Grade 11 or 12

Physics Curriculum

SC115 and SC116 (Honors)

Connecticut Technical High School System
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Hartford, Connecticut 06105

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CTECS - Vision of a Graduate

The Vision of a Graduate (VoG) at the Connecticut Technical Education and Career System (CTECS) embodies our commitment to preparing students for success in Connecticut's workforce.

Developed in collaboration with students, parents, staff, and employers, the VoG ensures that CTECS students are not only job-ready but also equipped to lead, innovate, and adapt in a dynamic world.

As educators, we are dedicated to developing these qualities by providing a comprehensive education that empowers our students to achieve their fullest potential and make meaningful contributions to society.

A Problem Solver

Problem solvers tackle challenges by identifying root causes of issues, brainstorming solutions, implementing effective strategies, and demonstrating adaptability.

- ➔ Engage students with open-ended, creative thinking tasks that require both conventional and innovative solutions.
- ➔ Facilitate group discussions and collaborative projects.
- ➔ Use real-world scenarios and hands-on activities.
- ➔ Highlight the importance of effort, persistence, and continuous learning.
- ➔ Provide regular feedback and encourage reflection.

Work Ready

To be work-ready includes a combination of technical expertise, soft skills, and personal qualities that ensure a graduate can effectively contribute to the workplace from day one.

- ➔ Set high standards for punctuality, responsibility, professionalism, and task completion.
- ➔ Use project-based learning and collaborative assignments.
- ➔ Emphasize clear written and verbal communication.
- ➔ Offer practical exercises like mock interviews and resume workshops.
- ➔ Integrate technology and teach digital literacy.

Respectful

Graduates who embody respectfulness emphasize the importance of treating others with dignity, valuing diversity, and fostering an inclusive and positive environment, both personally and professionally.

- ➔ Demonstrate personal, interpersonal, and professional skills.
- ➔ Show respect for diversity.
- ➔ Model respect through active listening and empathy.
- ➔ Set clear expectations for respectful interactions.
- ➔ Promote collaboration and group discussions.
- ➔ Celebrate respectful behavior.
- ➔ Address disrespect promptly and constructively.

Skilled Socially

Graduates who are skilled socially are equipped to navigate social environments, build relationships, and contribute positively to their communities and workplaces.

- ➔ Show awareness of global responsibility to others and the environment.
- ➔ Participate in community involvement.
- ➔ Design cooperative group projects and team activities
- ➔ Set expectations for respect and give regular feedback.
- ➔ Facilitate discussions on inclusivity, kindness, and respect.
- ➔ Model positive interactions and recognize strong social skills.

A Critical Thinker

Critical thinkers approach problems systematically by analyzing, evaluating, and synthesizing information to make well-informed decisions and contribute to innovative solutions.

- ➔ Encourage critical thinking individually and collaboratively.
- ➔ Design lessons that challenge assumptions and explore diverse viewpoints.
- ➔ Use open-ended questions, rigorous activities, and cross-curricular projects.
- ➔ Integrate project-based learning and real-world problem-solving.
- ➔ Offer reflective opportunities like journaling and discussions.
- ➔ Cultivate an environment that values curiosity and inquiry.

An Effective Communicator

Effective communicators convey ideas, information, and emotions accurately and persuasively, fostering understanding and collaboration.

- ➔ Communicate effectively using oral, written, visual, artistic, and technical modes.
- ➔ Include group discussions, presentations, and peer reviews.
- ➔ Promote active listening and thoughtful responses.
- ➔ Offer clear guidelines and constructive feedback.
- ➔ Stress clear, respectful, and purposeful communication.

CTECS Instructional Model

CTECS uses the Marzano Compendium to guide research-based instructional strategies that differentiate learning and promote access, engagement, and success for all students. Teachers apply these strategies to support diverse learners (including multilingual learners, students with disabilities, and students with varied academic or technical backgrounds) through scaffolds, modeling, guided practice, and multiple ways to participate and show understanding. This approach ensures every student can work toward proficiency in the Priority Standards and the competencies outlined in the CTECS Vision of a Graduate.

Curriculum Introduction

This curriculum document outlines the essential learning for this academic program and provides a clear structure for planning, instruction, and assessment. It includes the components required by NEASC Standard 2.2a, along with elements that reflect the unique nature of CTECS academic programs. The curriculum is organized to show what students learn in each course, how learning progresses across grade levels, and how instruction supports both technical skill development and the CTECS Vision of a Graduate.

Teachers should use this document to:

- Understand the overall structure and expectations of the course sequence
- Reference the Course Map to see the scope and sequence of Priority Standards
- Use the Priority Standards and Units of Study to guide daily, weekly, and cycle-based planning
- Integrate Big Ideas, Essential Questions, Skills/Learning Outcomes, vocabulary, and resources during lesson design
- Plan and implement formative assessments to monitor progress and guide instruction
- Prepare students for the District Summative Assessments, ensuring alignment with the Course Map
- Maintain consistency of instruction across campuses while adapting to student needs

Curriculum Components

Course Map

A Course Map serves as the scope and sequence for this course by outlining the progression of instructional units and the standards that guide teaching and assessment. While each campus will have individual student needs, cycle schedules, and industry-based opportunities, all instructors are expected to teach the standards outlined in the Course Map. Using the Course Map below, teachers will intentionally plan learning experiences that prepare students to meet the identified standards within the designated assessment windows.

Priority Standards (Units of Study)

Priority Standards identify the most essential learning in the trade program. They reflect the core technical competencies, safety practices, and industry-aligned skills that require the greatest instructional focus and appear on program assessments. In CTE programs, each Priority Standard also functions as a Unit of Study, because it includes the required components such as big ideas, essential questions, content topics, and skills/learning outcomes aligned to assessments.

Learning Outcomes

Learning outcomes are what students will know (Concepts) and be able to do (Skills). Concepts identify the major content topics within the Priority Standard (Unit of Study). They appear in the left column of the Learning Outcomes table and follow a similar coding structure as the Priority Standard. Skills are learning objectives that describe the measurable actions students must be able to perform to demonstrate proficiency. They appear in the right column of the Learning Outcomes table and show the progression of learning evidence in the Priority Standard.

Resources

Resources include the tools, equipment, texts, materials, and digital tools that support learning within each unit and reflect industry standards.

Assessment Practices

Teachers use ongoing formative assessments—such as questioning, checks for understanding, performance demonstrations, reflections, and teacher observation—to monitor progress, guide instruction, and support all learners in mastering the Priority Standards.

Vocabulary

Essential vocabulary includes the technical and academic terms students must understand and use accurately to engage in scientific learning and demonstrate proficiency on assessments. Vocabulary is foundational to safety, precision, and communication, and should be a primary initial focus within each unit and taught explicitly through modeling, demonstration, and repeated application.

Physics - Grade 11 or 12

Description of the Course

(1 credit) Physics allows students to continue to explore aspects of the physical sciences and to apply data collection, analysis, and interpretation skills related to those scientific concepts. Based on the Next Generation Science Standards, the course is made up of two related disciplines: Physical Science and Engineering, Technology, and Applications of Science. This framework articulates the standards as well as the science and engineering performances, disciplinary core ideas, and crosscutting concepts. Students will apply their knowledge of physics to various problem-solving activities with the use of science-specific technologies and standard laboratory tools.

Honors Physics is an accelerated course. Students are expected to complete several inquiry-based projects over the course of the year, in addition to meeting more challenging objectives. **Performance objectives should be presented to honors students with an increased level of complexity and rigor throughout the curriculum and higher levels of performance are to be expected of honors sections over the course of the year.**

CTECS Science Assessment & Instruction Guidelines

The grade-level **SEP (Science and Engineering Practices) Summative Assessments** for grades 9 through 11 and the **Basic Skills Assessment** for grade 12 are designed to measure mastery of the *science and engineering practices* identified by the NGSS (Next Generation and Science Standards). The practices describe behaviors that scientists engage in as they investigate and build models and theories about the natural world and the key set of engineering practices that engineers use as they design and build models and systems.

The SEPs are:

- **Asking Questions and Defining Problems**: A practice of science is to ask and refine questions that lead to descriptions and explanations of how the natural and designed world works and which can be empirically tested.
- **Developing and Using Models**: A practice of both science and engineering is to use and construct models as helpful tools for representing ideas and explanations. These tools include diagrams, drawings, physical replicas, mathematical representations, analogies, and computer simulations.
- **Planning and Carrying Out Investigations**: Scientists and engineers plan and carry out investigations in the field or laboratory, working collaboratively as well as individually. Their investigations are systematic and require clarifying what counts as data and identifying variables or parameters.
- **Analyzing and Interpreting Data**: Scientific investigations produce data that must be analyzed in order to derive meaning. Because data patterns and trends are not always obvious, scientists use a range of tools—including tabulation, graphical interpretation, visualization, and statistical analysis—to identify the significant features and patterns in the data. Scientists identify sources of error in the investigations and calculate the degree of certainty in the results. Modern technology makes the collection of large data sets much easier, providing secondary sources for analysis.
- **Using Mathematics and Computational Thinking**: In both science and engineering, mathematics and computation are fundamental tools for representing physical variables and their

relationships. They are used for a range of tasks such as constructing simulations; statistically analyzing data; and recognizing, expressing, and applying quantitative relationships.

- **Constructing Explanations and Designing Solutions**: The products of science are explanations and the products of engineering are solutions.
- **Engaging in Argument from Evidence**: Argumentation is the process by which explanations and solutions are reached.
- **Obtaining, and Evaluating, and Communicating Information**: Scientists and engineers must be able to communicate clearly and persuasively the ideas and methods they generate. Critiquing and communicating ideas individually and in groups is a critical professional activity.

Each grade-level SEP Summative Assessment is designed to assess mastery of specific practices. The expectation is that students should demonstrate mastery as outlined below in preparation for the NGSS Assessment in 11th grade. Cross-cutting concepts are incorporated across all courses.

Grade Level	**Science Engineering and Practices (SEPs) to be Mastered**
9 General Science	Asking Questions and Defining Problems
	Planning and Carrying Out Investigations
	Analyzing and Interpreting Data
10 Biology	Developing and Using Models
	Engaging in Argument from Evidence
	Obtaining, Evaluating, and Communicating Information
11 Chemistry Advanced Topics Physics	Using Mathematics and Computational Thinking
	Constructing Explanations and Designing Solutions

Cross-Cutting Concepts (incorporated into all courses)
Cause and Effect
Structure and Function
Systems and System Models
Scale, Proportion, and Quantity
Stability and Change
Energy and Matter
Patterns

Instruction, Grading and Assessment Considerations

The manner and pedagogy used to teach the Disciplinary Core Ideas (DCIs) is at the discretion of the instructors. They are, however, expected to support their students in demonstrating mastery of the SEPs on the common summative assessments by the end of the course, in unit order.

Instruction:

- Keeping in mind that all DCIs should be covered by the end of the school year for each course, instructors are encouraged to engage students in learning tasks that consider relevance, interest, school trades, and available materials and supplies.
- The instructional focus should be on the SEPs and the Cross-Cutting Concepts (CCCs) as identified by the NGSS.
- Instruction can be linear or spiraling and be designed around anchoring phenomena and/or storylines.
- Interim Based Assessment:
    - 11th Grade Physics: Students will be exposed to NGSS-style questions through the NGSS Practice Assessments. Skills of focus include: Test-Taking Skills, Navigating Multi-Select Questions, Desmos Calculator, Highlighting, Online Graphing.
    - Minimum of 1 Interim-Based Assessment practice session per quarter during Junior year.

Grading:

- As mandated by the District, Mandated Grading Categories are:
    - Assessment 40%
    - Labs/Projects 30%
    - Classwork/Homework 30%

Assessment: (Summative and Formative)

- Three-dimensional district-wide unit assessments will measure mastery of Science and Engineering Practices (SEPs) in alignment with Cross-Cutting Concepts (CCCs) and Disciplinary Core Ideas (DCIs).
- Claim Evidence Reasoning: CERs will measure a student's ability to use data, critical thinking, and scientific reasoning to form and support an argument.

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Course Map - Physics

Unit	Cycles	Big Ideas	Standards	Interim Assessments
Unit 1: Motion-Prerequisite Skill Development	1	• Use dimensional analysis to convert amongst imperial and metric units of measure. • Model physical situations on graphs, motion diagrams, and use scalars and vectors. • Kinematic equations can quantitatively analyze concepts of speed, velocity, and acceleration.	• Using Mathematics and Computational Thinking	
Unit 2: Direct Forces	2	• Use Newton's Laws of Motion to describe and analyze physical phenomena and apply the concepts to real-life situations. • Differentiate between mass and weight and use formulas to calculate each quantity. • Draw free-body diagrams to represent situations and label forces on the system.	• **HS-PS2-1** Motion and Stability: Forces and Interactions	
Unit 3: Energy	3	• Calculate and analyze Gravitational Potential Energy and Kinetic Energy in a system, algebraically manipulate the formulas, and apply the concepts to daily life. • Compare and contrast elastic and inelastic collisions in terms of energy conservation. • Apply the Law of Conservation of Energy to real-life scenarios and use the concept mathematically to perform energy balances. • Conceptually and mathematically describe the concept of work. • Design a device that uses energy conversions to accomplish a task.	• **HS-PS3-1** Energy Change of Components in a System • **HS-PS3-2** Macroscopic Energy Due to Particle Position and Motion • **HS-PS3-3**Energy Conversion Device Design	**PS3-1**
Unit 4: Momentum	4	• Momentum is conservative but energy can be conservative or non-conservative in a closed system. • Use given components to mathematically solve for Kinetic Energy, Gravitational Energy, and Momentum. • Solve Conservation of Energy and Conservation of Momentum problems.	• **HS-PS2-2** Motion and Stability: Forces and Interactions • **HS-PS2-3** Motion and Stability: Forces and Interactions	

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Unit 5: Thermal Energy	5	• Use the Laws of Thermodynamics to describe and analyze physical phenomena and apply the concepts to real-life situations. • Use the concept of specific heat capacity to mathematically calculate heat transfer. • Addition or removal of heat will cause phase changes in matter. • Heat can be transferred through conduction, convection, or radiation.	• **HS-PS3-4** The Second Law of Thermodynamics	
Unit 6: Waves	6	• Identify frequency, period, wavelength, and wave speed in scenarios and use mathematical formulas to describe their relationships. • Model the anatomy of a wave and describe how its attributes influence real-life expressions of a wave's energy, • Describe the electromagnetic spectrum and various wavelength bands, • Explain, compare, and contrast each expression of the wave-particle duality model. • Explore how technological devices utilize wave behavior to transmit energy and information.	• **HS-PS4-1** Wave Properties in Various Media • **HS-PS4-2** Digital Transmission and Storage of Information • **HS-PS4-3** Wave-Particle Duality of Electromagnetic Radiation • **HS-PS4-4** Absorption of Electromagnetic Radiation • **HS-PS4-5** Waves and Information Technology	**PS4-1**
Unit 7: Field Forces	7	• Differentiate between fields and forces and between contact forces and field forces. • Apply Newton's Law of Universal Gravitation and Coulomb's Law to physical scenarios and then compare and contrast the two laws.	• **HS-PS2-4** Motion and Stability: Forces and Interactions • **HS-PS3-5** Energy	**PS3-5**
Unit 8: Orbits And Circular Motion	8	• Compare and contrast centripetal and centrifugal forces. • Apply the Centripetal Acceleration Equation, the Centripetal Force Equation, and Kepler's Laws of Planetary Motion to describe real-life situations. • Based on a given launch speed, predict the resulting trajectory of a projectile.	• **HS-ESS1-4** Earth's Place in the Universe	
Unit 9: Electro-magnetism	9	• Describe the phenomenon of electromagnetic induction.	• **HS-PS 2-5** Electric Current and Magnetic Fields	**PS 2-5**

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Unit 1: Motion- Prerequisite Skill Development

Priority Standard (Performance Expectation):
Using Mathematics and Computational Thinking

Mathematical and computational thinking at the 9–12 level builds on K–8 and progresses to using algebraic thinking and analysis, a range of linear and nonlinear functions including trigonometric functions, exponentials and logarithms, and computational tools for statistical analysis to analyze, represent, and model data. Simple computational simulations are created and used based on mathematical models of basic assumptions.

