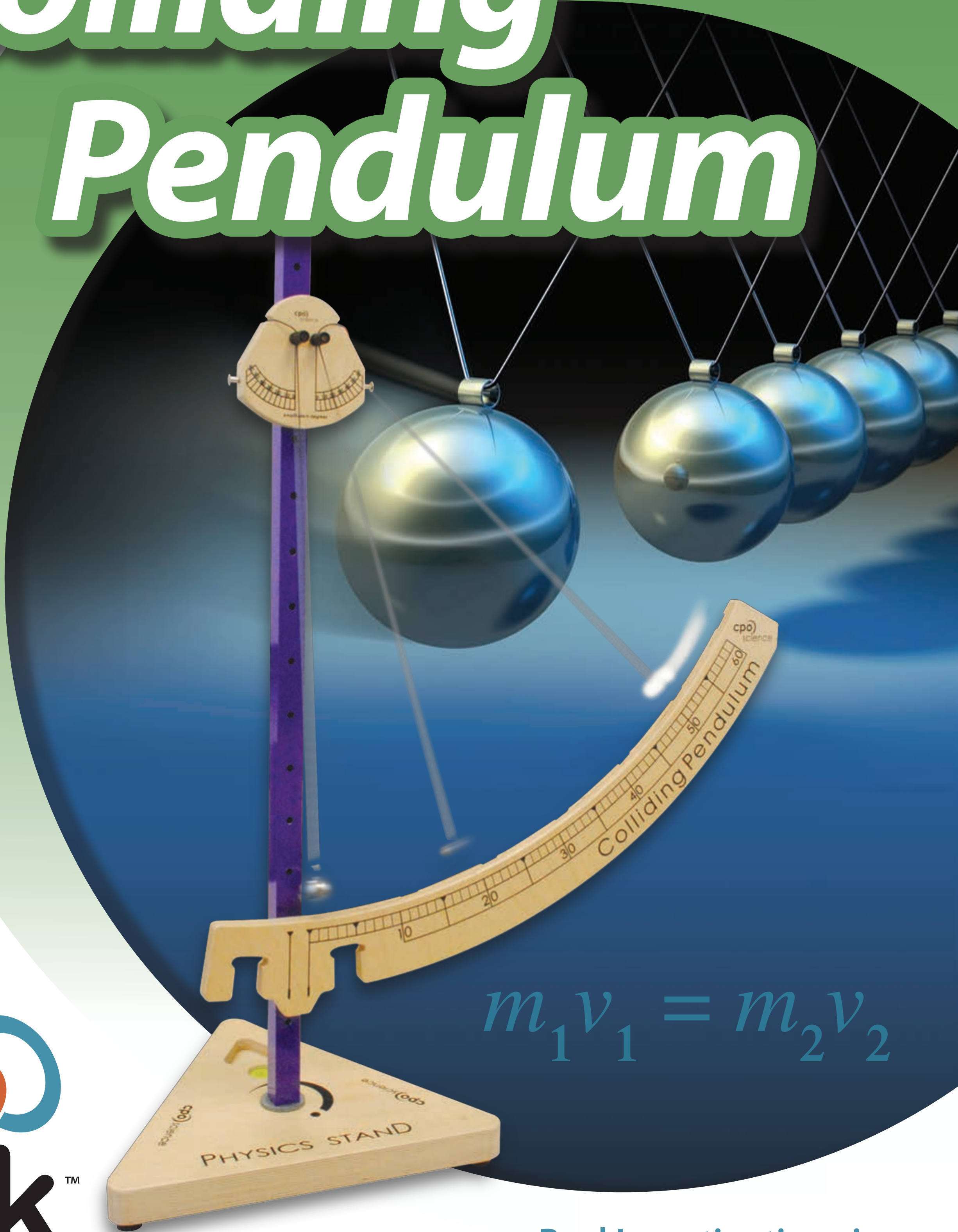
*Motion, Collisions, and Momentum*

# Colliding Pendulum




$$m_1v_1 = m_2v_2$$

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Real Investigations in Science and Engineering

