PUBLIC SCHOOLS OF EDISON TOWNSHIP

OFFICE OF CURRICULUM AND INSTRUCTION

# AP Physics C: Mechanics

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| Length of Course: | Term |
| Elective/Required: | Elective |
| Schools: | High Schools |
| Eligibility: | Grade 12 |
| Credit Value: | 6 Credits |
| Date Approved: | August 26, 2019 (Curriculum)<br>August 17, 2021 (Credit Value) |

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**Modifications will be made to accommodate IEP mandates for classified students.**

# STATEMENT OF PURPOSE

The AP Physics C: Mechanics curriculum was written in accordance to College Board requirements. The course is designed to be the equivalent of the first semester college calculus-based physics course.

The course covers Newtonian mechanics (including rotational dynamics and angular momentum); work, energy, and power; gravitation and simple harmonic motion. The course is focused on a series of learning objectives that clarify the knowledge and skills students should demonstrate to qualify for college credit and placement. Each learning objective combines physics content with one or more of seven foundational science practices.

- The student can use representations and models to communicate scientific phenomena and solve scientific problems.
- The student can use mathematics appropriately.
- The student can engage in scientific questioning to extend thinking or to guide investigations within the context of the AP course.
- The student can plan and implement data collection strategies in relation to a particular scientific question.
- The student can perform data analysis and evaluation of evidence.
- The student can work with scientific explanations and theories.
- The student is able to connect and relate knowledge across various scales, concepts and representations in and across domains.)

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The curriculum guide was created by:
Snehal Patel (JPS)
Jonathan Mayes (JPS)

Science Supervisor:
Laurie Maier

# Course Objectives

By the end of the AP Physics C: Mechanics course, students will be able to:

- **(NJSLS/HS-PS2-1)** Analyze data to support the claim that Newton's second law of motion describes the mathematical relationship among the net force on a macroscopic object, its mass, and its acceleration.
- **(NJSLS/HS-PS2-2)** Use mathematical representations to support the claim that the total momentum of a system of objects is conserved when there is no net force on the system.
- **(NJSLS/HS-PS2-3)** Apply scientific and engineering ideas to design, evaluate, and refine a device that minimizes the force on a macroscopic object during a collision.
- **(NJSLS/HS-PS2-4)** Use mathematical representations of Newton's Law of Gravitation and Coulomb's Law to describe and predict the gravitational and electrostatic forces between objects.
- **(NJSLS/HS-PS2-5)** 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.
- **(NJSLS/HS-PS2-6)** Communicate scientific and technical information about why the molecular-level structure is important in the functioning of designed materials.
- **(NJSLS/HS-PS3-1)** Create a computational model to calculate the change in the energy of one component in a system when the change in energy of the other component(s) and energy flows in and out of the system are known.
- **(NJSLS/HS-PS3-2)** Develop and use 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 position of particles (objects).
- **(NJSLS/HS-PS3-3)** Design, build, and refine a device that works within given constraints to convert one form of energy into another form of energy.
- **(NJSLS/HS-PS3-5)** 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.
- **(NJSLS/HS-PS4-1)** Use mathematical representations to support a claim regarding relationships among the frequency, wavelength, and speed of waves traveling in various media.
- **(NJSLS/HS-PS4-2)** Evaluate questions about the advantages of using digital transmission and storage of information.
- **(NJSLS/HS-PS4-3)** 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.
- **(NJSLS/HS-PS4-4)** Evaluate the validity and reliability of claims in published materials of the effects that different frequencies of electromagnetic radiation have when absorbed by matter.
- **(NJSLS/HS-PS4-5)** 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.
- **(NJSLS/HS-ESS1-4)** Use mathematical or computational representations to predict the motion of orbiting objects in the solar system.

**Engineering Design**

- **(NJSLS/HS-ETS1-1)** Analyze a major global challenge to specify qualitative and quantitative criteria and constraints for solutions that account for societal needs and wants.
- **(NJSLS/HS-ETS1-2)** Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering.
- **(NJSLS/HS-ETS1-3)** Evaluate a solution to a complex real-world problem based on prioritized criteria and trade-offs that account for a range of constraints, including cost, safety, reliability, and aesthetics, as well as possible social, cultural, and environmental impacts.
- **(NJSLS/HS-ETS1-4)** Use a computer simulation to model the impact of proposed solutions to a complex real-world problem with numerous criteria and constraints on interactions within and between systems relevant to the problem

**Technology**

- **(8.1.12.A.2)** Produce and edit a multi-page digital document for commercial or professional audience and present it to peers and/or professionals in that related area for review.
- **(8.1.12.A.5)** Create a report from a relational database consisting of at least two tables and describe the process, and explain the report results.

**Career Ready Practices**

- **(CRP4)** Communicate clearly and effectively with reason
- **(CRP8)** Utilize critical thinking to make sense of problems and persevere in solving them
- **(CRP11)** Use technology to enhance productivity

**ELA/Literacy**

- **(WHST.9-12.7)** Conduct short as well as more sustained research projects to answer a question (including a self-generated question) or solve a problem; narrow or broaden the inquiry when appropriate; synthesize multiple sources on the subject, demonstrating understanding of the subject under investigation.
- **(WHST.11-12.8)** Gather relevant information from multiple authoritative print and digital sources, using advanced searches effectively; assess the strengths and limitations of each source in terms of the specific task, purpose, and audience; integrate information into the text selectively to maintain the flow of ideas, avoiding plagiarism and overreliance on any one source and following a standard format for citation.
- **(SL.11-12.5)** Make strategic use of digital media (e.g., textual, graphical, audio, visual, and interactive elements) in presentations to enhance understanding of findings, reasoning, and evidence and to add interest.
- **(WHST.9-12.7)** Conduct short as well as more sustained research projects to answer a question (including a self-generated question) or solve a problem; narrow or broaden the inquiry when appropriate; synthesize multiple sources on the subject, demonstrating understanding of the subject under investigation.