Clarification Statement: This unit is focused on building necessary Science and Engineering Practices to navigate the course of physics. The focus is on kinematics to develop mathematical and conceptual background skills that will be required to master objectives throughout the remainder of the course.

Big Idea(s):

- Mathematical models, such as vector analysis and kinematic equations, are essential tools for quantitatively predicting and representing the motion of objects within a 4-quadrant coordinate system.

Essential Question(s):

- How do we know that a mathematical model (like a position-time graph) accurately represents the physical reality of an object's motion?
- How can we use dimensional analysis to verify the validity of complex physical calculations across different measurement systems?

Examples of Engaging Phenomenon:

- Skydiving is an activity that is pretty cool! The parachute design considers acceleration and opposing forces provided by air resistance of the parachute as it falls and approaches terminal velocity. https://www.skydiveorange.com/2021/12/08/the-physics-of-skydiving/
- Pilots of planes use vector addition to navigate when being affected by wind direction. https://www.physicsclassroom.com/mmedia/vectors/plane.cfm
- Race car design includes maximum speeds that can be obtained before the car will flip due to lift. Lift is what "lifts" an airplane upward. Wing-shaped spoilers on cars use the same concept to provide downforce. This downforce allows greater velocities by the race car. https://grassrootsmotorsports.com/articles/primer-aerodynamic-lift-and-you/#:~:text=The%20physics%20are%20fairly%20simple,sucks%20it%20onto%20the%20track.
- A roller coaster can never travel higher than its initial height, provided no additional force is applied. Using kinetic energy and conservation of energy, the motion of a rollercoaster can be predicted by designing for acceleration, velocity, and force experienced by passengers. https://science.howstuffworks.com/engineering/structural/roller-coaster3.htm

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https://www.teachengineering.org/lessons/view/duk_rollercoaster_music_less • Cars can be designed to provide maximum protection during impacts at great speeds. By designing *"crunch zones"* into the frame and body, forces can be reduced and redirected through the vehicle and around the passenger. Often an accident looks like it caused critical injuries; the car body is destroyed and in pieces. Rather than a bad outcome, the smashed metal is evidence of the energy distribution away from the passengers, keeping them safer. https://www.travelers.com/resources/auto/safe-driving/how-crumple-zones-work https://www.automotiveplastics.com/wp-content/uploads/CrumpleZones_123010.pdf • An airbag in a vehicle increases the time of impact and, thus, decreases the force to provide additional protection. https://www.wired.com/story/the-insane-physics-of-airbags/ https://www.pbs.org/video/how-do-airbags-work-dk8ixs/ • Artillery vertical distance and horizontal direction is adjusted by determining different vector angles for targeting a point on a worldwide grid-coordinate mapping system. Soldiers use this knowledge to successfully complete their missions. https://www.physicsclassroom.com/mmedia/vectors/mr.cfm https://www.youtube.com/watch?v=x5Rwrz_6NUI

Students will know: (Disciplinary Core Ideas)	As evidenced by: (Science & Engineering Practices)
PS2.A: Forces and Motion Newton's second law accurately predicts changes in the motion of macroscopic objects. ***DCI OBJECTIVES:*** • Metric (meter, liter, gram, etc.) and imperial or standard units (mile, gallon, pound, etc.). ◦ Scalars are measurements that have only a size or magnitude including distance, speed and time. Vectors are measurements that have a size and a direction including velocity, force, and acceleration. • Accuracy, how close a measurement is to the true value, and precision, how close multiple measurements are to each other. • Significant figures for accuracy and precision. • Scalars are measurements that have only a size or magnitude including distance, speed and time. Vectors	• Differentiate between scalars (example: speed) and vectors (example: velocity). • Differentiate between metric (meter, liter, gram, etc.) and imperial or standard units (mile, gallon, pound, etc.). • Use dimensional analysis to solve problems using correct units of measure. • Differentiate between accuracy, how close a measurement is to the true value, and precision, how close multiple measurements are to each other. • Use significant figures for accuracy and precision. • Use dimensional analysis • Represent a frame of reference using the 4- quadrant coordinate plane. • Draw and analyze motion diagrams to model motion. • Solve speed and acceleration problems to identify and predict quantities for velocity and acceleration components. Speed = distance/time $s = \Delta d / \Delta t$

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are measurements that have a size and a direction including velocity, force, and acceleration. ● Frame of reference using the 4- quadrant coordinate plane. ● Motion diagrams ● Speed = distance/time (s = Δd / Δt) ● Acceleration = velocity/time (a = Δv / Δt) ● Acceleration and Kinematic equations for quantitative values. $a = \frac{v_f - v_i}{t}$ $d = v_i t + \frac{1}{2} a t^2$ $a = \frac{v_f^2 - v_i^2}{2d}$ $d = \frac{1}{2}(v_f + v_i)t$	Acceleration = velocity/time a = Δv / Δt ● Calculate for acceleration and its components using kinematic equations to identify and predict quantitative values. $a = \frac{v_f - v_i}{t}$ $d = v_i t + \frac{1}{2} a t^2$ $a = \frac{v_f^2 - v_i^2}{2d}$ $d = \frac{1}{2}(v_f + v_i)t$ **Using Mathematics and Computational Thinking** ● Create a computational model or simulation of a phenomenon, designed device, process, or system. ● Use mathematical, computational, and/or algorithmic representations of phenomena or design solutions to describe and/or support claims and/or explanations. **Constructing Explanations and Designing Solutions** ● Design or refine a solution to a complex real-world problem, based on scientific knowledge, principles, and theories. ● Design or refine a solution to a complex real-world problem, based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and tradeoff considerations. **Analyzing and Interpreting Data** ● Analyze data using tools, technologies, and/or models (e.g., computational,

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	mathematical) in order to make valid and reliable scientific claims or determine an optimal design solution. ● Consider limitations of data analysis (e.g., measurement error, sample selection) when analyzing and interpreting data. **Observable features of the student performance by the end of the course:** ● Convert units using dimensional analysis. ● Manipulate 2-, 3-, and 4-variable equations to solve for an unknown. ● Draw diagrams to visually represent physics problems. ● Construct, analyze, and interpret position vs. time and velocity vs. time graphs.

Cross-Cutting Concepts:
Cause and Effect

- Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects.

Systems and System Models

- When investigating or describing a system, the boundaries and initial conditions of the system need to be defined.

Academic Vocabulary:

- Science vocabulary students ARE expected to know:

4-Quadrant Coordinate System, Acceleration, Average Speed, Average Velocity, Direction, Displacement, Distance, Gravitational Acceleration, Magnitude, Origin, Position, Resultant, Scalar, Speed, Vector, Velocity

Resources: NGSS Phenomenon Master List

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Unit 2: Direct Forces

Priority Standard (Performance Expectation): **HS-PS2-1 Motion and Stability: Forces and Interactions** 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.
Clarification Statement: Examples of data could include tables or graphs of position or velocity as a function of time for objects subject to a net unbalanced force, such as a falling object, an object rolling down a ramp, or a moving object being pulled by a constant force. Assessment is limited to one-dimensional motion and to macroscopic objects moving at non-relativistic speeds.
Big Idea(s): ● Newton's Laws of Motion establish a causal relationship where net unbalanced forces dictate the acceleration of macroscopic objects, allowing for the precise prediction of physical phenomena.
Essential Question(s): ● How do we know that Newton's Second Law (F=ma) describes a causal relationship rather than just a mathematical correlation between force, mass, and acceleration? ● When is friction useful and when is it harmful? How and why do we increase it or decrease it in daily life? ● How are external factors analyzed to predict resulting changes in speed and/or direction (if any)?
Examples of Engaging Phenomenon: ● Flymo Hover Lawnmower https://thewonderofscience.com/phenomenon/2018/7/12/flymo-hover-lawnmower ● Raw or Boiled Egg Experiment https://thewonderofscience.com/phenomenon/2018/7/11/raw-or-boiled-egg-experimentdex ● A Bed of Nails https://thewonderofscience.com/phenomenon/2018/7/9/a-bed-of-nails ● Reducing forces on passengers during a potential crash is a primary design challenge when designing a car. https://www.sciencebuddies.org/teacher-resources/lesson-plans/engineering-car-crash-safety-newton-third-law?from=Blog ● Newton's Cradle https://en.wikipedia.org/wiki/Newton%27s_cradle **NGSS Interim Assessment References Newton's Cradle (PS 3-1)** ● Rocket Launch https://www.youtube.com/watch?v=K6rUDI0MVXI

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- Designing catapults https://www.youtube.com/watch?v=VwENnFw4XgI
- The Magician's Tablecloth https://learning.sciencemuseumgroup.org.uk/resources/tablecloth-trick/
- Egg Pizza https://www.arborsci.com/blogs/cool/introducing-newtons-laws-with-learning-cycles
- Jelly Jar Accelerometer
  https://www.arborsci.com/blogs/cool/introducing-newtons-laws-with-learning-cycles
- Crash a cart with a mass into a cardboard box to show how inertia keeps the mass moving even after the cart stops. You can also try taping the mass to the cart to simulate a seatbelt.
- Use roller skates and a ball to show how throwing the ball pushes you in the opposite direction
- Tee-off Time https://www.arborsci.com/blogs/cool/introducing-newtons-laws-with-learning-cycles
- Balloon Rockets
  https://sciencebob.com/make-a-balloon-rocket/
  https://www.jpl.nasa.gov/edu/teach/activity/rocket-activity-heavy-lifting/
- Fan Cart Gizmo
- How does a bathroom scale work? "Glencoe Science Physics" Textbook p. 110
- Spring Scale Tug of War
  https://itservices.cas.unt.edu/~klittler/demo_room/mech_demos/1h10_30.html
  https://www.arborsci.com/blogs/cool/introducing-newtons-laws-with-learning-cycles
- Drop Away
  https://www.physicsclassroom.com/mmedia/vectors/pap.cfm
- Crater Experiment
  https://sciencing.com/second-law-motion-experiments-6952612.html
- Wagon and String
  https://sciencing.com/second-law-motion-experiments-6952612.html
- Dollar Bill Inertia Challenge
  https://stevespangler.com/experiments/dollar-bill-inertia-challenge/
- Jetpack Rockets
  https://www.youtube.com/watch?v=Hx9TwM4Pmhc
- Sled Launch
  https://www.youtube.com/watch?v=D4j5bcaV2Ws
- Physics of Football
  https://www.youtube.com/watch?v=08BFCZJDn9w
  https://www.youtube.com/watch?v=qu_P4lbmV_I&t=9s
  https://www.youtube.com/watch?v=e1lzB36aHD4&t=19s

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Students will know: (Disciplinary Core Ideas)	As evidenced by: (Science & Engineering Practices)
PS2.A: Forces and Motion Newton's second law accurately predicts changes in the motion of macroscopic objects. ● Newton's First Law of Motion, also known as the Law of Inertia, states that an object at rest will remain at rest and an object in motion will continue moving in a straight line at a constant speed, unless acted upon by an outside force. ● Newton's Second Law of Motion states that acceleration is proportional to the net force acting on an object. Friction can affect this law because it often acts in the opposite direction of motion, which can reduce the net force and acceleration. For example, when a block slides on a surface, friction slows the block down and eventually stops it. ● Newton's Second Law of Motion states that an object's acceleration (a) depends on both its mass (m) and the force (f) applied to it. It can be written mathematically as f=ma. It can be used to solve motion problems that involve constant forces. ● Newton's Third Law of Motion states that for every action, there is an equal and opposite reaction. ● When forces are balanced, no acceleration occurs; thus an object continues to move at a constant speed or stays at rest. This state is called Equilibrium. ● Difference between mass and weight. They may seem like the same thing, but in fact these two measurements are very different. Mass is the total amount of matter, or "stuff," in an object. Weight is	● Express the relationship Fnet=ma in terms of causality, namely that a net force on an object causes the object to accelerate. ● Utilize Newton's Second Law of Motion (f=ma) and the relationship between mass and weight (w=mg) to determine the weight, mass, or gravity of an object. ● Provide an example of how Newton's Second Law applies to daily life. ● Provide an example of how Newton's First Law applies to daily life. ● Manipulate Newton's Second Law of Motion to algebraically solve the formula for force, mass, or acceleration. ● Provide an example of how Newton's Third Law applies to daily life. ● Draw models (free-body diagrams) that represent balanced forces and models that explain unbalanced forces such as tension in ropes or springs. ● Define the System and label all Contact Forces and Field Forces present, when drawing free-body diagrams. A System is an object or collection of objects considered as a single group. All objects and forces can be considered as either internal or external to this System. **Using Mathematics and Computational Thinking** ● Create a computational model or simulation of a phenomenon, designed device, process, or system. ● Use mathematical, computational, and/or algorithmic representations of phenomena or design solutions to describe and/or support claims and/or explanations. **Constructing Explanations and Designing Solutions** ● Design or refine a solution to a complex real-world problem, based on scientific knowledge, principles, and theories.

the force of gravity on an object. Mass always stays the same, but weight can change depending on how much gravity is acting upon an object. ● The weight of an object is the force acting on the object due to the acceleration of gravity. Mathematically the formula can be written as w= mg, where w equals weight, m equals mass, and g equals the acceleration due to gravity (also called the gravitational constant.) On Earth the gravitational constant can be approximated as 9.81 meters per second squared (9.81 m/s^2). (The gravitational constant will vary based on the masses of each object and the distance between them.) ● Normal force is the force that surfaces exert to prevent solid objects from passing through each other. Normal force is a contact force. If two surfaces are not in contact, they can't exert a normal force on each other. Normal force can be determined by applying Newton's Second Law of Motion. ● When one object exerts a force on a second object, the second object always exerts a force of equal magnitude and in the opposite direction. ● Newton's Second Law of Motion states that acceleration is proportional to the net force acting on an object. Friction can affect this law because it often acts in the opposite direction of motion, which can reduce the net force and acceleration. For example, when a block slides on a surface, friction slows the block down and eventually stops it. ● Newton's Third Law of Motion states that for every action, there is an equal and opposite reaction.	● Design or refine a solution to a complex real-world problem, based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and tradeoff considerations. **Analyzing and Interpreting Data** ● Analyze data using tools, technologies, and/or models (e.g., computational, mathematical) in order to make valid and reliable scientific claims or determine an optimal design solution. ● Consider limitations of data analysis (e.g., measurement error, sample selection) when analyzing and interpreting data. **Observable features of the student performance by the end of the course:** ● Organize data that represent the net force on a macroscopic object, its mass (which is held constant), and its acceleration (e.g., via tables, graphs, charts, vector drawings). ● Use tools, technologies, and/or models to analyze the data and identify relationships within the datasets, including: ○ A more massive object experiencing the same net force as a less massive object has a smaller acceleration, and a larger net force on a given object produces a correspondingly larger acceleration; and ○ The result of gravitation is a constant acceleration on macroscopic objects as evidenced by the fact that the ratio of net force to mass remains constant. ● Use the analyzed data as evidence to describe that the relationship between the observed quantities are accurately modeled across the range of data by the formula a = Fnet/m (e.g., double force yields double acceleration, etc.). ● Use the data as empirical evidence to distinguish between causal and correlational relationships linking force, mass, and acceleration.