# Overview Chart for Investigations–Colliding Pendulum

| | Investigation | Key Question | Summary | Learning Goals | Vocabulary |
|---|---|---|---|---|---|
| A1 | **The Pendulum**<br>Pages 1–8<br>50 minutes | How can you change the period of a pendulum? | Students learn the vocabulary used to describe harmonic motion. They build pendulums and experiment with three independent variables to explore which has the greatest effect on the period of a pendulum: mass, amplitude, or string length. | • Learn terms used to describe harmonic motion.<br>• Practice testing a system with three independent variables.<br>• Construct a graph and use it to draw valid conclusions. | amplitude<br>cycle<br>damping<br>harmonic motion<br>oscillation<br>oscillator<br>period |
| A2 | **Making a Clock**<br>Pages 9–14<br>50 minutes | How can you use a pendulum to measure time? | Students design a timekeeping pendulum. They choose a number of cycles to equal 1 minute for their pendulum, then determine the length of the pendulum's period. Then they build their pendulum clock and test its accuracy against a stopwatch. | • Use a graph to make predictions.<br>• Build a pendulum clock that can accurately measure 1 minute. | pendulum |
| A3 | **Collisions**<br>Pages 15–20<br>50 minutes | What happens during collisions? | Students observe elastic collisions between the steel balls of the colliding pendulums. Next, they add small pieces of clay to the steel balls and repeat the experiment to observe inelastic collisions. They determine how the motion that occurs after a collision depends on the masses of the colliding objects. | • Observe different types of collisions.<br>• Distinguish between elastic and inelastic collisions.<br>• Predict what will happen in a collision based on the masses of the objects. | collision<br>deform<br>elastic collision<br>inelastic collision<br>momentum<br>Newton's second law<br>Newton's third law |
| A4 | **Designing a Collision**<br>Pages 21–26<br>50 minutes | How can you create a collision in which two moving pendulums collide and stop completely? | Students become familiar with the engineering cycle by building a pendulum design to solve a specific engineering problem. They will have to use the scientific concepts of collisions and Newton's third law to design a specific collision. | • Design a collision given requirements and constraints.<br>• Predict what happens in a collision using Newton's third law.<br>• Use the engineering cycle to solve an engineering problem. | constraints<br>criteria<br>engineer<br>engineering cycle |
| B1 | **Harmonic Motion**<br>Pages 27–34<br>150 minutes | How do we describe the back-and-forth motion of a pendulum? | Students are introduced to harmonic motion using a simple pendulum. They design and conduct an experiment to determine which of three variables has the greatest influence on the period of the pendulum. They apply their analysis to design an accurate clock that measures 30 seconds. | • Measure the amplitude and period of a pendulum.<br>• Predict how the period of a pendulum changes using knowledge of physical parameters such as mass, amplitude, and string length.<br>• Design and build a clock to measure a 30-second time interval. | amplitude<br>cycle<br>harmonic motion<br>oscillator<br>pendulum<br>period |

# Overview Chart for Investigations–Colliding Pendulum

| | Investigation | Key Question | Summary | Learning Goals | Vocabulary |
|---|---|---|---|---|---|
| B2 | **The 5-Second Pendulum**<br>Pages 35–40<br>50 minutes | What length of string would produce a 5-second pendulum? | Students use their data from the previous investigation to come up with an equation to calculate period from string length. They solve their equation for string length and then extrapolate the string length required for a 5-second pendulum. Then they compare their equation with Huygens's derived equation for pendulum period. | • State a hypothesis that describes how string length and period are related.<br>• Graph the hypothesized relationship and use the graph to derive an equation for determining the period given the string length.<br>• Use the equation to predict the string length needed to create a 5-second pendulum. | extrapolation<br>graph<br>inverse relationship<br>period |
| B3 | **Momentum**<br>Pages 41–48<br>100 minutes | How well is momentum conserved in collisions? | Students observe elastic collisions between balls of the same and differing masses. The speed of each ball before and after each collision is determined, and the total momentums are calculated. Students compare the total momentum before and after each collision to determine how well momentum is conserved. | • Perform elastic collisions between balls of various masses.<br>• Calculate the velocity and momentum of the balls before and after each collision.<br>• Determine whether momentum is conserved in each collision. | collision<br>elastic collision<br>inelastic collision<br>law of conservation of momentum<br>momentum<br>Newton's second law<br>Newton's third law |
| B4 | **Designing a Safety Device**<br>Pages 49–54<br>100 minutes | How do you design a device to minimize forces between colliding pendulums? | Students apply the engineering cycle to design a device that slows down a colliding pendulum. They must identify the requirements and constraints of the problem, and then design and build a prototype. They will evaluate and refine the prototype to find the best solution to the problem. | • Use the engineering cycle to design a device to reduce forces in a collision.<br>• Build and test a prototype safety device.<br>• Evaluate test results and refine the prototype. | constraints<br>criteria<br>engineer<br>engineering cycle<br>prototype |
| C1 | **Energy Conservation**<br>Pages 55–60<br>100 minutes | How can we use the law of energy conservation to analyze the motion of the pendulum? | Students consider the motion of a pendulum to determine where in the swing the potential and kinetic energies are greatest and least, and then use this information to predict the maximum velocity of the pendulum at different heights relative to an initial position. | • Describe the relationships between potential energy and kinetic energy in a system.<br>• Apply the law of conservation of energy to derive an equation for the maximum velocity of a pendulum.<br>• Experimentally verify the equation. | energy<br>kinetic energy<br>law of conservation of energy<br>potential energy |