**Math**

- **(HSN-Q.A.1)** Use units as a way to understand problems and to guide the solution of multi-step problems; choose and interpret units consistently in formulas; choose and interpret the scale and the origin in graphs and data displays.
- **(HSN-Q.A.2)** Define appropriate quantities for the purpose of descriptive modeling.
- **(HSN-Q.A.3)** Choose a level of accuracy appropriate to limitations on measurement when reporting quantities.

# Topics

- Motion is relative to a reference frame. Speed is the scalar change in position over time. Velocity is the vector change of position over time and can be represented with a vector arrow. Acceleration is the vector change of velocity over time.

$$V = \frac{dx}{dt} \qquad a = \frac{dV}{dt} = \frac{d^2x}{dt^2} \qquad x = x_o + V_0\Delta t + \frac{1}{2}a\Delta t^2$$

- Many sources can exert a force on a system, and can be described with a free body diagram of force vectors. If $\Sigma F = 0$then $a = 0$ assuming a non-accelerating reference frame.
- There are 4 fundamental forces of nature; electromagnetic, gravitational, strong nuclear, and weak nuclear. Surfaces exert electromagnetic forces perpendicular (Normal) to and parallel (friction) to the surface, and they are related by the measured coefficient of friction. $F_{f_s} \leq \mu_s F_N$ $F_{f_k} = \mu_k F_N$ $\mu = \frac{F_f}{F_N}$
- Assuming a non-accelerating reference frame, a net force will accelerate a mass and change its momentum over time. Momentum is a conserved vector (translational symmetry).

$$a = \frac{\Sigma F}{m} \quad F_{2\ on\ 1} = -F_{1\ on\ 2} \qquad \Sigma F = \frac{dp}{dt} = \frac{mdV}{dt} = ma \qquad p = mV \qquad \Sigma p_i + \Delta p = \Sigma p_f$$

- Work changes energy, and both are conserved scalars (temporal symmetry). Only the components of net force and displacement in the same dimension yield work; opposite directions = negative work; same direction = positive work.

$$W = \int F \cdot dr = \Delta E \qquad \Sigma E_i + \Delta E = \Sigma E_f$$

  Work can change motion (kinetic energy $K = \frac{1}{2}mv^2$) or be 'stored' (potential energy) based on the type of force doing work. The force of friction either does work on a system or changes the thermal energy.
- Power is the time rate at which work is done or energy is transferred.

$$P = \frac{dE}{dt} = \Sigma F \cdot V$$

- 2D vectors can be broken down into two 1D vectors with perpendicular dimensions (e.g. horizontal and vertical) which are independent using trigonometry then annotated separately. Examples of 2D motion are objects in motion on a ramp, on flat turns, on banked turns, circularly swinging on a string, projectiles, and orbits.
- For curved and circular motion such as projectiles and orbitals, a system must have a net centripetal force exerted on it perpendicular to the direction of a velocity component toward the center of curvature.
  For uniform circular motion where the velocity vector is entirely perpendicular to the net centripetal force $a_c = \frac{V^2}{r}$ $\quad V = 2\pi rf \quad f = \frac{1}{T} \quad \omega = 2\pi f = 2\pi\frac{1}{T}$
- The gravitational force is determined by the mass of the source, the mass of the system, the distance between them squared, and the gravitational constant which is measured by experiment. G is the fundamental constant of the gravitational interaction in our universe.

$$F_g = G\frac{M_{source}m_{system}}{r^2} = m_{system}g \qquad G = 6.67x10^{-11}\frac{m^3}{kg\ s^2}$$

  Gravitational field vectors help us predict gravitational forces as there is no contact between the source and system mass.

$$g = \frac{F_g}{m_{system}} = 9.8\frac{N}{kg}\ on\ Earth's\ surface \qquad a = g\ if\ \Sigma F = F_g$$

Work done separating system and source masses becomes bound gravitational potential energy. Projectiles and orbitals only have the gravitational force changing their motion, with a component of velocity perpendicular to the gravitational force.

Kepler's 1st, 2nd: equal areas in equal time, 3rd: $\frac{r^2}{T^3} = \frac{r'^2}{T'^3}$around the same mass.

- Repetitive motions can describe position as a portion of a total repetition (angle) instead of a position because the object will occupy the same position many times during its motion. Repetitive motions are described with angular velocity and angular acceleration
$$\theta = \theta_0 + \omega_0 \Delta t + \frac{1}{2}\alpha \Delta t^2.$$
- Systems occupy a nonzero space, not just a point as we had previously assumed. A distributed system can spin around its center of mass, rotationally moving relative to itself. Center of mass is the mean location at which the mass of a system is located. We account for distribution of mass with the moment of inertia scalar. Moment of inertia represents a resistance to changes in angular velocity or angular momentum, and determines the amount of angular acceleration that will be caused by a net torque exerted on a system
$$I = \int_0^m r^2\, dm.$$
- To analyze and evaluate a distributed system moving repetitively we use moment of inertia, angles, angular velocity, angular acceleration, torque, angular momentum, and rotational kinetic energy instead of mass, position, velocity, acceleration, force, momentum, and energy respectively.
$$\alpha = \frac{\Sigma\tau}{I} \quad \tau = F \times r_{moment} \qquad \Sigma\tau = \frac{dL}{dt} = I\alpha$$
- A massive system attached to the end of a spring will repetitively move when stretched or compressed then released due to the restoring force the spring exerts on the mass toward the spring's equilibrium position.

$F_{spring\ on\ system} = -k\Delta x \quad \omega_s = \sqrt{\frac{k}{m}}$ For a pendulum $\omega_p = \sqrt{\frac{g}{L}}$.