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Cross-Cutting Concepts:
Cause and Effect
- Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects.

Systems & Systems Models
- When investigating or describing a system, the boundaries and initial conditions of the system need to be defined.

Academic Vocabulary:
- Science vocabulary students ARE expected to know:

Acceleration, At rest, Balanced Force, Direction, Equilibrium, Force, Free Body Diagram, Friction, Gravitational Acceleration, Gravity, Inertia, Mass, Motion, Net Force, Normal Force, Unbalanced Force, Weight

- Additional tier 2 words that students should be familiar with:

Magnitude, System, Tension

Science vocabulary students are NOT expected to know:
Jerk, terminal velocity

Resources: NGSS Phenomenon Master List

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Unit 3: Energy

Priority Standard (Performance Expectation):
HS-PS3-1 Energy
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.

HS-PS3-2 Macroscopic Energy Due to Particle Position and Motion
Develop and use models to illustrate that energy at the macroscopic scale can be accounted for as a combination of energy associated with the motion of particles (objects) and energy associated with the relative positions of particles (objects).

HS-PS3-3 Energy Conversion Device Design
Design, build, and refine a device that works within given constraints to convert one form of energy into another form of energy.

Clarification Statement: Emphasis is on explaining the meaning of mathematical expressions used in the model. Assessment Boundary: Assessment is limited to basic algebraic expressions or computations; to systems of two or three components; and to thermal energy, kinetic energy, and/or the energies in gravitational, magnetic, or electric fields.

Examples of phenomena at the macroscopic scale could include the conversion of kinetic energy to thermal energy, the energy stored due to position of an object above the earth, and the energy stored between two electrically-charged plates. Examples of models could include diagrams, drawings, descriptions, and computer simulations.

Emphasis is on both qualitative and quantitative evaluations of devices. Examples of devices could include Rube Goldberg devices, wind turbines, solar cells, solar ovens, and generators. Examples of constraints could include use of renewable energy forms and efficiency.Assessment for quantitative evaluations is limited to total output for a given input. Assessment is limited to devices constructed with materials provided to students.

Big Idea(s):
- Energy is a conserved, quantitative property of a system that manifests as motion at the macroscopic scale and particle interaction at the microscopic scale.

Essential Question(s):
- How do we know that energy is truly conserved in a system when mechanical energy appears to be "lost" to the environment?
- How can we use the molecular-level motion of particles to explain the manifestations of energy we observe at the macroscopic scale?

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Examples of Engaging Phenomenon:

- Rube Goldberg Machines
  https://www.youtube.com/watch?v=UFSn8IwgQfw
  https://www.youtube.com/watch?v=qybUFnY7Y8w
  https://www.youtube.com/watch?v=lWIGo2FOaJk&ab_channel=GreatBigStory
  https://www.youtube.com/watch?v=lLruc27jrOg&ab_channel=Joseph%27sMachines
  https://www.youtube.com/watch?v=7RUE2BdI3BM&t=208s&ab_channel=Joseph%27Machines
  https://www.youtube.com/watch?v=0lz8_aaKNXA
  https://www.youtube.com/watch?v=mm1NfUUCJgc
  https://www.youtube.com/watch?v=lSX9fOSJ0KI&ab_channel=Joseph%27sMachines
- The Gravity Light https://thewonderofscience.com/phenomenon/2018/7/9/the-gravity-light
- Magnetic Cannon https://thewonderofscience.com/phenomenon/2017/10/8/ps2-motion-and-stability-forces-and-interactions
- Fire Piston
  https://thewonderofscience.com/phenomenon/2018/7/12/fire-piston
- The Collapsing Train Car https://thewonderofscience.com/phenomenon/2018/6/10/the-collapsing-train-car
- Solar Cars
  https://thewonderofscience.com/phenomenon/2018/7/8/solar-cars
- Earthships
  https://thewonderofscience.com/phenomenon/2018/7/5/earthships
- Apple on a String https://sciencing.com/science-projects-with-balloons-sound-vibration-12746567.html
- Ball Experiment https://sciencing.com/science-projects-with-balloons-sound-vibration-12746567.html
- Classroom Discussion: Pretend to be planning to drop a marble or a bowling ball. What would the difference be between the two items? Consider impact and fall rate. Lead the discussion to include the variables in the PE formula. PE=mgh, so more mass and more height will lead to more potential energy, causing more force when the object is dropped.
- Ball Drop
  https://www.uml.edu/docs/ball_drop_complete_tcm18-264104.pdf
- Kinetic Energy Ball Drop (Fancy Kit Not Needed) https://www.flinnsci.com/kinetic-energy-ball-drop---demonstration-kit/ap7187/#variantDetails
- Newton's Cradle https://science.howstuffworks.com/innovation/inventions/newtons-cradle.htm#:~:text=If%20Ball%20One%20had%2010,no%20energy%20along%20the%20way.
  https://www.quinticsports.com/newtons-cradle-conservation-of-momentum-and-energy/
  https://www.phys.vt.edu/outreach/projects-and-demos/demonstrations-wiki/mechanics/newtons-cradle.html
  https://www.scienceofgadgets.com/post/how-newton-s-cradle-demonstrates-conservation-laws

CTE Connected Phenomena

- Culinary Connection- Why do you see the bubbles in the center of the pan first rather than the sides when you are boiling water?

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• Auto Connection- Newer cars often look worse after an accident, but are actually safer for the passengers. Why? • HVAC Connection- Why is insulation used on pipes?	
Students will know: (Disciplinary Core Ideas)	As evidenced by: (Science & Engineering Practices)
PS3.A: Definitions of Energy • Energy is a quantitative property of a system that depends on the motion and interactions of matter and radiation within that system. That there is a single quantity called energy is due to the fact that a system's total energy is conserved, even as, within the system, energy is continually transferred from one object to another and between its various possible forms. • At the macroscopic scale, energy manifests itself in multiple ways, such as in motion, sound, light, and thermal energy. • These relationships are better understood at the microscopic scale, at which all of the different manifestations of energy can be modeled as a combination of energy associated with the motion of particles and energy associated with the configuration (relative position of the particles). In some cases the relative position energy can be thought of as stored in fields (which mediate interactions between particles). This last concept includes radiation, a phenomenon in which energy stored in fields moves across space. PS3.B: Conservation of Energy and Energy Transfer • Conservation of energy means that the total change of energy in any system is always equal to the total energy transferred into or out of the system. • Energy cannot be created or destroyed, but it can be transported from one place to another and transferred between systems. • Mathematical expressions, which quantify how the	• Manipulate the Gravitational Potential Energy formula to algebraically solve for mass, gravitational constant, and height. • Provide an example of how Gravitational Potential Energy applies to daily life. • Manipulate the Kinetic Energy formula to algebraically solve for mass and velocity. • Provide an example of how Kinetic Energy applies to daily life. • Provide an example of how the Law of Conservation of Energy applies to daily life. • Manipulate the formula algebraically to solve for the unknown variable. $PE_1 + KE_1 = PE_2 + KE_2$ can be rewritten as $mgh_1 + ½ mv_1^2 = mgh_2 + ½ mv_2^2$. • Design and construct a device that converts one form of energy to another. Examples could include: windmill, solar cooker, Rube Goldberg Machine, rubber band car, and many more. • Calculate and analyze Gravitational Potential Energy and Kinetic Energy in a system, algebraically manipulate the formulas, and apply the concepts to daily life. • Compare and contrast elastic and inelastic collisions in terms of energy conservation. • Apply the Law of Conservation of Energy to real-life scenarios and use the concept mathematically to perform energy balances. • Describe, conceptually and mathematically, the concept of work. • Design a device that uses energy conversions to accomplish a task. **Using Mathematics and Computational Thinking** • Create a computational model or simulation of a phenomenon, designed device, process, or system. • Use mathematical, computational, and/or algorithmic representations of phenomena or design solutions to describe and/or support claims and/or explanations.

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stored energy in a system depends on its configuration (e.g. relative positions of charged particles, compression of a spring) and how kinetic energy depends on mass and speed, allow the concept of conservation of energy to be used to predict and describe system behavior.
- The availability of energy limits what can occur in any system.

PS3.D: Energy in Chemical Processes
- Although energy cannot be destroyed, it can be converted to less useful forms—for example, to thermal energy in the surrounding environment.

ETS1.A: Defining and Delimiting an Engineering Problem
- Criteria and constraints also include satisfying any requirements set by society, such as taking issues of risk mitigation into account, and they should be quantified to the extent possible and stated in such a way that one can tell if a given design meets them.

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DCI OBJECTIVES:

- Gravitational Potential Energy is the energy an object has due to its position above Earth (or another body), otherwise thought of as energy due to its height. We know this energy exists because it takes effort to lift an object up to a height and also because when we release an object, it falls, gaining kinetic energy.

- Gravitational Potential Energy (GPE) can be calculated by using the formula GPE=mgh where m= mass, g= gravitational constant, and h= height.

Constructing Explanations and Designing Solutions
- Design or refine a solution to a complex real-world problem, based on scientific knowledge, principles, and theories.
- Design or refine a solution to a complex real-world problem, based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and tradeoff considerations.

Developing and Using Models
- Develop and use a model based on evidence to illustrate the relationships between systems or between components of a system.
- Develop and/or use a model (including mathematical and computational) to generate data to support explanations, predict phenomena, analyze systems, and/or solve problems

Observable features of the student performance by the end of the course:

- Identify and describe the components to be computationally modeled, including the boundaries of the system and that the reference level for potential energy = 0 (the potential energy of the initial or final state does not have to be zero); The initial energies of the system's components (e.g., energy in fields, thermal energy, kinetic energy, energy stored in springs — all expressed as a total amount of Joules in each component), including a quantification in an algebraic description to calculate the total initial energy of the system; The energy flows in or out of the system, including a quantification in an algebraic description with flow into the system defined as positive; and the final energies of the system components, including a quantification in an algebraic description to calculate the total final energy of the system.
- Create a computational model (e.g., simple computer program, spreadsheet, simulation software package application), using the algebraic descriptions of the initial and final energy state of the system, along with the energy flows, that is based on the principle of the conservation of energy. Use the computational model to calculate changes in the energy of one component of the system when changes in the energy of the other components and the energy flows are known.

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• Kinetic Energy is a form of energy that an object or a particle has by reason of its motion. If work, which transfers energy, is done on an object by applying a net force, the object speeds up and thereby gains kinetic energy. • Kinetic Energy (KE) can be calculated by using the formula $KE=\frac{1}{2} mv^2$ where m= mass and v= velocity. • Collisions can cause objects' energy to change. The total kinetic energy of a system before and after a collision can be used to analyze the collision. In elastic collisions, the kinetic energy of the system is conserved. In inelastic collisions, however, the total kinetic energy is not conserved, and some of the kinetic energy is converted into other forms of energy, such as sound or thermal energy. • The Law of Conservation of Energy, also known as the First Law of Thermodynamics, states that energy can't be created or destroyed, but it can change forms. The total amount of energy in the universe remains constant, and the sum of all forms of energy in a closed system is always the same. • Mechanical energy is the energy that is possessed by an object due to its motion or due to its position. Mechanical energy can be either kinetic energy (energy of motion) or potential energy (stored energy of position). Mathematically it can be expressed as $ME = KE + PE$. • Mechanical energy "loss" is when mechanical energy is dissipated away as heat, rather than being destroyed (not possible according to the Law of Conservation of Energy.) This loss can happen	• Predict the maximum possible change in the energy of one component of the system for a given set of energy flows, using the computational model. Identify and describe the limitations of the computational model, based on the assumptions that were made in creating the algebraic descriptions of energy changes and flows in the system. • Develop models in which they identify and describe the relevant components, including: energy flows between the system and the surroundings, Clearly depicting both a macroscopic, such as motion, sound, light, thermal energy, potential energy or energy in fields, and a molecular/atomic-level such as motions (kinetic energy) of particles representation of the system; and depicting the forms in which energy is manifested at two different scales. • Describe the relationships between components in their models, including changes in the relative position of objects in gravitational, magnetic or electrostatic fields that can affect the energy of the fields (e.g., charged objects moving away from each other change the field energy). As one form of energy increases, others must decrease by the same amount as energy is transferred among and between objects and fields. • Show that in closed systems the energy is conserved on both the macroscopic and molecular/atomic scales so that as one form of energy changes, the total system energy remains constant, as evidenced by the other forms of energy changing by the same amount or changes only by the amount of energy that is transferred into or out of the system. Use their models to illustrate that energy at the macroscopic scale can be accounted for as a combination of energy associated with the motions of particles/objects and energy associated with the relative positions of particles/objects on both the macroscopic and microscopic scales. • Design a device that converts one form of energy into another form of energy and develop a plan for the device in which they identify: scientific principles, forms of energy that will be converted from one form to another, losses of energy by the design system to the surrounding environment and describe: the scientific rationale for choices of materials and structure of the device, including how student-generated evidence influenced the design; and that this device is an example of how the application of scientific knowledge and engineering design can increase benefits for modern civilization while decreasing costs and risk.

through resistive forces, such as friction or drag. These forces can drain an object's kinetic energy in a way that makes it difficult to recover. The lost energy is then converted into thermal energy and remains within the universe. Thus, it is "lost" from the system but DID NOT magically disappear. ● If energy is conserved in a system, the total amount of Mechanical Energy will stay constant, but the ratio between Potential Energy and Kinetic Energy may change. Mathematically this concept can be written as $PE_1 + KE_1 = PE_2 + KE_2$. ● By combining formulas, $PE_1 + KE_1 = PE_2 + KE_2$ can be rewritten as $mgh_1 + ½ mv_1^2 = mgh_2 + ½ mv_2^2$. ● Work (W) is the transfer of energy by a force acting on an object as it is displaced. No matter how much force is applied, if the object does not move, no scientific work has been done. Mathematically work can be expressed as W= Fd, where F= force and d= distance. ● The Work-Energy Theorem states that Work is equal to the change in Kinetic Energy, $W = \Delta KE$.	● Describe and quantify (when appropriate) prioritized criteria and constraints for the design of the device, along with the tradeoffs implicit in these design solutions. Examples of constraints to be considered are cost and efficiency of energy conversion. ● Build and systematically and quantitatively evaluate the performance of the device against the criteria and constraints. ● Improve, using the results of the tests, the device performance by increasing the efficiency of energy conversion, keeping in mind the criteria and constraints, and noting any modifications in tradeoffs.

