change in momentum of an object or system at two different points in time. Often designated Before/After or Initial/Final. Often due to changes</p> $\Delta p = mv_F - mv_I$ <p><b>Conservation of Momentum</b> – for a closed system the total momentum of the system will remain constant (usually before and after a collision)</p> $p_I = p_F$ $m_1v_{1i} + m_2v_{2i} = m_1v_{1F} + m_2v_{2F}$ <p><b>Closed system</b> – a system that is not impacted by forces outside the system (usually friction or air resistance).</p> <p><b>Open system</b> – a system that is subject to forces from outside the system (usually friction or air resistance).</p> <p><b>Internal Force</b> – forces that result from the interaction of objects that are part of the defined system. These forces cannot affect the total momentum (or energy) of the system but will change the individual momentum (and energy) of objects during two object collisions.</p> <p><b>External (Outside) Force</b> – force that results from objects outside of the defined system interacting with objects that are inside the defined system. These forces can change the total momentum (and energy) of the system. Friction and Air resistance are common outside forces in AP Physics 1.</p> <p><b>Impulse (I)</b> – the product of average Force and time force is applied</p> $Impulse = Force * time$ $I = Ft$ <p><b>Center of Mass (center of gravity)</b> – the point where the total mass of an object or system can be treated as a point mass. For a uniform density object the center of mass is at the geometric center of the object (AKA centroid). For a system of objects, the center of mass can be thought of as the average mass position (see example calculations in link). The center of mass of a system is particularly useful when analyzing the motion of systems with conservation of linear momentum because for scenarios where momentum is conserved the center of mass will have constant velocity. A common demonstration to find center of mass can be experimentally is to take a nonuniform object like a hammer and find the point where the object will balance on a single finger without rotating.</p>				
Related Vocabulary				
Collision Types:				
Elastic				
Inelastic				

Perfectly Inelastic Explosion				
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