- Waves are a repetitive disturbance which translate energy without translating matter. Transverse waves oscillate perpendicular to the direction of motion (sine waves) and longitudinal waves oscillate parallel to the direction of motion. Waves have an amplitude, period, frequency, wavelength, and wave velocity. The source or creator of a wave determines the frequency and amplitude. The medium the wave travels through determines wave speed. Wavelength depends on frequency and velocity.
$$\lambda = \frac{v}{f}$$
Amplitudes add when waves occupy the same location, called superposition or interference. Possible standing waves within a medium are called harmonics. Transverse waves interfering with themselves create a standing wave. Similar frequencies interfere to create a beat frequency $f_{beat} = |f_1 - f_2|$. Sound is a longitudinal wave.The intensity (loudness) of sound decreases as sound propagates due to the sound wave having to cover a larger area. $I \sim \frac{1}{r^2}$
- Two different electric charges, which are conventionally referred to as positive charge and negative charge, determine how charged objects interact. Charge is conserved. Electric forces are exerted by electric fields created by charges.
$$F_e = k\frac{Q_{source}q_{system}}{\triangle x^2} = Eq_{system} \quad \varepsilon_o = 8.85\ x\ 10^{-12} C^2/Nm^2 \quad k = 9x10^9 Nm^2/C^2$$

$$\Delta U_e = q\Delta V = \int F_e \cdot \Delta x = F_e . dr \quad U_e = qV = \text{k}\frac{Q_{source}q_{system}}{\triangle x}$$

$$E = \frac{F_e}{q_{system}} = \frac{\Delta V}{\Delta x} = k\frac{Q_{source}}{\triangle x^2} \quad V = \frac{U_e}{q_{system}}$$

The particles which make up atoms are neutrons with no charge and positive protons in the nucleus, and negative electrons outside the central nucleus.

$|q_e| = 1.6\text{x}10^{-19}$ C $m_p = 1.673\text{x}10^{-27}$ kg = $938.3\text{x}10^8$ eV $m_n = 1.675\text{x}10^{-27}$ kg = $939.6\text{x}10^8$ eV

$m_e = 9.11$ x $10^{-31}$ kg = 5.11 x $10^5$ eV 1 u = 1.66 x $10^{-27}$ kg = 931 MeV/$c^2$

An object can either allow the flow of electrons (conductor), not allow the flow of electrons (insulator), or somewhat allow the flow of electrons (semiconductor).

- When analyzing extended charged systems we analyze the amount of E-field which permeates an area of the system or of a hypothetical surface (called a Gaussian surface). Gauss' Law $\Phi_E = EA = \oint EdA = \frac{Q}{\varepsilon_o}$
- Oppositely charged parallel plates create a uniform electric field between the plates and store energy are called capacitors. The ability to store charge or energy in a capacitor is capacitance, which is based on materials placed in the capacitor called dielectrics (quantified by a constant) and the shape of the capacitor.

$$C = \kappa\varepsilon_o\frac{A}{\Delta x} \qquad Q = C\Delta V \qquad U_c = \frac{1}{2}Q\Delta V = \frac{1}{2}C\Delta V^2$$

Multiple capacitors have an equivalent capacitance based on their configuration.

$$C_p = \sum C \qquad \frac{1}{C_s} = \sum\frac{1}{C}$$

- Electric circuits are conductors connecting a voltage source (like a battery or generator) to a resistor which uses that voltage to convert electric energy to another form.

The amount of charge which flows over time is called electric current $= \frac{\Delta Q}{\Delta t} = \frac{dQ}{dt}$ .

Current in a circuit is dependent on the voltage provided to the circuit's resistors $I = \frac{\Delta V}{R}$.

Voltage used by resistors is dependent on the current and resistance $\Delta V = IR$.

The electromotive force abbreviated as EMF [$\varepsilon$] is the ideal potential difference provided by a battery if it had no internal resistance. $\Delta V_{terminal} = \varepsilon - Ir_{internal}$

- Resistance of an object is dependent on the shape and size of the object, along with the resistivity the material it is made from as $R = \rho\frac{l}{A}$.

Multiple resistors can be simplified to a single equivalent resistance.

$$R_{series} = \sum R \qquad \frac{1}{R_{parallel}} = \sum\frac{1}{R}$$

- Due to conservation of charge, all currents going into a junction must be the same as all currents leaving a junction. This is called Kirchoff's junction rule.

$$\Sigma I_{in\ junction} = \Sigma I_{out\ junction}$$

Due to conservation of energy, the sum of all voltages in any loop is zero. This is called Kirchoff's loop rule.

$$\Delta V_{loop} = 0$$

- Magnetic fields are created by changing electric fields and exert magnetic force on changing electric fields.

$$\mu_o = 4\pi\ x\ 10^{-7} Tm/A \qquad B = \frac{\mu_o I}{2\pi r} \qquad F_m = qv\ x\ B \qquad F_m = Il\ x\ B$$

Similarly, a changing magnetic flux over time creates a voltage.

$$\Phi_B = BA = \oint BdA \quad \varepsilon = \frac{\Delta\Phi_B}{\Delta t} = \frac{d\Phi_B}{dt}$$

- The speed of light/EM waves is c=299792458 m/s regardless of observer's frame of reference. This makes space and time dependent on velocity.

$$\gamma = \frac{1}{\sqrt{1 - v^2/c^2}}$$
$$L = L_0/\gamma$$
$$\Delta t = \Delta t_0 \gamma$$
$$u = \frac{v + u'}{1 + vu'/c^2}$$

$$E = mc^2$$
$$E = \sqrt{p^2c^2 + m_0^2c^4}$$
$$m = m_0\gamma$$

- Light has wave and particle characteristics, as does everything else. It has a quantized energy like a particle. It also has a frequency and can interfere like a wave. It has neither a position and momentum simultaneously with precision, nor an energy and duration. This is described by Heisenberg's uncertainty principle. Evidence for this is shown in the double slit experiment, blackbody radiation's 'ultraviolet catastrophe', and the photoelectric effect

$$E_{photon} = hf$$
$$K_{max} = E_{photon} - \phi_{work}$$
$$\lambda = \frac{h}{p}$$

$$\Delta p \Delta x \geq \frac{h}{4\pi}$$
$$\Delta E \Delta t \geq \frac{h}{4\pi}$$
$$h = 6.63x10^{-34}Js = 4.14x10^{-15}eVs$$