Cross-Cutting Concepts:
Systems and System Models
- Models can be used to predict the behavior of a system, but these predictions have limited precision and reliability due to the assumptions and approximations inherent in models.

Energy and Matter
- Energy cannot be created or destroyed—only moves between one place and another place, between objects and/or fields, or between systems.

Academic Vocabulary:
- Science vocabulary students ARE expected to know:

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Constraints, Convert, Energy, Energy Transfer, Energy Transformation, Gravitational Potential Energy, Kinetic Energy, Law of Conservation of Energy, Mechanical Energy, Potential Energy, Velocity, Work, Work-Energy Theorem - Additional tier 2 words that students should be familiar with: Elastic Potential Energy, Electrical Energy, Light Energy, Lost Energy, Risk Mitigation, Sound Energy, Thermal Energy Science vocabulary students are NOT expected to know: Entropy, second law of thermodynamics, thermodynamics, Stirling cycle, Carnot cycle, capacitor, inductance, inductor, Faraday's law
Resources: NGSS Phenomenon Master List

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Unit 4: Momentum

Priority Standard (Performance Expectation): **HS-PS2-2 Motion and Stability: Forces and Interactions** 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. **HS-PS2-3Motion and Stability: Forces and Interactions** Apply science and engineering ideas to design, evaluate, and refine a device that minimizes the force on a macroscopic object during a collision.
Clarification Statement: Emphasis is on the quantitative conservation of momentum in interactions and the qualitative meaning of this principle. Assessment is limited to systems of two macroscopic bodies moving in one dimension. Examples of evaluation and refinement could include determining the success of the device at protecting an object from damage and modifying the design to improve it. Examples of a device could include a football helmet or a parachute. Assessment is limited to qualitative evaluations and/or algebraic manipulations.
Big Idea(s): ● In closed systems, total momentum is always conserved during interactions, providing a fundamental framework for designing technologies that minimize impact forces
Essential Question(s): ● How do we know that increasing the time interval of a collision is the most effective scientific strategy for minimizing the net force on a macroscopic object? ● How does conservation of momentum govern interactions between objects or systems? ● How can knowledge of momentum be used to improve safety in collisions?
Examples of Engaging Phenomenon:

• Two billiard balls collide on a frictionless pool table in an elastic collision. An elastic collision conserves energy and momentum. https://letstalkscience.ca/educational-resources/stem-explained/billiards-and-collisions https://www.youtube.com/watch?v=yFXUzf0ZC7c • A car crashes into a parked vehicle. In an inelastic collision, momentum is conserved, but kinetic energy is not. The two vehicles might stick together after the collision, conserving momentum while losing energy. https://www.physicsclassroom.com/mmedia/momentum/treci.cfm#:~:text=The%20total%20kinetic%20energy%20before,known%20as%20an%20inelastic%20collision. https://www.thoughtco.com/what-is-the-physics-of-a-car-collision-2698920 https://www.youtube.com/watch?v=QUbsZwuhPvY • A lump of clay is thrown at a wall and sticks to it. In a perfectly inelastic collision, the objects stick together after the collision, moving as one. Momentum is conserved, but kinetic energy is lost, typically transformed into heat, sound, or deformation energy. • As a rocket launches, it expels gas downwards and gains upward momentum. The momentum of the expelled gas in one direction is balanced by the momentum of the rocket in the opposite direction, demonstrating the conservation of momentum. https://www.youtube.com/watch?v=RzNJV611O4Y • A firecracker explodes into fragments. The momentum of the firecracker fragments is conserved and the vector sum of the momentum of firecracker fragments after the explosion equals the initial momentum at the instant of the explosion. https://www.physicsclassroom.com/class/momentum/Lesson-2/Momentum-Conservation-in-Explosions • A gun fires a bullet and the gun recoils in the opposite direction. The momentum of the bullet and the gun are equal and opposite, demonstrating the conservation of momentum in the system. http://ffden-2.phys.uaf.edu/211_fall2013.web.dir/Rex_Hallmann/The_Physics_of_Guns/Physics_of_Guns.html • A hockey puck hitting the wall has both momentum and kinetic energy. Momentum is always conserved while KE may or may not be conserved. https://twu.tennis-warehouse.com/learning_center/hockeyphysics.php https://www.wbspenguins.com/blog/the-science-of-ice-hockey/ https://www.nsf.gov/news/mmg/?series_name=Science%20of%20NHL%20Hockey • When a soccer player kicks the ball, force is applied over a short time period, imparting an impulse to the ball. This impulse changes the ball's momentum, causing it to accelerate in the direction of the kick. https://www.youtube.com/watch?v=gyKEhYEYly8 https://tuitionphysics.com/june-2024/the-physics-behind-soccer-making-the-perfect-kick/ • Reducing forces on passengers during a potential crash is a primary design challenge when designing a car. https://www.sciencebuddies.org/teacher-resources/lesson-plans/engineering-car-crash-safety-newton-third-law?from=Blog • Newton's Cradle https://en.wikipedia.org/wiki/Newton%27s_cradle

Students will know: (Disciplinary Core Ideas)	As evidenced by: (Science & Engineering Practices)
PS2.A: Forces and Motion • If a system interacts with objects outside itself, the total momentum of the system can change; however, any such change is balanced by changes in the	• Use components of kinetic energy to solve for unknown quantities using KE= $(^1/_2)\ mv^2$. • Use components of potential energy to solve for unknown quantities using

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momentum of objects outside the system.

DCI OBJECTIVES:

- Kinetic Energy: KE= ($^1/_2$) mv^2.
- Conservation of energy in elastic collisions:

$$m_1v_{1i} + m_2v_{2i} = m_1v_{1f} + m_2v_{2f}$$

- Momentum: ρ = mv.
- Momentum is conservative in a closed system.
- Energy can be conservative or non-conservative in a closed system.
- An unbalanced force applied over time on an object produces a change in its momentum.
- Conservation of energy in inelastic collisions:

$$m_1v_{1i} + m_2v_{2i} = (m_1 + m_2)v_f$$

- Conservation of momentum involving elastic and inelastic collisions.

PE=mgh.

- Apply principles of conservation of energy in elastic collisions to analyze and solve problems using

$$m_1v_{1i} + m_2v_{2i} = m_1v_{1f} + m_2v_{2f}$$

- Use components of momentum to solve for unknown quantities using ρ = mv.
- Apply principles of conservation of energy to analyze and solve problems involving inelastic collisions using

$$m_1v_{1i} + m_2v_{2i} = (m_1 + m_2)v_f$$

- Solve conservation of momentum problems involving elastic and inelastic collisions.
- Use given components to mathematically solve for Kinetic Energy, Gravitational Energy, and Momentum.
- Solve Conservation of Energy and Conservation of Momentum problems.

Using Mathematics and Computational Thinking
- Create a computational model or simulation of a phenomenon, designed device, process, or system.
- Use mathematical, computational, and/or algorithmic representations of phenomena or design solutions to describe and/or support claims and/or explanations.

Constructing Explanations and Designing Solutions
- Design or refine a solution to a complex real-world problem, based on scientific knowledge, principles, and theories.
- Design or refine a solution to a complex real-world problem, based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and tradeoff considerations.

Analyzing and Interpreting Data
- Analyze data using tools, technologies, and/or models (e.g., computational,

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	mathematical) in order to make valid and reliable scientific claims or determine an optimal design solution. ● Consider limitations of data analysis (e.g., measurement error, sample selection) when analyzing and interpreting data. **Developing and Using Models** ● Develop and use a model based on evidence to illustrate the relationships between systems or between components of a system. ● Develop and/or use a model (including mathematical and computational) to generate data to support explanations, predict phenomena, analyze systems, and/or solve problems. **Observable features of the student performance by the end of the course:** ● Design a device that minimizes the force on a macroscopic object during a collision. Incorporate the concept that for a given change in momentum, force in the direction of the change in momentum is decreased by increasing the time interval of the collision ($F\Delta t = m\Delta v$); and explicitly make use of the principle above so that the device has the desired effect of reducing the net force applied to the object by extending the time the force is applied to the object during the collision. Describe the scientific rationale for their choice of materials and for the structure of the device. ● Describe and quantify (when appropriate) the criteria and constraints, along with the tradeoffs implicit in these design solutions. Examples of constraints to be considered are cost, mass, the maximum force applied to the object, and requirements set by society for widely used collision-mitigation devices (e.g., seatbelts, football helmets). ● Evaluate the proposed device design or design solution, including describing the rationales for the design and comparing the design to the list of criteria and constraints. Test and evaluate the device based on its ability to minimize the force on the test object during a collision. Identify any unanticipated effects or design performance issues that the device exhibits. ● Improve, using the test results, the device performance by extending the impact time, reducing the device mass, and/or considering cost-benefit analysis. ● Define the system of the two interacting objects that is represented

	mathematically, including boundaries and initial conditions. Identify and describe the momentum of each object in the system as the product of its mass and its velocity, p = mv (p and v are restricted to one-dimensional vectors), using the mathematical representations. Identify the claim, indicating that the total momentum of a system of two interacting objects is constant if there is no net force on the system. ● Model and describe, using the mathematical representations, the physical interaction of the two objects in terms of the change in the momentum of each object as a result of the interaction. Use the mathematical representations to model and describe the total momentum of the system by calculating the vector sum of momenta of the two objects in the system. ● Identify, using the analysis of the motion of the objects before the interaction, a system with essentially no net force on it. Based on the analysis of the total momentum of the system, support the claim that the momentum of the system is the same before and after the interaction between the objects in the system, so that momentum of the system is constant. Identify that the analysis of the momentum of each object in the system indicates that any change in momentum of one object is balanced by a change in the momentum of the other object, so that the total momentum is constant.

Cross-Cutting Concepts:
Systems and System Models
- Models can be used to predict the behavior of a system, but these predictions have limited precision and reliability due to the assumptions and approximations inherent in models.

Cause and Effect
- Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects.

Academic Vocabulary:
- Science vocabulary students ARE expected to know:

Collision, Elastic Collision, Inelastic Collision, Kinetic Energy, Law of Conservation of Energy, Law of Conservation of Momentum, Mechanical Energy, Momentum, Potential Energy

- Additional tier 2 words that students should be familiar with:

Conservative, Non-conservative, Perfect Elastic Collision, Perfect Inelastic Collision

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Science vocabulary students are NOT expected to know: inertial frame-of-reference, electric potential, electromotive force, permeating, quantum property, Laplace force, electrodynamics, magnetic dipole, electrostatic, general relativity, Ampere’s Law, Coulomb force, Lorentz force
Resources: NGSS Phenomenon Master List ● Shock Stickers for measuring impacts

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Unit 5: Thermal Energy

Priority Standard (Performance Expectation):
HS-PS3-4 The Second Law of Thermodynamics

Plan and conduct an investigation to provide evidence that the transfer of thermal energy when two components of different temperature are combined within a closed system results in a more uniform energy distribution among the components in the system (second law of thermodynamics).

Clarification Statement: Emphasis is on analyzing data from student investigations and using mathematical thinking to describe the energy changes both quantitatively and conceptually. Examples of investigations could include mixing liquids at different initial temperatures or adding objects at different temperatures to water. Assessment is limited to investigations based on materials and tools provided to students.

Big Idea(s):

- The Second Law of Thermodynamics dictates that thermal energy transfer in closed systems inevitably evolves toward a more uniform distribution (entropy).
- Addition or removal of heat will cause phase changes in matter.
- Heat can be transferred through conduction, convection, or radiation.

Essential Question(s):

- How can we describe and measure the flow of thermal energy between and within systems?
- How do we know that thermal energy transfer between objects will always result in a more stable, uniform energy state within a closed system?