# Overview Chart for Investigations–Colliding Pendulum

| | Investigation | Key Question | Summary | Learning Goals | Vocabulary |
|---|---|---|---|---|---|
| C2 | **Newton's Second Law and the Pendulum**<br>Pages 61–68<br>50 minutes | How can Newton's second law be used to establish a relationship for the period of a pendulum? | Students analyze a free-body diagram to determine the restoring force on a pendulum bob. They then use Newton's second law to derive a formula for the period of a pendulum. | • Write an expression for the period of the pendulum based on Newton's second law.<br>• Compare calculated values for the period with values obtained experimentally.<br>• Gain an understanding of the interdependence of scientific laws. | approximation<br>cycle<br>equilibrium<br>harmonic motion<br>inertia<br>Newton's second law<br>period<br>restoring force |
| C3 | **Elastic Collisions**<br>Pages 69–76<br>50–100 minutes | How well are momentum and energy conserved in elastic collisions? | Students observe collisions between balls of the same and different masses. Using photogates, the velocities of the balls before and after each collision are determined. Students determine whether momentum and kinetic energy are conserved in elastic collisions. | • Perform elastic collisions between balls of various masses.<br>• Calculate the velocity, momentum, and kinetic energy of the balls before and after each collision.<br>• Determine whether momentum and energy are conserved in each collision. | elastic collision<br>kinetic energy<br>law of conservation of energy<br>law of conservation of momentum<br>momentum<br>Newton's third law |
| C4 | **Inelastic Collisions**<br>Pages 77–82<br>100 minutes | What happens to momentum and energy during inelastic collisions? | Students create inelastic collisions between balls of the same and differing masses. They then compare the momentum and energy before and after each collision to determine whether momentum and kinetic energy are conserved. | • Perform inelastic collisions between balls of various masses.<br>• Calculate the velocity, momentum, and kinetic energy of the each ball before and after each collision.<br>• Determine whether momentum and kinetic energy are conserved in each collision. | inelastic collision |

# Next Generation Science Standards Correlation

CPO Science *Link* investigations are designed for successful implementation of the Next Generation Science Standards. The following chart shows the NGSS Performance Expectations and dimensions that align to the investigations in this title.

| NGSS Performance Expectations | Colliding Pendulum Investigations |
|---|---|
| MS-PS2-1. Apply Newton's Third Law to design a solution to a problem involving the motion of two colliding objects. | A3, A4 |
| MS-PS4-1. Use mathematical representations to describe a simple model for waves that includes how the amplitude of a wave is related to the energy in a wave. | A1, A2 |
| 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. | C2 |
| 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. | B3, C3, C4 |
| HS-PS2-3. Apply scientific and engineering ideas to design, evaluate, and refine a device that minimizes the force on a macroscopic object during a collision | B4 |
| 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. | C1 |
| HS-PS4-1. Use mathematical representations to support a claim regarding relationships among the frequency, wavelength, and speed of waves traveling in various media. | B1, B2 |

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# Next Generation Science Standards Correlation (cont'd)

| NGSS Science and Engineering Practices | Colliding Pendulum Investigations |
|---|---|
| Analyzing and Interpreting Data | C2 |
| Constructing Explanations and Designing Solutions | A3, A4, B4 |
| Using Mathematics and Computational Thinking | A1, A2, B1, B2, B3, C1, C3, C4 |

| NGSS Disciplinary Core Ideas | Colliding Pendulum Investigations |
|---|---|
| ETS1.A: Defining and Delimiting an Engineering Problem | B4 |
| ETS1.C: Optimizing the Design Solution | B4 |
| PS2.A: Forces and Motion | A3, A4, B3, B4, C2, C3, C4 |
| PS3.A: Definitions of Energy | C1 |
| PS3.B: Conservation of Energy and Energy Transfer | C1 |
| PS4.A: Wave Properties | A1, A2, B1, B2 |

| NGSS Crosscutting Concepts | Colliding Pendulum Investigations |
|---|---|
| Cause and Effect | B1, B2, B4, C2 |
| Patterns | A1, A2 |
| Systems and System Models | A3, A4, B3, C1, C3, C4 |