Unit of Study: Quarter 1: Translations

## Targeted State Standards:

(NJSLS/HS-PS2-1) Analyze data to support the claim that Newton's second law of motion describes the mathematical relationship among the net force on a macroscopic object, its mass, and its acceleration.
(NJSLS/HS-PS2-2) Use mathematical representations to support the claim that the total momentum of a system of objects is conserved when there is no net force on the system.
(NJSLS/HS-PS2-3) Apply scientific and engineering ideas to design, evaluate, and refine a device that minimizes the force on a macroscopic object during a collision.
(NJSLS/HS-PS3-1) Create a computational model to calculate the change in the energy of one component in a system when the change in energy of the other component(s) and energy flows in and out of the system are known.
(NJSLS/HS-PS3-2) Develop and use 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 position of particles (objects).
(NJSLS/HS-PS3-3) Design, build, and refine a device that works within given constraints to convert one form of energy into another form of energy.
(NJSLS/HS-ETS1-1) Analyze a major global challenge to specify qualitative and quantitative criteria and constraints for solutions that account for societal needs and wants.
(NJSLS/HS-ETS1-2) Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering.
(NJSLS/HS-ETS1-3) Evaluate a solution to a complex real-world problem based on prioritized criteria and trade-offs that account for a range of constraints, including cost, safety, reliability, and aesthetics, as well as possible social, cultural, and environmental impacts.
(NJSLS/HS-ETS1-4) Use a computer simulation to model the impact of proposed solutions to a complex real-world problem with numerous criteria and constraints on interactions within and between systems relevant to the problem
(WHST.9-12.7) Conduct short as well as more sustained research projects to answer a question (including a self-generated question) or solve a problem; narrow or broaden the inquiry when appropriate; synthesize multiple sources on the subject, demonstrating understanding of the subject under investigation.
(WHST.11-12.8) Gather relevant information from multiple authoritative print and digital sources, using advanced searches effectively; assess the strengths and limitations of each source in terms of the specific task, purpose, and audience; integrate information into the text selectively to maintain the flow of ideas, avoiding plagiarism and overreliance on any one source and following a standard format for citation.
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(HSN-Q.A.1) Use units as a way to understand problems and to guide the solution of multi-step problems; choose and interpret units consistently in formulas; choose and interpret the scale and the origin in graphs and data displays.
(HSN-Q.A.2) Define appropriate quantities for the purpose of descriptive modeling.
(HSN-Q.A.3) Choose a level of accuracy appropriate to limitations on measurement when reporting quantities.
(8.1.12.A.2) Produce and edit a multi-page digital document for commercial or professional audience and present it to peers and/or professionals in that related area for review.
(8.1.12.A.5) Create a report from a relational database consisting of at least two tables and describe the process, and explain the report results.
(CRP4) Communicate clearly and effectively with reason
(CRP8). Utilize critical thinking to make sense of problems and persevere in solving them.
(CRP11) Use technology to enhance productivity.

## Unit Objectives/Enduring Understandings: (Students will be able to.....)

- Motion is relative to a reference frame. Speed is change in position over time. Velocity is the vector change of position over time and can be represented with a vector arrow. Acceleration is the vector change of velocity over time.

  $$V = \frac{dx}{dt} \qquad a = \frac{dV}{dt} = \frac{d^2x}{dt^2} \qquad x = x_o + V_0\Delta t + \frac{1}{2}a\Delta t^2$$

- Many sources can exert a force on a system, and can be described with a free body diagram of force vectors. If $\Sigma F = 0$then $a = 0$ assuming a non-accelerating reference frame.
- There are 4 fundamental forces of nature; electromagnetic, gravitational, strong nuclear, and weak nuclear. Surfaces exert electromagnetic forces perpendicular (Normal) to and parallel (friction) to the surface, and they are related by the measured coefficient of friction. $F_{f_s} \leq \mu_s F_N$ $F_{f_k} = \mu_k F_N$ $\mu = \frac{F_f}{F_N}$
- Assuming a non-accelerating reference frame, a net force will accelerate a mass and change it's momentum over time. Momentum is a conserved vector (translational symmetry).

  $$a = \frac{\Sigma F}{m} \qquad F_{2\ on\ 1} = -F_{1\ on\ 2} \qquad \Sigma F = \frac{dp}{dt} = \frac{mdV}{dt} = ma \qquad p = mV \qquad \Sigma p_i + \Delta p = \Sigma p_f$$

- Work changes energy, and both are conserved scalars (temporal symmetry). Only the components of net force and displacement in the same dimension yield work; opposite directions = negative work; same direction = positive work.

$$W = \int F \cdot dr = \Delta E \qquad \Sigma E_i + \Delta E = \Sigma E_f$$

Work can change motion (kinetic energy $K = \frac{1}{2}mv^2$) or be 'stored' (potential energy) based on the type of force doing work. The force of friction either does work on a system or changes the thermal energy.

- Power is the time rate at which work is done or energy is transferred.

$$P = \frac{dE}{dt} = \Sigma F \cdot V$$

**Essential Questions:** What defines motion? How is motion modeled? What happens when objects collide and how can this be avoided or mitigated?

**Big Idea:**

1. Change: Interactions produce changes in motion.
2. Force Interactions: Forces characterize interactions between objects or systems.
4. Conservation: Conservation laws constrain interactions.