Examples of Engaging Phenomenon:

- The temperature of a can of soda decreases when the can is placed in a container of ice.
- Hot coffee cools down after cold cream is added to the cup.
- A scoop of ice cream begins to melt when added to cold soda in a glass.
- A foam cup has 200 grams of room temperature water after 100 grams of hot water are mixed with 100 grams of cold water.
- Ice blocks melt at different rates on different objects based on their thermal conductivities.
  https://www.youtube.com/watch?v=c4KRwOyrNPw
  https://www.youtube.com/watch?v=UIAD-mEP6L0
- Calorimetry Lab or Calorimetry Gizmo
- Water balloon over flame and balloon doesn't pop due to the thermal energy absorption of water.
  Fire Water Balloon - Cool Science Experiment | Educational Videos by Mocomi Kids

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Students will know: (Disciplinary Core Ideas)	As evidenced by: (Science & Engineering Practices)
PS3.B: Conservation of Energy and Energy Transfer ● Energy cannot be created or destroyed, but it can be transported from one place to another and transferred between systems. Uncontrolled systems always evolve toward more stable states—that is, toward more uniform energy distribution (e.g., water flows downhill, objects hotter than their surrounding environment cool down). **PS3.D: Energy in Chemical Processes** ● Although energy cannot be destroyed, it can be converted to less useful forms — for example, to thermal energy in the surrounding environment. ***DCI OBJECTIVES:*** ● The First Law of Thermodynamics states that energy cannot be created or destroyed. ● Heat, *Q,* is related to the internal energy, *U,* of the system and work, *W,* done by the system as the first law of thermodynamics states $\Delta U = Q - W$. ● The Second Law of Thermodynamics states that for a spontaneous process, the entropy of the universe increases. Entropy is the degree of disorder in the system. ● The Third Law of Thermodynamics states that a perfect crystal at Absolute Zero (zero Kelvin) has zero entropy. ● Specific heat capacity is the amount of heat energy required to raise the temperature of a substance by a certain amount. It is an intrinsic property of the substance. ● Heat transfer: Q=heat, m=mass, c=specific heat capacity,	● Calculate heat transfer using the equation $Q=mC(T_f - T_i)$ where Q=heat, m=mass, c=specific heat capacity, T_f=final temperature, and T_i- initial temperature. ● Differentiate between temperature and heat. Temperature is a measurement, while heat is a process of energy transfer. Temperature refers to the average kinetic energy of particles in a substance. Heat represents the transfer of thermal energy from a hotter object to a cooler one. **Using Mathematics and Computational Thinking** ● Create a computational model or simulation of a phenomenon, designed device, process, or system. ● Use mathematical, computational, and/or algorithmic representations of phenomena or design solutions to describe and/or support claims and/or explanations. **Constructing Explanations and Designing Solutions** ● Design or refine a solution to a complex real-world problem, based on scientific knowledge, principles, and theories. ● Design or refine a solution to a complex real-world problem, based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and tradeoff considerations. **Planning and Carrying Out Investigations** ● Plan and conduct an investigation individually and collaboratively to produce data to serve as the basis for evidence, and in the design: decide on types, how much, and accuracy of data needed to produce reliable measurements and consider limitations on the precision of the data (e.g., number of trials, cost, risk, time), and refine the design accordingly. **Observable features of the student performance by the end of the course:**

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T_f=final temperature, and T_i- initial temperature. ● Temperature is a measurement, while heat is a process of energy transfer. Temperature refers to the average kinetic energy of particles in a substance. Heat represents the transfer of thermal energy from a hotter object to a cooler one. ● States or phases of matter include solid, liquid, gas, and plasma. Each state has its own molecular behavior and observable properties. ● Adding or removing an amount of heat from a substance will lead to a phase change. ● Heat energy can be transferred through conduction, convection, or radiation. Conduction involves heat transfer through direct contact. Convection occurs through the movement of particles in a fluid as density allows cooler parts to sink and warmer parts to float, setting up a circular convection cell. Radiation is an electromagnetic wave that can travel through a vacuum.	● Describe the purpose of the investigation that includes the idea that the transfer of thermal energy when two components of different temperature are combined within a closed system results in a more uniform energy distribution among the components in the system (second law of thermodynamics). ● Develop an investigation plan and describe the data that will be collected and the evidence to be derived from the data including the measurement of the reduction of temperature of the hot object and the increase in temperature of the cold object.The goal is to show that the thermal energy lost by the hot object is equal to the thermal energy gained by the cold object and that the distribution of thermal energy is more uniform after the interaction of the hot and cold components. The plan should also include heat capacity of the components in the system, obtained from scientific literature. ● Describe how a nearly closed system will be constructed, including the boundaries and initial conditions of the system; the data that will be collected, including masses of components and initial and final temperatures; and the experimental procedure, including how the data will be collected, the number of trials, the experimental setup, and equipment required. ● Collect and record data that can be used to calculate the change in thermal energy of each of the two components of the system. ● Evaluate their investigation including the accuracy and precision of the data collected, as well as the limitations of the investigation, and the ability of the data to provide the evidence required. If necessary, students refine the plan to produce more accurate, precise, and useful data that address the experimental question. Identify potential causes of the apparent loss of energy from a closed system (which should be zero in an ideal system) and adjust the design of the experiment accordingly.

Cross-Cutting Concepts:
Systems and System Models

- When investigating or describing a system, the boundaries and initial conditions of the system need to be defined and their inputs and outputs analyzed and described using models.

Academic Vocabulary:

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- Science vocabulary students ARE expected to know:

Absolute Zero, Entropy, Gas, Heat, Heat Conduction, Heat Convection, Heat Radiation, Kelvin, Kinetic Energy, Liquid, Molecular Energy, Phase Change, Plasma, Solid, Specific Heat, Specific Heat Capacity, States of Matter, Temperature, Thermal Energy, Work

- Additional tier 2 words that students should be familiar with:

Boiling, Calorimetry, Condensation, Freezing, Joule, Macroscopic Scale, Melting, Microscopic Scale, Sublimation

Science vocabulary students are NOT expected to know:

Entropy, root mean velocity, Boltzmann's constant, gravitational fields, fusion, fission

Resources: NGSS Phenomenon Master List

- Ice Block Kit

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Unit 6: Waves

Priority Standard (Performance Expectation):

HS-PS4-1 Wave Properties in Various Media
Use mathematical representations to support a claim regarding relationships among the frequency, wavelength, and speed of waves traveling in various media.

HS-PS4-2 Digital Transmission and Storage of Information
Evaluate questions about the advantages of using digital transmission and storage of information.

HS-PS4-3 Wave-Particle Duality of Electromagnetic Radiation
Evaluate the claims, evidence, and reasoning behind the idea that electromagnetic radiation can be described either by a wave model or a particle model, and that for some situations one model is more useful than the other.

HS-PS4-4 Absorption of Electromagnetic Radiation
Evaluate the validity and reliability of claims in published materials of the effects that different frequencies of electromagnetic radiation have when absorbed by matter.

HS-PS4-5 Waves and Information Technology
Communicate technical information about how some technological devices use the principles of wave behavior and wave interactions with matter to transmit and capture information and energy.

Clarification Statement: Examples of data could include electromagnetic radiation traveling in a vacuum and glass, sound waves traveling through air and water, and seismic waves traveling through the Earth. Assessment is limited to algebraic relationships and describing those relationships qualitatively.

Examples of advantages could include that digital information is stable because it can be stored reliably in computer memory, transferred easily, and copied and shared rapidly. Disadvantages could include issues of easy deletion, security, and theft.

Emphasis is on how the experimental evidence supports the claim and how a theory is generally modified in light of new evidence. Examples of a phenomenon could include resonance, interference, diffraction, and photoelectric effect. Assessment does not include using quantum theory.

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Emphasis is on the idea that photons associated with different frequencies of light have different energies, and the damage to living tissue from electromagnetic radiation depends on the energy of the radiation. Examples of published materials could include trade books, magazines, web resources, videos, and other passages that may reflect bias. Assessment is limited to qualitative descriptions. Clarification Statement: Examples could include solar cells capturing light and converting it to electricity; medical imaging; and communications technology. Assessments are limited to qualitative information. Assessments do not include band theory.
Big Idea(s): ● Waves transfer energy and information through various media, with electromagnetic radiation exhibiting a dual wave-particle nature that determines its interaction with matter.
Essential Question(s): ● How do we know that electromagnetic radiation is best described by a particle model in some scenarios and a wave model in others? ● How do we know that specific frequencies of the EM spectrum are fundamentally dangerous to living tissue while others are safe? ● How are frequency, wavelength and speed of waves related? ● How do waves transfer energy without necessarily transferring matter? ● Why are waves useful for transferring information?
Examples of Engaging Phenomenon: ● Demonstrate microwave uneven cooking. Why is it so hard to cook foods evenly in a microwave and how do they work? https://www.youtube.com/watch?v=ssj02s9HQds https://www.youtube.com/watch?v=kp33ZprO0Ck ● A person sees a fish through the glass wall of a rectangular fish tank. The person moves and looks through the end of the tank. The fish appears to be in a different place. Why? https://mammothmemory.net/physics/refraction/refraction-and-spearing-a-fish/refractio n-and-spearing-a-fish.html https://micro.magnet.fsu.edu/primer/java/refraction/fishtank/index.html ● A person uses email to back up all of their personal data. ● When light hits a metal, a stream of electrons are ejected from the metal. When the color of the light pointed at the metal changes, the kinetic energy of the stream of electrons changes. https://minerva.union.edu/malekis/CVision2003/MainPage/Course%20Content/Physics%20of%20Color/PhysicsofColor.htm ● How do bluetooth headphones work? https://www.iop.org/explore-physics/physics-around-you/technology-our-lives/bluetooth https://lookingglass.montroseschool.org/front-page-scroll/2023/02/09/how-do-bluetooth-headphones-work/ ● A student places a glass bowl filled with soup in a microwave. After a minute in the microwave, the soup is hotter than the glass bowl. https://www.comsol.com/blogs/why-does-a-microwave-heat-food-unevenly https://www.youtube.com/watch?v=PMrDEQvmAGo ● A lit candle is placed at one end of a tube filled with carbon dioxide. A student standing at the other end of the tube can see the candle’s

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flame. When looking through a monitor that looks at the infrared radiation emitted by the flame, the student can no longer see the candle's flame. https://www.youtube.com/watch?v=SeYfl45X1wo https://scied.ucar.edu/learning-zone/how-climate-works/carbon-dioxide-absorbs-and-re-emits-infrared-radiation ● Astronauts aboard the International Space Station are exposed to a different amount of ultraviolet radiation from the Sun than humans on Earth. https://science.howstuffworks.com/do-astronauts-need-sunscreen-in-space.htm https://www.lpi.usra.edu/education/explore/space_health/space_radiation/index_print.shtml ● In 2020, NASA sent a rover to Mars with multiple materials on it in order to test whether or not they can be used as space suits for future Mars travelers. Orthofabric was chosen to be sent on the mission, while Spectra was not. https://www.nasa.gov/centers-and-facilities/johnson/nasas-perseverance-rover-will-carry-first-spacesuit-materials-to-mars/ ● When using light detection and ranging (LiDAR) over a forested area, the light reflects off multiple surfaces and affects the accuracy of elevation models. https://oceanservice.noaa.gov/facts/lidar.html#:~:text=Lidar%20%E2%80%94%20Light%20Detection%20and%20Ranging,the%20surface%20of%20the%20Earth. https://www.faro.com/en/Resource-Library/Article/What-is-Lidar ● Solar cells only capture about 20% of the energy from the sun. https://www.youtube.com/watch?v=8RjGHmlOu58 https://physicsworld.com/a/sunny-superpower-solar-cells-close-in-on-50-efficiency/ ● Marine radar is mounted to the front of ships used for collision avoidance. Occasionally, the radar can distort the coast line and report a straight coastline when it is curved. Water reflects radar, blanking out entire regions of radar screens.

Students will know: (Disciplinary Core Ideas)	As evidenced by: (Science & Engineering Practices)
● The wavelength and frequency of a wave are related to one another by the speed of travel of the wave, which depends on the type of wave and the medium through which it is passing. ● Wave Properties Information can be digitized (e.g., a picture stored as the values of an array of pixels); in this form, it can be stored reliably in computer memory and sent over long distances as a series of wave pulses. **PS4.B: Electromagnetic Radiation** ● Electromagnetic radiation (e.g., radio, microwaves, light) can be modeled as a wave of changing electric and	● Calculate wavelength and wave speed problems using the formula $\lambda = {}^{v}/_{f}$ where λ is the wavelength, v is the wave velocity, and f is the frequency. ● Calculate frequency problems using the formula $f = {}^{1}/_{T}$, where f is the frequency and T is the period. ● Model the anatomy of a wave to identify wavelength, frequency, and amplitude. ● Approximate the speed of light by measuring the wavelength and frequency. One method is to use a microwave oven to melt shredded cheese or a chocolate bar and measure between the observable hot spots that indicate the wavelength (λ) value. The microwave specifications label will list the frequency, f. The formula $c=\lambda f$ can then be used to calculate the wave velocity of light, c.

magnetic fields or as particles called photons. The wave model is useful for explaining many features of electromagnetic radiation, and the particle model explains other features. ● When light or longer wavelength electromagnetic radiation is absorbed in matter, it is generally converted into thermal energy (heat). Shorter wavelength electromagnetic radiation (ultraviolet, X-rays, gamma rays) can ionize atoms and cause damage to living cells. ● Photoelectric materials emit electrons when they absorb light of a high-enough frequency. **PS4.C: Information Technologies and Instrumentation** ● Multiple technologies based on the understanding of waves and their interactions with matter are part of everyday experiences in the modern world (e.g., medical imaging, communications, scanners) and in scientific research. They are essential tools for producing, transmitting, and capturing signals and for storing and interpreting the information contained in them. **PS3.D: Energy in Chemical Processes** ● Solar cells are human-made devices that capture the sun's energy and produce electrical energy. ***DCI OBJECTIVES:*** ● Frequency, period, wavelength, and wave speed are related. Frequency is defined as the number of cycles per unit of time. Period, the inverse of frequency, is the time it takes for an object to make one cycle. Wavelength is the distance from one crest to another of a wave. Wave speed is the distance traveled by a given point on a wave in a given interval of time.	● Identify frequency, period, wavelength, and wave speed in scenarios and use mathematical formulas to describe their relationships. ● Describe the electromagnetic spectrum and various wavelength bands, ● Explain, compare, and contrast each expression of the wave-particle duality model. **Using Mathematics and Computational Thinking** ● Create a computational model or simulation of a phenomenon, designed device, process, or system. ● Use mathematical, computational, and/or algorithmic representations of phenomena or design solutions to describe and/or support claims and/or explanations. ● Describe the wave-particle duality model and justify why each is useful. Sometimes we model light as a wave and other times we model it as a particle called a photon. The wave model is better for light dispersion. The particle model is better for explaining optics. **Constructing Explanations and Designing Solutions** ● Design or refine a solution to a complex real-world problem, based on scientific knowledge, principles, and theories. ● Design or refine a solution to a complex real-world problem, based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and tradeoff considerations. **Engaging in Argument from Evidence** ● Compare and evaluate competing arguments or design solutions in light of currently accepted explanations, new evidence, limitations (e.g., trade-offs), constraints, and ethical issues. ● Evaluate the claims, evidence, and/or reasoning behind currently accepted explanations or solutions to determine the merits of arguments. **Asking Questions and Defining Problems** ● Ask questions that arise from careful observation of phenomena, or unexpected results, to clarify and/or seek additional information.