# Common Core State Standards Correlation

| CCSS-Mathematics | | Colliding Pendulum Investigations |
|---|---|---|
| MP.2 | Reason abstractly and quantitatively. | A1, A2, A3, A4, B1, B2, B3, C1, C2, C3, C4 |
| MP.4 | Model with mathematics. | A1, A2, B1, B3, C1, C2, C3, C4 |
| 6.RP.A.1 | Understand the concept of a ratio and use ratio language to describe a ratio relationship between two quantities. | A1, A2 |
| 6.RP.A.3 | Use ratio and rate reasoning to solve real-world and mathematical problems. | A1 |
| 7.RP.A.2 | Recognize and represent proportional relationships between quantities. | A1, A2 |
| 6.NS.C.5 | Understand that positive and negative numbers are used together to describe quantities having opposite directions or values; use positive and negative numbers to represent quantities in real-world contexts, explaining the meaning of 0 in each situation. | A3, A4 |
| 6.EE.A.2 | Write, read, and evaluate expressions in which letters stand for numbers. | A3, A4 |
| 7.EE.B.3 | Solve multi-step real-life and mathematical problems posed with positive and negative rational numbers in any form, using tools strategically. Apply properties Apply properties of operations to calculate with numbers in any form; convert between forms as appropriate; and assess the reasonableness of answers using mental computation and estimation strategies | A3, A4 |
| 7.EE.B.4 | Use variables to represent quantities in a real-world or mathematical problem, and construct simple equations and inequalities to solve problems by reasoning about the quantities. | A3, A4 |
| 8.F.A.3 | Interpret the equation $y = mx + b$ as defining a linear function, whose graph is a straight line; give examples of functions that are not linear. | A1, A2 |
| HSN-Q.A.1 | Use units as a way to understand problems and to guide the solution of multi-step problems; choose and interpret units consistently in formulas; choose and interpret the scale and the origin in graphs and data displays. | B3, C1, C2, C3, C4 |
| HSN-Q.A.2 | Define appropriate quantities for the purpose of descriptive modeling. | B3, C1, C2, C3, C4 |
| HSN-Q.A.3 | Choose a level of accuracy appropriate to limitations on measurement when reporting quantities. | B3, C1, C2, C3, C4 |
| HSA-SSE.A.1 | Interpret expressions that represent a quantity in terms of its context. | B1, B2, C2 |
| HSA-SSE.B.3 | Choose and produce an equivalent form of an expression to reveal and explain properties of the quantity represented by the expression. | B1, B2, C2 |
| HSA-CED.A.1 | Create equations and inequalities in one variable and use them to solve problems. | B3, C2, C3, C4 |
| HSA-CED.A.2 | Create equations in two or more variables to represent relationships between quantities; graph equations on coordinate axes with labels and scales. | B3, C2, C3, C4 |
| HSA.CED.A.4 | Rearrange formulas to highlight a quantity of interest, using the same reasoning as in solving equations. | B1, B3, B2, C2, C3, C4 |
| HSF-IF.C.7 | Graph functions expressed symbolically and show key features of the graph, by in hand in simple cases and using technology for more complicated cases. | C2 |
| HSS-IS.A.1 | Represent data with plots on the real number line (dot plots, histograms, and box plots). | C2 |

# Common Core State Standards Correlation (cont'd)

| CCSS-English Language Arts & Literacy | | Colliding Pendulum Investigations |
|---|---|---|
| SL.8.5 | Integrate multimedia and visual displays into presentations to clarify information, strengthen claims and evidence, and add interest. | A1, A2 |
| SL.11-12.5 | Make strategic use of digital media (e.g., textual, graphical, audio, visual, and interactive elements) in presentations to enhance understanding of findings, reasoning, and evidence and to add interest. | C1 |
| RST.6-8.1 | Cite specific textual evidence to support analysis of science and technical texts, attending to the precise details of explanations or descriptions. | A3, A4 |
| RST.6-8.3 | Follow precisely a multistep procedure when carrying out experiments, taking measurements, or performing technical tasks. | A3, A4 |
| RST.11-12.1 | Cite specific textual evidence to support analysis of science and technical texts, attending to important distinctions the author makes and to any gaps or inconsistencies in the account. | C2 |
| RST.11-12.7 | Integrate and evaluate multiple sources of information presented in diverse formats and media (e.g., quantitative data, video, multimedia) in order to address a question or solve a problem. | B1, B2, B4, C2 |
| WHST.6-8.7 | Conduct short research projects to answer a question (including a self-generated question), drawing on several sources and generating additional related, focused questions that allow for multiple avenues of exploration. | A3, A4 |
| WHST.9-12.9 | Draw evidence from informational texts to support analysis, reflection, and research. | C2 |