**Unit Assessment:** (What is the authentic evidence that students have achieved the targeted standards/unit objectives?)
Quarterly Exam
Class Assessments

| Concepts | Skills | Progress Indicators | Activities/Strategies<br>Technology Implementation/ Interdisciplinary Connections | Assessment Check Points |
|---|---|---|---|---|
| PS2.A: Forces and Motion<br>Newton's second law accurately predicts changes in the motion of macroscopic objects. (HS-PS2-1)<br>Momentum is defined for a particular frame of reference; it is the mass times the velocity of the object. (HS-PS2-2)<br>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 momentum of objects outside the system. (HS-PS2-2),(HS-PS2-3)<br><br>PS3.A: Definitions of Energy<br>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. (HS-PS3-1),(HS-PS3-2)<br>At the macroscopic scale, energy | Planning and Carrying Out Investigations<br>Planning and carrying out investigations to answer questions or test solutions to problems in 9–12 builds on K–8 experiences and progresses to include investigations that provide evidence for and test conceptual, mathematical, physical and empirical models.<br>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. (HS-PS2-5)<br><br>Analyzing and Interpreting Data<br>Analyzing data in 9–12 builds on K–8 and progresses to introducing more detailed statistical analysis, the | Patterns<br>Different patterns may be observed at each of the scales at which a system is studied and can provide evidence for causality in explanations of phenomena. (HS-PS2-4)<br>Cause and Effect<br>Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects. (HS-PS2- 1),(HS-PS2-5)<br>Systems can be designed to cause a desired effect. (HS-PS2-3)<br><br>Systems and System Models<br>When investigating or describing a system, the boundaries and initial conditions of the system need to be defined. (HS-PS2-2)<br>Structure and Function<br>Investigating or designing new systems or structures requires a detailed examination of the properties of different materials, the structures of different components, and connections of | Simulations<br>Modelling and measurement software<br>Graphic organizers and visualizations<br>Live experiments with equipment<br>Individual/Group Problem Solving (textbook, AP practice problems, problems involving interdisciplinary connections)<br>Halliday textbook problems - Chapter(s) 1,2,3,5,6,7,8,9 | Formative Assessments<br>Summative Assessments<br>Performance Assessments<br>Laboratory Investigations |

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| manifests itself in multiple ways, such as in motion, sound, light, and thermal energy. (HS-PS3-2) (HS-PS3-3)<br><br>PS3.B: Conservation of Energy and Energy Transfer<br>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. (HS-PS3-1)<br>Energy cannot be created or destroyed, but it can be transported from one place to another and transferred between systems. (HS-PS3-1),(HS-PS3-4)<br>Mathematical expressions, which quantify how the 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. (HS-PS3-1)<br>The availability of energy limits what can occur in any system. (HS-PS3-1)<br>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). (HS-PS3-4)<br><br>PS3.D: Energy in Chemical Processes<br>Although energy cannot be destroyed, it can be converted to less useful forms—for example, to thermal energy in the surrounding environment. (HS-PS3-3),(HS-PS3-4)<br><br>ETS1.A: Defining and Delimiting an Engineering Problem<br>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. (secondary to HS-PS2-3)<br>Humanity faces major global | comparison of data sets for consistency, and the use of models to generate and analyze data.<br>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. (HS-PS2-1)<br><br>Using Mathematics and Computational Thinking<br>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.<br>Use mathematical representations of phenomena to describe explanations. (HS-PS2-2),(HS-PS2-4)<br><br>Constructing Explanations and Designing Solutions<br>Constructing explanations and designing solutions in 9–12 builds on K–8 experiences and progresses to explanations and designs that are supported by multiple and independent student- generated sources of evidence consistent with scientific ideas, principles, and theories.<br>Apply scientific ideas to solve a design problem, taking into account possible unanticipated effects. (HS-PS2-3)<br><br>Obtaining, Evaluating, and Communicating Information<br>Obtaining, evaluating, and communicating information in 9–12 builds on K–8 and progresses to evaluating the validity and reliability of the claims, methods, | components to reveal its function and/or solve a problem. (HS-PS2-6)<br>Cause and Effect<br>Cause and effect relationships can be suggested and predicted for complex natural and human designed systems by examining what is known about smaller scale mechanisms within the system. (HS-PS3-5)<br>Systems and System Models<br>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. (HS-PS3-4)<br>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. (HS- PS3-1)<br>Energy and Matter<br>Changes of energy and matter in a system can be described in terms of energy and matter flows into, out of, and within that system. (HS- PS3-3)<br>Energy cannot be created or destroyed—only moves between one place and another place, between objects and/or fields, or between systems. (HS-PS3-2) | | |

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| challenges today, such as the need for supplies of clean water and food or for energy sources that minimize pollution, which can be addressed through engineering. These global challenges also may have manifestations in local communities. (HS-ETS1-1)<br><br>ETS1.B: Developing Possible Solutions<br>When evaluating solutions, it is important to take into account a range of constraints, including cost, safety, reliability, and aesthetics, and to consider social, cultural, and environmental impacts. (HS-ETS1-3)<br>Both physical models and computers can be used in various ways to aid in the engineering design process. Computers are useful for a variety of purposes, such as running simulations to test different ways of solving a problem or to see which one is most efficient or economical; and in making a persuasive presentation to a client about how a given design will meet his or her needs. (HS-ETS1-4)<br><br>ETS1.C: Optimizing the Design Solution<br>Criteria may need to be broken down into simpler ones that can be approached systematically, and decisions about the priority of certain criteria over others (trade-offs) may be needed. (secondary to HS-PS2-3) | and designs.<br>Communicate scientific and technical information (e.g. about the process of development and the design and performance of a proposed process or system) in multiple formats (including orally, graphically, textually, and mathematically). | | | |

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| Resources: Essential Materials, Supplementary Materials, Links to Best Practices<br>Experimental equipment pertinent to lab activities.<br>Computer Simulations and Software<br>Video Experiments<br>Fundamentals of Physics, Halliday and Resnick | Instructional Adjustments: Modifications, student difficulties, possible misunderstandings<br>Graphic organizers<br>Pre-attentive visual representations<br>Curriculum outline |

Clarification Statement: Assessment and instruction will focus on both qualitative and quantitative predictive models from patterns in data, and analyses of same.

Assessment Boundary: Assessment on topics covered in this and previous section’s standards excluding all topics pertaining to relativistic or quantum mechanics or requiring multivariable calculus.