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• Wavelength and wave speed: $\lambda = {}^{v}/_{f}$ where λ is the wavelength, v is the wave velocity, and f is the frequency. • Frequency: $f = {}^{1}/_{T}$, where f is the frequency and T is the period. • The speed of waves is dependent on the properties of a medium. • Amplitude is an independent property of waves. It is a measure of the wave's displacement from equilibrium and models the wave's intensity. • Anatomy of a wave: wavelength, frequency, and amplitude. • Waves transfer energy without transferring matter. • Waves can correspond with binary codes to transfer information. • Frequency is a measure of the energy of different types of electromagnetic waves. • Radio Waves, Microwaves, Infrared, Visible Light, Ultraviolet, X-rays, and Gamma Rays are different wavelength bands in the spectrum of electromagnetic waves, the speed of which in a vacuum is approximately $3 \text{ X } 10^8$ m/s, and less when passing through other media. • Wave-particle duality model. Sometimes we model light as a wave and other times we model it as a particle called a photon. The wave model is better for light dispersion. The particle model is better for explaining optics.	• Define a design problem that involves the development of a process or system with interacting components and criteria and constraints that may include social, technical and/or environmental considerations. **Obtaining, Evaluating, and Communicating Information** • Evaluate the validity and reliability of multiple claims that appear in scientific and technical texts or media reports, verifying the data when possible. • Gather, read, and evaluate scientific and/or technical information from multiple authoritative sources, assessing the evidence and usefulness of each source. • Communicate technical information or ideas (e.g. about phenomena and/or the process of development and the design and performance of a proposed process or system) in multiple formats (including orally, graphically, textually, and mathematically). **Observable features of the student performance by the end of the course:** • Identify and describe the relevant components in the mathematical representations: mathematical values and the relationships between frequency, wavelength, and speed of waves traveling in various specified media. • Demonstrate that the product of the frequency and the wavelength of a particular type of wave in a given medium is constant, and identify this relationship as the wave speed according to the mathematical relationship $v = f\lambda$. Use data to show and predict that the wave speed for a particular type of wave changes as the medium through which the wave travels changes. Express the relative change in terms of cause (different media) and effect (different wavelengths but same frequency). • Assess claims, using the mathematical relationship $v = f\lambda$, about any of the three quantities when the other two quantities are known for waves traveling in various specified media. Use the mathematical relationships to distinguish between cause and correlation with respect to the supported claims. • Evaluate the given phenomenon questions in terms of whether or not answers to the questions would: provide examples of features associated

• Waves can experience constructive (additive amplitude) or destructive (subtractive amplitude) interference. It can cause phenomena including uneven heating or hot spots in a microwave, feedback with a guitar, and ocean superwaves. • Speed of light and the relationship to wavelength and frequency. The formula $c=\lambda f$ can be used to calculate the wave velocity of light, c. • Gamma, Ultraviolet (UV), and X-rays are ionizing radiation. Ionizing radiation has enough energy to ionize atoms by detaching electrons from them and can cause damage to living cells. • **Validity Activity Clothing OR Validity Activity Sunscreen** • Some technological devices use the principles of wave behavior and wave interactions with matter to transmit and capture information and energy. Some examples include: solar cells, the Photoelectric Effect, spectroscopy, infrared scanners, X-Ray imaging, CT/CAT scans, and ultrasound.	with digital transmission and storage of information (e.g., can be stored reliably without degradation over time, transferred easily, and copied and shared rapidly; can be easily deleted; can be stolen easily by making a copy; can be broadly accessed); and in their evaluation of the given questions, describe the stability and importance of the systems that employ digital information as they relate to the advantages and disadvantages of digital transmission and storage of information; and discuss the relevance of the answers to the question to real-life examples (e.g., emailing your homework to a teacher, copying music, using the internet for research, social media). • Evaluate the given questions in terms of whether or not answers to the questions would provide means to empirically determine whether given features are advantages or disadvantages. • Identify the given explanation that is to be supported by the claims, evidence, and reasoning to be evaluated, and that includes the following idea: Electromagnetic radiation can be described either by a wave model or a particle model, and for some situations one model is more useful than the other. Identify the given claims to be evaluated. Identify the given evidence to be evaluated, including the following phenomena: Interference behavior by electromagnetic radiation and the photoelectric effect. Identify the given reasoning to be evaluated. • Evaluate the given evidence for interference behavior of electromagnetic radiation to determine how it supports the argument that electromagnetic radiation can be described by a wave model. Evaluate the phenomenon of the photoelectric effect to determine how it supports the argument that electromagnetic radiation can be described by a particle model. Evaluate the given claims and reasoning for modeling electromagnetic radiation as both a wave and particle, considering the transfer of energy and information within and between systems, and why for some aspects the wave model is more useful and for other aspects the particle model is more useful to describe the transfer of energy and information. • Obtain at least two claims proposed in published material (using at least two sources per claim) regarding the effect of electromagnetic radiation that is absorbed by matter. One of these claims deals with the effect of electromagnetic radiation on living tissue.

	• Reason about the data presented, including the energies of the photons involved (i.e., relative wavelengths) and the probability of ionization, to analyze the validity and reliability of each claim. Determine the validity and reliability of the sources of the claims. Describe the cause and effect reasoning in each claim, including the extrapolations to larger scales from cause and effect relationships of mechanisms at small scales (e.g., extrapolating from the effect of a particular wavelength of radiation on a single cell to the effect of that wavelength on the entire organism). Communicate technical information and ideas, including fully describing at least two devices and the physical principles upon which the devices depend. One of the devices must depend on the photoelectric effect for its operation. Cite the origin of the information as appropriate. • Identify the wave behavior utilized by the device or the absorption of photons and production of electrons for devices that rely on the photoelectric effect, and qualitatively describe how the basic physics principles were utilized in the design through research and development to produce this functionality (e.g., absorbing electromagnetic energy and converting it to thermal energy to heat an object; using the photoelectric effect to produce an electric current). For each device, discuss the real-world problem it solves or need it addresses, and how civilization now depends on the device. Identify and communicate the cause and effect relationships that are used to produce the functionality of the device.

Cross-Cutting Concepts:

Cause and Effect
- Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects.

Systems and System Models
- Models can be used to predict the behavior of a system, but these predictions have limited precision and reliability due to the assumptions and approximations inherent in models.

Stability and Change
- For natural and built systems alike, conditions of stability and determinants of rates of change or evolution of a system are critical elements of study.

Academic Vocabulary:
- Science vocabulary students ARE expected to know:

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Amplitude, Electromagnetic Radiation, Electromagnetic Spectrum, Frequency, Gamma Rays, Infrared, Interference, Ionizing Radiation, Medium, Microwaves, Period, Radiation, Radio Waves, Speed of Light, Speed of Sound, Ultraviolet, Vacuum, Visible Light, Wave, Wave-Particle Duality, Wave Source, Wave Velocity/Speed, Wavelength, X-Rays - Additional tier 2 words that students should be familiar with: Analog, Digital Science vocabulary students are NOT expected to know: Clausius–Mossotti relation, dielectric constant, Fermat's principle, phase velocity, permittivity, permeability.
Resources: NGSS Phenomenon Master List ● Photoelectric Effect Gizmo

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Unit 7: Field Forces

Priority Standard (Performance Expectation):

HS-PS2-4 Motion and Stability: Forces and Interactions

Use mathematical representations of Newton's Law of Gravitation and Coulomb's Law to describe and predict the gravitational and electrostatic forces between objects.

HS-PS3-5 Energy
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.

Clarification Statement: Emphasis is on both quantitative and conceptual descriptions of gravitational and electric fields. Assessment is limited to systems with two objects.

Examples of models could include drawings, diagrams, and texts, such as drawings of what happens when two charges of opposite polarity are near each other. Assessment is limited to systems containing two objects.

Big Idea(s):

- Gravitational and electrostatic interactions are governed by fields that permeate space, where changes in the relative position of objects result in measurable changes in stored energy.

Essential Question(s):

- How do we know that a single mathematical model—the inverse square law—can accurately predict the motion of both cosmic bodies and subatomic particles?
- The Inverse Square Mystery: Why does doubling the distance between two objects reduce the force between them to one-fourth, rather than just one-half?
- The Comparison: How can a tiny refrigerator magnet overcome the gravitational pull of the entire Earth, and what does that tell us about the relative strengths of these two forces?
- The Mathematical Twin: How can one mathematical model—the inverse square law—describe two completely different phenomena like a planet orbiting a sun and an electron orbiting a nucleus?The Invisible Battery: When you force two repelling magnets together, where exactly is that energy being "stored" before you let them go?
- The Energy Swap: How does the potential energy in a system change as the distance between two interacting objects increases or decreases?
- The Field as Evidence: How do field line maps (electric or magnetic) provide evidence for the amount of energy stored in a system?

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Examples of Engaging Phenomenon:

- Why can you jump slightly higher in Denver versus Connecticut? https://www.nba.com/news/is-impact-of-denvers-altitude-fact-or-fiction
- How can we predict what it would be like to walk on Mars? John Carter 2012 Gravity on Mars Scene
- Magnetic free energy devices- Are the electric companies hiding the secrets to FREE energy? https://www.youtube.com/watch?v=92nsAaMvQcs
- Bending a stream of water with an electrically-charged balloon https://www.youtube.com/watch?v=uvG4cjc_4W4
- Demonstrate: Two magnets are held close together such that they attract each other. When the magnets are further away from each other, it is easier to keep them apart. (Relation to Coulomb's Law and Universal Gravitation) https://physicsworld.com/a/sunny-superpower-solar-cells-close-in-on-50-efficiency/ https://www.electricaltechnology.org/2020/12/coulombs-laws-of-magnetic-force.html

Students will know: (Disciplinary Core Ideas)	As evidenced by: (Science & Engineering Practices)
PS2.B: Types of Interactions ● Newton's law of universal gravitation and Coulomb's law provide the mathematical models to describe and predict the effects of gravitational and electrostatic forces between distant objects. Forces at a distance are explained by fields (gravitational, electric, and magnetic) permeating space that can transfer energy through space. Magnets or electric currents cause magnetic fields; electric charges or changing magnetic fields cause electric fields. **PS3.C: Relationship Between Energy and Forces** ● When two objects interacting through a field change relative position, the energy stored in the field is changed. ***DCI OBJECTIVES:*** ● Charged particles are sources of electric fields and are subject to the forces of the electric fields from other charges. ● Fields and forces are related but not interchangeable. Fields are regions in space that can induce a force onto an	● Manipulate and apply Newton's Law of Universal Gravitation $F_G = -G\frac{m_1 m_2}{r^2}$ ● Manipulate and apply Coulomb's Law $F_E = K\frac{q_1 q_2}{r^2}$ to determine and predict interactions between charges, with q_1 and q_2 defined as the electrical charges, Coulomb's constant (K = $9x10^9$ N*m^2/C^2), r as the distance between objects, and F_E as the electrical force. ● Compare and contrast Coulomb's Law and Newton's Law of Universal Gravity. For example, Coulomb's Law has a different constant leading to a stronger force and both involve the inverse-square law. $U_E = K\frac{q_1 q_2}{r}$ with q_1 and q_2 defined as the electrical charges, Coulomb's constant (K = $9x10^9$ N*m^2/C^2), r as the distance between objects, and U_E as the electrostatic potential energy. ● Differentiate between fields and forces and between contact forces and field forces. **Using Mathematics and Computational Thinking** ● Create a computational model or simulation of a phenomenon,

appropriate particle (charge for an electric field, mass for a gravitational field).

- Forces can be categorized as Contact Forces or Field Forces. A Contact Force is when a physical object touches another physical object and exerts a force on it. Pushes and pulls are examples of Contact Forces. Field Forces affect objects without actually touching them. Examples of Field Forces include gravity and magnetism.

- Newton's Law of Universal Gravitation: $F_G = -G\frac{m_1 m_2}{r^2}$
- When F_G is gravitational force, G is the gravitational constant (6.67x10^{-11} m^3*kg^{-1}*s^{-2}), m_1 and m_2 are the masses of the two objects, and r is the distance between them.

- Different planets yield a different acceleration due to gravity since they possess differing masses. Different heights yield a different acceleration due to gravity since they possess a different distance between them.

- Coulomb's Law: $F_E = K\frac{q_1 q_2}{r^2}$ is used to determine and predict interactions between charges, with q_1 and q_2 defined as the electrical charges, Coulomb's constant (K = 9x10^9 N*m^2/C^2), r as the distance between objects, and F_E as the electrical force.

- Energy and relative positions in electric fields: $U_E = K\frac{q_1 q_2}{r}$ with q_1 and q_2 defined as the electrical charges, Coulomb's constant (K = 9x10^9 N*m^2/C^2), r as the distance between objects, and U_E as the electrostatic potential energy.

designed device, process, or system.

- Use mathematical, computational, and/or algorithmic representations of phenomena or design solutions to describe and/or support claims and/or explanations.

Constructing Explanations and Designing Solutions

- Design or refine a solution to a complex real-world problem, based on scientific knowledge, principles, and theories.
- Design or refine a solution to a complex real-world problem, based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and tradeoff considerations.

Developing and Using Models

- Develop and use a model based on evidence to illustrate the relationships between systems or between components of a system.
- Develop and/or use a model (including mathematical and computational) to generate data to support explanations, predict phenomena, analyze systems, and/or solve problems.

Observable features of the student performance by the end of the course:

- Define the system of the interacting objects that is mathematically represented. Using the given mathematical representations, identify and describe the gravitational attraction between two objects as the product of their masses divided by the separation distance squared $\left(F_g = -G\frac{m_1 m_2}{d^2}\right)$, where a negative force is understood to be attractive. Using the given mathematical representations, identify and describe the electrostatic force between two objects as the product of their individual charges divided by the separation distance squared $\left(F_e = k\frac{q_1 q_2}{d^2}\right)$, where a negative force is understood to be attractive.
- Predict, using the given mathematical formulas, the gravitational force between objects or predict the electrostatic force between charged objects.
- Describe, based on the given mathematical models, that the ratio

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	between gravitational and electric forces between objects with a given charge and mass is a pattern that is independent of distance. Describe that the mathematical representation of the gravitational field only predicts an attractive force because mass is always positive. Describe that the mathematical representation of the electric field predicts both attraction and repulsion because electric charge can be either positive or negative. ● Describe that the change in the energy of objects interacting through electric or gravitational forces depends on the distance between the objects, using the given formulas for the forces as evidence

Cross-Cutting Concepts:

Patterns

- Observed patterns of forms and events guide organization and classification, and they prompt questions about relationships and the factors that influence them.

Cause and Effect

- Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects.

Energy and Matter

- Energy cannot be created or destroyed—only moves between one place and another place, between objects and/or fields, or between systems.

Academic Vocabulary:

- Science vocabulary students ARE expected to know:

Contact Force, Coulomb, Electric Charge, Electric Field, Electric Potential Energy, Electrostatic, Field Force

- Additional tier 2 words that students should be familiar with:

Electric Kinetic Energy, Electron, Proton

Science vocabulary students are NOT expected to know:

electric potential, electromotive force, permeating, quantum property, Laplace force, electrodynamics, magnetic dipole, general relativity, Ampere’s Law, Coulomb force,

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Lorentz force, semiconductor, superconductor, torque, Gauss' Law, Faraday's Law, Lenz's Law
Resources: NGSS Phenomenon Master List

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Unit 8: Orbits and Circular Motion

Priority Standard (Performance Expectation): **HS-ESS1-4 Earth's Place in the Universe** Use mathematical or computational representations to predict the motion of orbiting objects in the solar system.
Clarification Statement: Emphasis is on Newtonian gravitational laws governing orbital motions, which apply to human-made satellites as well as planets and moons. Mathematical representations for the gravitational attraction of bodies and Kepler's Laws of orbital motions should not deal with more than two bodies, nor involve calculus.
Big Idea(s): ● Newtonian gravitation and Kepler's Laws provide the mathematical foundation to predict the elliptical trajectories and orbital velocities of both natural and human-made satellites.
Essential Question(s): ● How do we know that the distance between an orbiting body and its gravitational center dictates its necessary orbital velocity to maintain a stable trajectory?
Examples of Engaging Phenomenon: ● How can scientists protect us from killer asteroids? Vox: Protecting the Earth from Killer Asteriods ● How can we predict that the Earth is not going to fall into the sun? https://www.wtamu.edu/~cbaird/sq/2013/07/01/why-doesnt-the-earth-fall-down/ ● How does a centrifuge work? https://www.youtube.com/watch?v=NqVaMiTI8Uw ● Why do they design tracks to have Banked Curves ? ● The International Space Station orbits Earth at an altitude of 250 miles with a speed of 5 miles per second while a global positioning system (GPS) satellite orbits ten times as far and half as fast. https://www.youtube.com/shorts/9iPKWmy7U24 ● China's Tiangong space station's orbital speed can no longer be controlled. It is expected to burn up in the atmosphere as it falls to the Earth. https://www.youtube.com/watch?v=xFUH2NSp0rg ● The shape of Comet Shoemaker-Levy 9's orbit changed just before it collided with Jupiter in 1994. https://www.youtube.com/shorts/dp6EGCtxYpI

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• In 100 years, the moon will be about half a meter further from Earth and Earth's rotation will be 2 milliseconds slower. https://www.livescience.com/space/the-moon/will-earth-ever-lose-its-moon • Earth's Rotation https://www.popularmechanics.com/science/environment/a60333710/earth-rotation-leap-second/	
Students will know: (Disciplinary Core Ideas)	As evidenced by: (Science & Engineering Practices)
ESS1-4.B: Earth and the Solar System • Kepler's laws describe common features of the motions of orbiting objects, including their elliptical paths around the sun. Orbits may change due to the gravitational effects from, or collisions with, other objects in the solar system. ***DCI OBJECTIVES:*** • Centripetal force is a constant force directed toward the center of the circle. • An object moving at a constant tangential speed in a circular path can also have constant acceleration. Acceleration is a vector quantity involving speed and direction. If the object is not speeding up or slowing down, it is still changing direction as it travels around the circle, thus changing acceleration. • Centripetal acceleration (a_c) depends on the object's speed (v) and the radius of the circle (r) as modeled by the Centripetal Acceleration Equation $a_c=v^2/r$. As the velocity increases, the acceleration increases. As the radius increases, the acceleration decreases. • Centrifugal force is an apparent force that seems to act toward the outside of the circle when an object is in circular motion. It is only an apparent force, not a real force, since nothing is actually pushing or pulling the object outward. Instead, it is the object's inertia tendency to continue in a straight line that makes it seem as if it is being pulled out of the circular orbit.	• Apply the Centripetal Force Equation $F_c= mv^2/r$ where F_c is the centripetal force, m is the mass, v is the velocity, and r is the radius of the circle. • Explain why different launch speeds result in varying trajectories including falling, projectile motion, circular motion, or elliptical motion. • Compare and contrast centripetal and centrifugal forces. • Apply the Centripetal Acceleration Equation, the Centripetal Force Equation, and Kepler's Laws of Planetary Motion to describe real-life situations. **Using Mathematics and Computational Thinking** • Create a computational model or simulation of a phenomenon, designed device, process, or system. • Use mathematical, computational, and/or algorithmic representations of phenomena or design solutions to describe and/or support claims and/or explanations. **Constructing Explanations and Designing Solutions** • Design or refine a solution to a complex real-world problem, based on scientific knowledge, principles, and theories. • Design or refine a solution to a complex real-world problem, based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and tradeoff considerations. **Observable features of the student performance by the end of the course:** • Identify and describe the following relevant components in the

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● Centripetal Force Equation $F_c = mv^2/r$ where F_c is the centripetal force, m is the mass, v is the velocity, and r is the radius of the circle. ● Different launch speeds result in varying trajectories including falling, projectile motion, circular motion, or elliptical motion. ○ If an object is launched with a very low horizontal velocity, it will simply fall to the ground due to gravity, following a straight downward falling path. ○ When an object is launched with a moderate horizontal velocity, it follows a curved path (a parabola) due to the constant downward pull of gravity, a classic example of projectile motion. ○ If an object is launched with a specific horizontal velocity (approximately 8000 m/s from Earth's surface), it can achieve a circular orbit, where the constant inward pull of gravity balances the object's forward motion, keeping it in a circular path. ○ If the object is launched with a speed greater than that required for a circular orbit, it will follow an elliptical path, with the gravitational pull causing the speed to vary as the object moves closer to or further from the central body ● Kepler's First Law of Planetary Motion (The Law of Orbits): All the planets revolve around the sun in elliptical orbits having the Sun at one of the foci. The foci of an ellipse are two fixed points on the major axis, equidistant from the center, that define the shape of the ellipse. ● Kepler's Second Law of Planetary Motion (The Law of Equal Areas): The radius vector drawn from the sun to the planet sweeps out equal areas in equal intervals of time. As the orbit is not circular, the planet's kinetic energy is not constant in its path. It has more kinetic energy near the perihelion (the part	given mathematical or computational representations of orbital motion: the trajectories of orbiting bodies, including planets, moons, or human-made spacecraft; each of which depicts a revolving body's eccentricity $e = f/d$, where f is the distance between foci of an ellipse, and d is the ellipse's major axis length (Kepler's first law of planetary motion). ● Depict that the square of a revolving body's period of revolution is proportional to the cube of its distance to a gravitational center ($T^2 \propto R^3$, where T is the orbital period and R is the semimajor axis of the orbit — Kepler's third law of planetary motion), the given mathematical or computational representations of orbital motion. ● Predict the relationship between the distance between an orbiting body and its star, and the object's orbital velocity (i.e., that the closer an orbiting body is to a star, the larger its orbital velocity will be), using the given mathematical or computational representation of Kepler's second law of planetary motion (an orbiting body sweeps out equal areas in equal time).

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of the orbit closest to the Sun), and less kinetic energy near the aphelion (the part of the orbit farthest from the Sun), causing more speed at the perihelion and less speed at the aphelion. ● Kepler's Third Law of Planetary Motion (The Law of Periods): Predict the period or distance of objects in the solar system around a common gravitational center. The square of the time period of revolution of a planet around the sun in an elliptical orbit is directly proportional to the cube of its semi- major axis, T2 □ a3. Thus, the shorter the orbit of the planet around the Sun, the shorter the time taken to complete one revolution. T is the orbital period and R is the average radius (or the semi-major axis of the ellipse). $$\frac{{T_a}^2}{{R_a}^3} = \frac{{T_b}^2}{{R_b}^3}$$	

Cross-Cutting Concepts:
Scale, Proportion, and Quantity

- In considering phenomena, it is critical to recognize what is relevant at different measures of size, time, and energy and to recognize how changes in scale, proportion, or quantity affect a system's structure or performance.

Academic Vocabulary:

- Science vocabulary students ARE expected to know:

Astronomical Unit (AU), Centrifugal, Centripetal, Ellipse, Gravitational Constant, Orbit, Period, Projectile, Satellite, Semi-major Axis, Semi-minor Axis, Trajectory

- Additional tier 2 words that students should be familiar with:

Eccentricity, Focus (plural = foci), Revolution, Rotation

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Science vocabulary students are NOT expected to know: Aphelion, perihelion, angular momentum

Unit 9: Electromagnetism

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Priority Standard (Performance Expectation):
HS-PS 2-5 Electric Current and Magnetic Fields

Plan and conduct an investigation to provide evidence that an electric current can produce a magnetic field and that a changing magnetic field can produce an electric current.

Assessment Boundary: Assessment is limited to designing and conducting investigations with provided materials and tools.

Big Idea(s):

- Electromagnetic induction is the reciprocal process where electric currents generate magnetic fields and changing magnetic fields induce electric currents, forming the basis for modern energy technology.

Essential Question(s):

- How do we know that an electric current is the fundamental cause of a magnetic field, and how can this causal relationship be manipulated to generate electrical movement?
- How does the magnetic field change when we add another magnet to the system and how does changing the distance between magnets affect the amount of energy transferred out of the field?

Examples of Engaging Phenomenon:

- Automotive: How does an electric motor work? https://www.youtube.com/watch?v=CWulQ1ZSE3c
- A radio emits music from its speakers. After a magnet in the speakers is removed, no sound can be heard. https://www.youtube.com/shorts/jzN7v_GNSJo
- A generator converts mechanical energy into electrical energy. It consists of a rectangular coil, called the armature, composed of a number of copper wires wound around an iron core. A strong permanent magnet is placed around the coil. The armature is then rotated between the magnets. Two slip rings are connected to the arms of the armature in order to provide a movable contact. The slip rings are connected to metallic brushes to pass current from the armature. When operating, the position of the armature inside the magnet keeps changing. When the magnetic field lines are perpendicular to the moving coil, the induced electromagnetic field produced increases because the number of intercepting magnetic field lines is at its maximum. https://www.electricgeneratorsdirect.com/stories/1485-How-Generators-Work.html#:~:text=An%20electric%20generator%20works%20by,wire%20next%20to%20a%20magnet.
- A transformer is a device that changes (or transforms) an alternating voltage to another voltage of greater or smaller value.The transformer consists of two coils, a primary coil and a secondary coil, that are wrapped around an iron core. The alternating current is applied across the primary coil, and the new voltage output is obtained across the secondary coil. In order for a step-up transformer to convert a low voltage into a high voltage by decreasing the current, the number of turns in the primary coil is less than the number of turns in the secondary coil.

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A step-down transformer converts a high voltage to a low voltage by increasing the current, so the number of turns in the primary coil is greater than the number of turns in the secondary coil. https://www.keysight.com/used/us/en/knowledge/guides/how-does-a-transformer-work#:~:text=Transformers%20operate%20using%20electromagnetic%20induction,windings%20determines%20the%20voltage%20conversion. ● More electrical current is produced by a windmill when the wind speed is greater. Wind Power! Designing a Wind Turbine Physics of Wind Turbines ● Merchandise from a store that uses electromagnetic anti-shoplifting devices will set off an alarm at the exit if the tag is not removed. YOUTUBE How Antitheft Tags Work ● An electromagnet at a junkyard can lift old cars, while a homemade electromagnet cannot pick up much more than a few paper clips. Creating an Electromagnet How Electromagnets Work

Students will know: (Disciplinary Core Ideas)	As evidenced by: (Science & Engineering Practices)
PS2.B: Types of Interactions ● Newton's Law of Universal Gravitation and Coulomb's Law provide the mathematical models to describe and predict the effects of gravitational and electrostatic forces between distant objects. ● Forces at a distance are explained by fields (gravitational, electric, and magnetic) permeating space that can transfer energy through space. ● Magnets or electric currents cause magnetic fields; electric charges or changing magnetic fields cause electric fields. **PS3.A: Definitions of Energy** ● "Electrical energy" may mean energy stored in a battery or energy transmitted by electric currents. ***DCI OBJECTIVES:*** ● An electric force is the attractive or repulsive interaction between any two or more charged bodies. An electric field is a region in space where the charged object	**Using Mathematics and Computational Thinking** ● Create a computational model or simulation of a phenomenon, designed device, process, or system. ● Use mathematical, computational, and/or algorithmic representations of phenomena or design solutions to describe and/or support claims and/or explanations. **Constructing Explanations and Designing Solutions** ● Design or refine a solution to a complex real-world problem, based on scientific knowledge, principles, and theories. ● Design or refine a solution to a complex real-world problem, based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and tradeoff considerations. **Planning and Carrying Out Investigations** ● Plan and conduct an investigation individually and collaboratively to produce data to serve as the basis for evidence, and in the design: decide on types, how much, and accuracy of data needed to produce reliable measurements and consider limitations on the precision of the data (e.g., number of trials, cost, risk, time), and refine the design accordingly

experiences a force due to its electric charge. The electric force causes the formation of the electric field around the source. ● Magnets have a magnetic field around them, a region of space where a magnetic force can be felt. Magnetic fields are created from moving charged particles, a relativistic effect of the electrostatic force, sometimes simply explained as the result of a moving charge. Charges can either move within the atom (stronger with the alignment of magnetic dipoles) or along a current carrying wire. Electric current through a conductive material also generates a magnetic field. ● When a magnetic field changes in either strength or direction, it creates a change in the magnetic flux through a loop of wire or a conductor. This change in magnetic flux induces an electric field. The induced electric field creates a potential difference, or voltage, across the ends of the conductor. If the conductor forms a closed loop (a circuit), this potential difference will drive an electric current to flow through the circuit, completing the circuit. This phenomenon is known as electromagnetic induction. ● When a wire carrying an electric current is placed in a magnetic field, it experiences a force. Calculate that force using the formula $F = ILB$, where F is the force, I is the current, L is the length of the wire, and B is the magnetic field strength. The force will be perpendicular to both the current and the magnetic field, and its direction can be determined using the Right-Hand rule. ● Turning a magnet in an electromagnetic field can induce a change in energy.	**Observable features of the student performance by the end of the course:** 1. Describe the phenomenon under investigation, which includes the following idea: that an electric current produces a magnetic field and that a changing magnetic field produces an electric current. 2. Develop an investigation plan and describe the data that will be collected and the evidence to be derived from the data about 1) an observable effect of a magnetic field that is uniquely related to the presence of an electric current in the circuit, and 2) an electric current in the circuit that is uniquely related to the presence of a changing magnetic field near the circuit. Describe why these effects seen must be causal and not correlational, citing specific cause-effect relationships. 3. Include, in the investigation plan, the use of an electric circuit through which electric current can flow, a source of electrical energy that can be placed in the circuit, the shape and orientation of the wire, and the types and positions of detectors; a means to indicate or measure when electric current is flowing through the circuit; a means to indicate or measure the presence of a local magnetic field near the circuit; and a design of a system to change the magnetic field in a nearby circuit and a means to indicate or measure when the magnetic field is changing. In the plan, state whether the investigation will be conducted individually or collaboratively. 4. Measure and record electric currents and magnetic fields. 5. Evaluate their investigation, including an evaluation of the accuracy and precision of the data collected and limitations of the investigation, and the ability of the data to provide the evidence required. If necessary, refine the investigation plan to produce more accurate, precise, and useful data such that the measurements or indicators of the presence of an electric current in the circuit and a magnetic field near the circuit can provide the required evidence.