## Targeted State Standards:

(NJSLS/HS-PS2-1) Analyze data to support the claim that Newton's second law of motion describes the mathematical relationship among the net force on a macroscopic object, its mass, and its acceleration.
(NJSLS/HS-PS2-2) Use mathematical representations to support the claim that the total momentum of a system of objects is conserved when there is no net force on the system.
(NJSLS/HS-PS2-3) Apply scientific and engineering ideas to design, evaluate, and refine a device that minimizes the force on a macroscopic object during a collision.
(NJSLS/HS-PS2-4) Use mathematical representations of Newton's Law of Gravitation and Coulomb's Law to describe and predict the gravitational and electrostatic forces between objects.
(NJSLS/HS-PS3-1) Create a computational model to calculate the change in the energy of one component in a system when the change in energy of the other component(s) and energy flows in and out of the system are known.
(NJSLS/HS-PS3-2) Develop and use 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 position of particles (objects).
(NJSLS/HS-PS3-3) Design, build, and refine a device that works within given constraints to convert one form of energy into another form of energy.
(NJSLS/HS-ESS1-4) Use mathematical or computational representations to predict the motion of orbiting objects in the solar system.
(NJSLS/HS-ETS1-1) Analyze a major global challenge to specify qualitative and quantitative criteria and constraints for solutions that account for societal needs and wants.
(NJSLS/HS-ETS1-2) Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering.
(NJSLS/HS-ETS1-3) Evaluate a solution to a complex real-world problem based on prioritized criteria and trade-offs that account for a range of constraints, including cost, safety, reliability, and aesthetics, as well as possible social, cultural, and environmental impacts.
(NJSLS/HS-ETS1-4) Use a computer simulation to model the impact of proposed solutions to a complex real-world problem with numerous criteria and constraints on interactions within and between systems relevant to the problem
(WHST.9-12.7) Conduct short as well as more sustained research projects to answer a question (including a self-generated question) or solve a problem; narrow or broaden the inquiry when appropriate; synthesize multiple sources on the subject, demonstrating understanding of the subject under investigation.
(WHST.11-12.8) Gather relevant information from multiple authoritative print and digital sources, using advanced searches effectively; assess the strengths and limitations of each source in terms of the specific task, purpose, and audience; integrate information into the text selectively to maintain the flow of ideas, avoiding plagiarism and overreliance on any one source and following a standard format for citation.
(SL.11-12.5) Make strategic use of digital media (e.g., textual, graphical, audio, visual, and interactive elements) in presentations to enhance understanding of findings, reasoning, and evidence and to add interest.
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(HSN-Q.A.2) Define appropriate quantities for the purpose of descriptive modeling.
(HSN-Q.A.3) Choose a level of accuracy appropriate to limitations on measurement when reporting quantities.
(8.1.12.A.2) Produce and edit a multi-page digital document for commercial or professional audience and present it to peers and/or professionals in that related area for review.
(8.1.12.A.5) Create a report from a relational database consisting of at least two tables and describe the process, and explain the report results.
(CRP4) Communicate clearly and effectively with reason
(CRP8). Utilize critical thinking to make sense of problems and persevere in solving them.
(CRP11) Use technology to enhance productivity.

## Unit Objectives/Enduring Understandings: (Students will be able to.....)

- 2D vectors can be broken down into two 1D vectors with perpendicular dimensions (e.g. horizontal and vertical) which are independent using trigonometry then annotated separately. Examples of 2D motion are objects in motion on a ramp, flat turns, banked turns, circularly swinging on a string, projectiles, and orbits.
- For curved and circular motion such as projectiles and orbitals, a system must have a net centripetal force exerted on it perpendicular to the direction of a velocity component toward the center of curvature.

  For uniform circular motion where the velocity vector is entirely perpendicular to the net centripetal force $a_c = \frac{V^2}{r}$ $\quad V = 2\pi r f$ $\quad f = \frac{1}{T}$ $\quad \omega = 2\pi f = \frac{1}{2\pi T}$
- The gravitational force is determined by the mass of the source, the mass of the system, the distance between them squared, and the gravitational constant which is measured by experiment. G is the fundamental constant of the gravitational interaction in our universe.

  $$F_g = G\frac{M_{source}m_{system}}{r^2} = m_{system}g \qquad G = 6.67x10^{-11}\frac{m^{\ 3}}{kg\,s^2}$$

  Gravitational field vectors help us predict gravitational forces as there is no contact between the source and system mass.

  $$g = \frac{F_g}{m_{system}} = 9.8\frac{N}{kg}\ on\ Earth's\ surface \qquad a = g\ if\ \Sigma F = F_g$$

  Work done separating system and source masses becomes bound gravitational potential energy.

Projectiles and orbitals only have the gravitational force changing their motion, with a component of velocity perpendicular to the gravitational force.

Kepler's 1st, 2nd: equal areas in equal time, 3rd: $\frac{r^2}{T^3} = \frac{r'^2}{T'^3}$around the same mass.

- Repetitive motions can describe position as a portion of a total repetition (angle) instead of a position because the object will occupy the same position many times during its motion. Repetitive motions are described with angular velocity and angular acceleration $\theta = \theta_0 + \omega_0 \Delta t + \frac{1}{2}\alpha \Delta t^2$.
- Systems occupy a nonzero space, not just a point as we had previously assumed. A distributed system can spin around its center of mass, rotationally moving relative to itself. Center of mass is the mean location at which the mass of a system is located. We account for distribution of mass with the moment of inertia scalar. Moment of inertia represents a resistance to changes in angular velocity or angular momentum, and determines the amount of angular acceleration that will be caused by a net torque exerted on a system $I = \int_0^m r^2 dm$.
- To analyze and evaluate a distributed system moving repetitively we use moment of inertia, angles, angular velocity, angular acceleration, torque, angular momentum, and rotational kinetic energy instead of mass, position, velocity, acceleration, force, momentum, and energy respectively.

$$\alpha = \frac{\Sigma\tau}{I} \quad \tau = F \times r_{moment} \quad \Sigma\tau = \frac{dL}{dt} = I\alpha$$

- A massive system attached to the end of a spring will repetitively move when stretched or compressed then released due to the restoring force the spring exerts on the mass toward the spring's equilibrium position. $F_{spring\ on\ system} = -k\Delta x$ $\omega_s = \sqrt{\frac{k}{m}}$ For a pendulum $\omega_p = \sqrt{\frac{g}{L}}$
- Waves are a repetitive disturbance which translate energy without translating matter. Transverse waves oscillate perpendicular to the direction of motion (sine waves) and longitudinal waves oscillate parallel to the direction of motion. Waves have an amplitude, period, frequency, wavelength, and wave velocity. The source or creator of a wave determines the frequency and amplitude. The medium the wave travels through determines wave speed. Wavelength depends on frequency and velocity.

$$\lambda = \frac{v}{f}$$

Amplitudes add when waves occupy the same location, called superposition or interference. Transverse waves interfering with themselves create a standing wave. Possible standing waves within a medium are called harmonics.

**Essential Questions:** How do we keep track of time? Why do objects orbit around each other in space?

## Big Idea:

1. Change: Interactions produce changes in motion.
2. Force Interactions: Forces characterize interactions between objects or systems.
3. Fields: Fields predict and describe interactions.
4. Conservation: Conservation laws constrain interactions.

**Unit Assessment:** (What is the authentic evidence that students have achieved the targeted standards/unit objectives?)

Quarterly Exam
Class Assessments

| Concepts | Skills | Progress Indicators | Activities/Strategies<br>Technology Implementation/ Interdisciplinary Connections | Assessment Check Points |
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| PS2.A: Forces and Motion<br>Newton's second law accurately predicts changes in the motion of macroscopic objects. (HS-PS2-1)<br>Momentum is defined for a particular frame of reference; it is the mass times the velocity of the object. (HS-PS2-2)<br>If a system interacts with objects outside itself, the total momentum of the system can change; | Planning and Carrying Out Investigations<br>Planning and carrying out investigations to answer questions or test solutions to problems in 9–12 builds on K–8 experiences and progresses to include investigations that provide evidence for and test conceptual, mathematical, physical and empirical models. | Patterns<br>Different patterns may be observed at each of the scales at which a system is studied and can provide evidence for causality in explanations of phenomena. (HS-PS2-4)<br>Cause and Effect<br>Empirical evidence is required to differentiate between cause and correlation and make claims | Simulations<br>Modelling and measurement software<br>Graphic organizers and visualizations<br>Live experiments with equipment<br>Individual/Group Problem Solving (textbook, AP practice problems, problems involving interdisciplinary connections) | Formative Assessments<br>Summative Assessments<br>Performance Assessments<br>Laboratory Investigations |

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| however, any such change is balanced by changes in the momentum of objects outside the system. (HS-PS2-2),(HS-PS2-3)<br><br>PS3.A: Definitions of Energy<br>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. (HS-PS3-1),(HS-PS3-2)<br>At the macroscopic scale, energy manifests itself in multiple ways, such as in motion, sound, light, and thermal energy. (HS-PS3-2)(HS-PS3-3)<br><br>PS3.B: Conservation of Energy and Energy Transfer<br>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. (HS-PS3-1)<br>Energy cannot be created or destroyed, but it can be transported from one place to another and transferred between systems. (HS-PS3-1),(HS-PS3-4)<br>Mathematical expressions, which quantify how the 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. (HS-PS3-1)<br>The availability of energy limits what can occur in any system. (HS-PS3-1)<br>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 | 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. (HS-PS2-5)<br><br>Analyzing and Interpreting Data<br>Analyzing data in 9–12 builds on K–8 and progresses to introducing more detailed statistical analysis, the comparison of data sets for consistency, and the use of models to generate and analyze data.<br>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. (HS-PS2-1)<br><br>Using Mathematics and Computational Thinking<br>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.<br>Use mathematical representations of phenomena to describe explanations. (HS-PS2-2),(HS-PS2-4)<br><br>Constructing Explanations and Designing Solutions<br>Constructing explanations and designing solutions in 9–12 builds on K–8 experiences and | about specific causes and effects. (HS-PS2- 1),(HS-PS2-5)<br>Systems can be designed to cause a desired effect. (HS-PS2-3)<br><br>Systems and System Models<br>When investigating or describing a system, the boundaries and initial conditions of the system need to be defined. (HS-PS2-2)<br>Structure and Function<br>Investigating or designing new systems or structures requires a detailed examination of the properties of different materials, the structures of different components, and connections of components to reveal its function and/or solve a problem. (HS-PS2-6)<br>Cause and Effect<br>Cause and effect relationships can be suggested and predicted for complex natural and human designed systems by examining what is known about smaller scale mechanisms within the system. (HS-PS3-5)<br>Systems and System Models<br>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. (HS-PS3-4)<br>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. (HS- PS3-1)<br>Energy and Matter<br>Changes of energy and matter in a system can be described in terms of energy and matter flows into, out of, and within that system. (HS- PS3-3)<br>Energy cannot be created or destroyed—only moves between one place and another place, between objects and/or fields, or between systems. (HS-PS3-2) | Halliday textbook problems - Chapter(s) 4,6,10,11,12,13 | |

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| environment cool down). (HS-PS3-4)<br><br>PS3.D: Energy in Chemical Processes<br>Although energy cannot be destroyed, it can be converted to less useful forms—for example, to thermal energy in the surrounding environment. (HS-PS3-3),(HS-PS3-4)<br><br>ETS1.A: Defining and Delimiting an Engineering Problem<br>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. (secondary to HS-PS2-3)<br>Humanity faces major global challenges today, such as the need for supplies of clean water and food or for energy sources that minimize pollution, which can be addressed through engineering. These global challenges also may have manifestations in local communities. (HS-ETS1-1)<br><br>ETS1.B: Developing Possible Solutions<br>When evaluating solutions, it is important to take into account a range of constraints, including cost, safety, reliability, and aesthetics, and to consider social, cultural, and environmental impacts. (HS-ETS1-3)<br>Both physical models and computers can be used in various ways to aid in the engineering design process. Computers are useful for a variety of purposes, such as running simulations to test different ways of solving a problem or to see which one is most efficient or economical; and in making a persuasive presentation to a client about how a given design will meet his or her needs. (HS-ETS1-4) | progresses to explanations and designs that are supported by multiple and independent student- generated sources of evidence consistent with scientific ideas, principles, and theories.<br>Apply scientific ideas to solve a design problem, taking into account possible unanticipated effects. (HS-PS2-3)<br><br>Obtaining, Evaluating, and Communicating Information<br>Obtaining, evaluating, and communicating information in 9–12 builds on K–8 and progresses to evaluating the validity and reliability of the claims, methods, and designs.<br>Communicate scientific and technical information (e.g. about the process of development and the design and performance of a proposed process or system) in multiple formats (including orally, graphically, textually, and mathematically). | | | |