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Cross-Cutting Concepts: **Cause and Effect** ● Events have causes, sometimes simple, sometimes multifaceted. A major activity of science is investigating and explaining causal relationships and the mechanisms by which they are mediated. ● Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects.
Academic Vocabulary: - Science vocabulary students ARE expected to know: Ampere, Charged Particle, Electric Current, Electric Generator, Electric Motor, Electrical Conductor, Electrical Insulator, Electromagnetism, Induction, Magnetic Field, Magnetic Field Line, Permanent Magnet, Polarity, Tesla - Additional tier 2 words that students should be familiar with: Circuit, Field Lines, Magnetic Flux, Potential Difference, Resistance, Right-Hand Rule, Transformer, Volt, Voltage, Work Science vocabulary students are NOT expected to know: electric potential, electromotive force, permeating, quantum property, Laplace force, electrodynamics, magnetic dipole, electrostatic, general relativity, Ampere’s Law, Coulomb force, Lorentz force
Resources: NGSS Phenomenon Master List

Extension Units:

Extension Units Link

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Appendix A: Vocabulary

- **4-Quadrant Coordinate System** – A system of positions along number lines with an x and y axis that intersect to have an origin of (0,0) coordinate at the intersection point.
- **Absolute Zero** – The lowest possible temperature (0 Kelvin, -459.67°F, or -273.15°C), where all molecular motion theoretically stops.
- **Acceleration** – Change in velocity and/or direction of a moving object; also defined as the rate at which velocity changes with time.
- **Ampere** – The ampere, or "amp" for short, measures electric current.
- **Amplitude** – A measure of the wave's displacement from equilibrium; it models the wave's intensity.
- **Analog** – Signals that are transmitted physical waves and have gradual increases and decreases.
- **Astronomical Unit (AU)** – A unit of length used in astronomy, representing the average distance between the Earth and the Sun, approximately 149.6 million kilometers.
- **At rest** – An object that does not change position with time.
- **Average Speed** – Distance traveled divided by time interval.
- **Average Velocity** – The average of the distance traveled over a time interval in a specific direction.
- **Balanced Force** – Forces that are equal in magnitude but opposite in direction leading to a net force that is equal to zero so no change or movement occurs.
- **Boiling** – The process in which a liquid turns into a gas when heated to its boiling point, forming bubbles throughout the liquid.
- **Calorimetry** – The process of measuring the amount of heat released or absorbed during a chemical reaction.
- **Centrifugal** – The energy of a moving object in a circle trying to stay in a straight line when it cannot; not really a force, but rather the result of inertia.
- **Centripetal** – The force, always directed towards the center, on an object in a circular path that keeps the object moving along the path.
- **Charged Particle** – An elementary particle carrying a positive or negative electric charge.
- **Circuit** – A closed path through which an electric current may flow.
- **Collision** – Interaction between two or more masses to influence motion.
- **Condensation** – The process in which a gas cools and turns into a liquid.
- **Conservative** – Mechanical energy is conserved.

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- **Constraints** – Rules or conditions that limit an object's motion, position, or both.
- **Contact Force** – Any force that occurs as a result of objects touching each other.
- **Convert** – The process of changing one form of energy into another.
- **Coulomb** – The standard unit of electric charge (SI) equal to the amount of electricity that a 1-ampere current carries in one second.
- **Digital** – Signals that are transmitted in the form of 1's and 0's and are entirely on or off with no in-betweens.
- **Direction** – A vector quantity that measures from position to position; the course along which something moves; indicates where the vector is pointed (e.g., North, South, Up, Down).
- **Displacement** – The straight-line distance measured from the origin; a vector quantity.
- **Distance** – A scalar quantity that measures from one position to another position.
- **Eccentricity** – A measure of how much a curve, like an ellipse, deviates from being perfectly circular.
- **Elastic Collision** – A collision in which there is no net loss in kinetic energy in the system; both momentum and kinetic energy are conserved.
- **Elastic Potential Energy** – The energy that an object has when its shape is deformed and then returns to its original shape.
- **Electric Charge** – The physical property of matter that causes it to experience a force when placed in an electromagnetic field.
- **Electric Current** – The flow of electricity in a circuit or the amount of electricity flowing through a circuit.
- **Electric Field** – The region of space that surrounds electrically charged particles.
- **Electric Generator** – A device that converts mechanical (kinetic) energy into electrical energy.
- **Electric Kinetic Energy** – The kinetic energy possessed by moving electric charges (electrons).
- **Electric Motor** – A device that converts electrical energy into mechanical (kinetic) energy.
- **Electric Potential Energy** – A measure of the potential energy between two charged particles based on their charges and distance.
- **Electrical Conductor** – A material that permits electrons to flow freely from particle to particle.
- **Electrical Energy** – The energy derived from electric potential energy or kinetic energy of charged particles.
- **Electrical Insulator** – A material that prevents electron flow from particle to particle.
- **Electromagnetic Radiation** – Waves of the electromagnetic field that move through space and carry momentum and radiant energy.
- **Electromagnetic Spectrum** – The full range of electromagnetic radiation, organized by frequency or wavelength.
- **Electromagnetism** – The production of a magnetic field by current flowing in a conductor.
- **Electron** – A subatomic particle with a negative electric charge found in the electron cloud surrounding the atom.
- **Ellipse** – A closed curve (oval shape) where the sum of the distances from any point on the curve to the two foci remains the same.

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- **Energy** – The ability to do work, or to exert a force that causes an object to move.
- **Energy Transfer** – The relocation of energy from one place to another.
- **Energy Transformation** – Also known as energy conversion, the process of changing energy from one form to another.
- **Entropy** – A measure of the disorder or randomness in a system; tends to increase over time.
- **Equilibrium** – When the size and direction of all forces acting on an object are exactly balanced so the net force is equal to zero.
- **Field Force** – The region of space surrounding a body within which it can exert a force on another similar body not in contact with it.
- **Field Lines** – A series of lines that represent the strength and direction of an electric, magnetic, or electromagnetic field.
- **Focus (plural = foci)** – The point(s) where rays meet after being reflected or refracted; also the two points used to define an ellipse.
- **Force** – The push or pull on an object with mass that causes it to change its velocity.
- **Free Body Diagram** – A graphical illustration used to visualize the applied forces and resulting reactions on a body.
- **Freezing** – The process in which a liquid turns into a solid when cooled.
- **Frequency** – The inverse of the period; the number of cycles per unit of time (usually a second).
- **Friction** – Force that resists the sliding or rolling of one object over another.
- **Gamma Rays** – A type of electromagnetic radiation with much shorter wavelengths than visible light.
- **Gas** – A state of matter where particles move rapidly and are far apart, expanding to fill its container.
- **Gravitational Acceleration (g)** – The constant acceleration an object experiences during freefall; average value on Earth is 9.81 m/s^2.
- **Gravitational Constant (G)** – The proportionality constant used in Newton's Law of Gravitation, measured in Nm^2/kg^2.
- **Gravitational Potential Energy** – The energy acquired by an object due to a change in its position when present in a gravitational field.
- **Gravity** – An invisible force that pulls objects toward each other.
- **Heat** – The transfer of energy from a warmer object to a cooler object due to a difference in temperature.
- **Heat Conduction** – The transfer of heat through physical contact.
- **Heat Convection** – The transfer of heat through the movement of fluids (liquids or gases).
- **Heat Radiation** – Process by which energy is emitted by a heated surface in the form of electromagnetic radiation.
- **Induction** – The process of generating electrical current in a conductor by placing it in a changing magnetic field.
- **Inelastic Collision** – A collision in which there is a loss of kinetic energy, though momentum is conserved.
- **Inertia** – A property of matter by which it remains at rest or in unchanging motion unless acted on by an external force.
- **Infrared** – Radiation that falls between microwaves and visible light in the electromagnetic spectrum.
- **Interference** – A phenomenon where two waves superimpose to form a resultant wave of greater or lesser amplitude.

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- **Ionizing Radiation** – Radiation with enough energy to knock electrons out of atoms, creating ions.
- **Joule** – The SI unit of work or energy, equal to the work done by a force of one Newton moving one meter.
- **Kelvin** – The SI base unit of thermodynamic temperature.
- **Kinetic Energy** – The energy an object possesses because of its motion.
- **Law of Conservation of Energy** – Energy can neither be created nor destroyed, only converted from one form to another.
- **Law of Conservation of Momentum** – Total momentum before a collision is equal to the total momentum after the collision.
- **Light Energy** – A type of electromagnetic radiation that can be seen by the human eye.
- **Liquid** – A state of matter where particles are close but move freely, taking the shape of the container.
- **Lost Energy** – Energy converted into unusable forms (like heat or sound) during a transfer.
- **Macroscopic Scale** – Objects and events large enough to be visible with the naked eye.
- **Magnetic Field** – The region around a magnetic material or moving charge where magnetic force acts.
- **Magnetic Field Line** – An imaginary line representing the direction and strength of a magnetic field.
- **Magnetic Flux** – The number of magnetic field lines passing through a given closed surface.
- **Magnitude** – A quantity, number, or amount; the measure of force or strength.
- **Mass** – A scalar measurement of the quantity of matter.
- **Mechanical Energy** – The sum of kinetic and potential energy in a system.
- **Medium** – A material that moves energy or light from one location to another.
- **Melting** – The process in which a solid turns into a liquid when heated.
- **Microscopic Scale** – Scale of objects requiring a lens or microscope to be seen.
- **Microwaves** – Electromagnetic radiation falling between radio waves and infrared.
- **Molecular Energy** – The total energy contained within a molecule.
- **Momentum** – A product of mass and velocity ($p = mv$).
- **Motion** – Change with time of the position or orientation of a body.
- **Net Force** – The combined effect of all forces acting on an object.
- **Non-conservative** – A system where mechanical energy is not conserved, often dissipated as heat.
- **Normal Force** – The force that surfaces exert to prevent solid objects from passing through each other.
- **Orbit** – A regular, repeating path that one object in space takes around another.
- **Origin** – A position that is (0,0) or the starting point of a vector on a graph.
- **Perfect Elastic Collision** – A collision where all momentum and kinetic energy are conserved.
- **Perfect Inelastic Collision** – A collision where all momentum is conserved, but kinetic energy is not.
- **Period** – The time it takes for one complete cycle or oscillation to occur.
- **Permanent Magnet** – A material where the magnetic field is generated by its own internal structure.

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- **Phase Change** – A physical change between different states of matter (e.g., solid to liquid).
- **Plasma** – A high-energy state of matter consisting of charged particles (ions and electrons).
- **Polarity** – The property of having distinct, opposite poles or charges.
- **Position** – Measures a point at a particular time within a frame of reference.
- **Potential Difference** – The difference in energy that charge carriers have between two points; also known as voltage.
- **Potential Energy** – Stored energy that depends upon the relative position of parts of a system.
- **Projectile** – An object that once projected continues in motion by its own inertia and is influenced only by gravity.
- **Proton** – A subatomic particle with a positive charge found in the nucleus.
- **Radiation** – The emission of energy in the form of electromagnetic waves or subatomic particles.
- **Radio Waves** – Electromagnetic radiation with much longer wavelengths than visible light.
- **Resistance** – The degree to which a substance opposes the passage of an electric current.
- **Resultant** – The resulting vector from the addition of two or more vectors.
- **Revolution** – The circular motion of an object around another object.
- **Right-Hand Rule** – A convention that predicts the direction of fields relative to each other.
- **Risk Mitigation** – An approach to reduce the impact or probability of a risk.
- **Rotation** – The circular motion of an object around a central axis.
- **Satellite** – An object that orbits a larger object.
- **Scalar** – A quantity or amount that has magnitude but no direction.
- **Semi-major Axis** – Half the length of the longest axis of an ellipse.
- **Semi-minor Axis** – The shorter half of an ellipse's diameter.
- **Solid** – A state of matter where particles are tightly packed in a fixed shape.
- **Sound Energy** – Energy transmitted through a medium in the form of waves.
- **Specific Heat / Capacity** – The amount of heat required to raise the temperature of a unit mass by 1°C.
- **Speed** – A scalar quantity; the magnitude of velocity at an instant in time.
- **Speed of Light (c)** – Exactly 299,792,458 m/s in a vacuum.
- **Speed of Sound** – How fast a sound wave is passed from particle to particle through a medium.
- **States of Matter** – The physical forms of matter: solid, liquid, gas, and plasma.
- **Sublimation** – Solid changing directly into a gas without becoming a liquid.
- **System** – A collection of objects identified to make a problem easier to analyze.
- **Temperature** – A measure of the average kinetic energy of the particles in a substance.
- **Tension** – Pulling or stretching force along an object like a rope or chain.
- **Tesla** – A unit of magnetic field strength.

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- **Thermal Energy** – The total kinetic energy of particles in a substance.
- **Trajectory** – The path an object takes as it moves through space.
- **Transformer** – A device that changes alternating voltage to a different value.
- **Ultraviolet** – Radiation falling between visible light and X-rays.
- **Unbalanced Force** – Forces not equal in magnitude that cause an object to accelerate.
- **Vacuum** – Space in which there is no matter.
- **Vector** – A quantity that has both magnitude and direction.
- **Velocity** – A quantity designating how fast and in what direction an object is moving.
- **Visible Light** – The segment of the electromagnetic spectrum the human eye can view.
- **Volt / Voltage** – Measurement of electric potential energy difference per unit charge.
- **Wave** – A disturbance that transfers energy and momentum through a medium.
- **Wave-Particle Duality** – The theory that waves can act like particles and vice versa.
- **Wave Source** – The location where a disturbance initiates.
- **Wave Velocity/Speed** – Distance traveled by a point on a wave in a given time interval.
- **Wavelength** – The distance from one crest to another (or trough to trough).
- **Weight** – Gravitational force of attraction; changes based on the strength of gravity.
- **Work** – The transfer of energy by a force acting on an object as it is displaced.
- **Work-Energy Theorem** – The work done by the net force on an object is equal to the change in its kinetic energy.
- **X-Rays** – Electromagnetic radiation falling between ultraviolet and gamma rays.