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| ETS1.C: Optimizing the Design Solution<br>Criteria may need to be broken down into simpler ones that can be approached systematically, and decisions about the priority of certain criteria over others (trade-offs) may be needed. (secondary to HS-PS2-3) | | | | |

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(NJSLS/HS-PS2-4) Use mathematical representations of Newton's Law of Gravitation and Coulomb's Law to describe and predict the gravitational and electrostatic forces between objects.
(NJSLS/HS-PS2-5) 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.
(NJSLS/HS-PS2-6) Communicate scientific and technical information about why the molecular-level structure is important in the functioning of designed materials.
(NJSLS/HS-PS3-1) Create a computational model to calculate the change in the energy of one component in a system when the change in energy of the other component(s) and energy flows in and out of the system are known.
(NJSLS/HS-PS3-2) Develop and use 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 position of particles (objects).
(NJSLS/HS-PS3-3) Design, build, and refine a device that works within given constraints to convert one form of energy into another form of energy.
(NJSLS/HS-PS3-5) 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.
(NJSLS/HS-PS4-1) Use mathematical representations to support a claim regarding relationships among the frequency, wavelength, and speed of waves traveling in various media.
(NJSLS/HS-PS4-2) Evaluate questions about the advantages of using digital transmission and storage of information.
(NJSLS/HS-PS4-3) 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.
(NJSLS/HS-PS4-4) Evaluate the validity and reliability of claims in published materials of the effects that different frequencies of electromagnetic radiation have when absorbed by matter.
(NJSLS/HS-PS4-5) 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.
(NJSLS/HS-ESS1-4) Use mathematical or computational representations to predict the motion of orbiting objects in the solar system.
(NJSLS/HS-ETS1-1) Analyze a major global challenge to specify qualitative and quantitative criteria and constraints for solutions that account for societal needs and wants.
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(CRP4) Communicate clearly and effectively with reason
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(CRP11) Use technology to enhance productivity.

## Unit Objectives/Enduring Understandings: (Students will be able to.....)

- Two different electric charges, which are conventionally referred to as positive charge and negative charge, determine how charged objects interact. Charge is conserved. Electric forces are exerted by electric fields created by charges.

$$F_e = k\frac{Q_{source}q_{system}}{\triangle x^2} = Eq_{system} \quad \mathcal{E}_o = 8.85 \; x \; 10^{-12} C^2/Nm^2 \quad k = 9x10^9 Nm^2/C^2$$

$$\Delta U_e = q\Delta V = F_e \cdot \Delta x = \int F_e . dr \quad U_e = qV = k\frac{Q_{source}q_{system}}{\triangle x}$$

$$E = \frac{F_e}{q_{system}} = \frac{\Delta V}{\Delta x} = k\frac{Q_{source}}{\triangle x^2} \quad V = \frac{U_e}{q_{system}}$$

The particles which make up atoms are neutrons with no charge and positive protons in the nucleus, and negative electrons outside the central nucleus.

$|q_e| = 1.6x10^{-19}$ C $m_p = 1.673x10^{-27}$ kg = $938.3x10^8$ eV $m_n = 1.675x10^{-27}$ kg = $939.6x10^8$ eV

$m_e = 9.11 \; x \; 10^{-31}$ kg = $5.11 \; x \; 10^5$ eV 1 u = $1.66 \; x \; 10^{-27}$ kg = 931 MeV/$c^2$

An object can either allow the flow of electrons (conductor), not allow the flow of electrons (insulator), or somewhat allow the flow of electrons (semiconductor).

- When analyzing extended charged systems we analyze the amount of E-field which permeates an area of the system or of a hypothetical surface (called a Gaussian surface). Gauss' Law $\Phi_E = EA = \oint EdA = \frac{Q}{\varepsilon_o}$

- Oppositely charged parallel plates create a uniform electric field between the plates and store energy are called capacitors. The ability to store charge or energy in a capacitor is capacitance, which is based on materials placed in the capacitor called dielectrics (quantified by a constant) and the shape of the capacitor.

$$C = \kappa\varepsilon_o\frac{A}{\Delta x} Q = C\Delta V \quad U_c = \frac{1}{2}Q\Delta V = \frac{1}{2}C\Delta V^2$$

Multiple capacitors have an equivalent capacitance based on their configuration.

$$C_p = \sum C \quad \frac{1}{C_s} = \sum \frac{1}{C}$$

- Electric circuits are conductors connecting a voltage source (like a battery or generator) to a resistor which uses that voltage to convert electric energy to another form.
  The amount of charge which flows over time is called electric current $= \frac{\Delta Q}{\Delta t} = \frac{dQ}{dt}$ .
  Current in a circuit is dependent on the voltage provided to the circuit's resistors $I = \frac{\Delta V}{R}$.
  Voltage used by resistors is dependent on the current and resistance $\Delta V = IR$.
  The electromotive force abbreviated as EMF [$\mathcal{E}$] is the ideal potential difference provided by a battery if it had no internal resistance. $\Delta V_{terminal} = \varepsilon - Ir_{internal}$
- Resistance of an object is dependent on the shape and size of the object, along with the resistivity the material it is made from as $R = \rho\frac{l}{A}$.
  Multiple resistors can be simplified to a single equivalent resistance.

$$R_{series} = \sum R \quad \frac{1}{R_{parallel}} = \sum \frac{1}{R}$$

- Due to conservation of charge, all currents going into a junction must be the same as all currents leaving a junction. This is called Kirchoff's junction rule.

$$\Sigma I_{in\ junction} = \Sigma I_{out\ junction}$$

Due to conservation of energy, the sum of all voltages in any loop is zero. This is called Kirchoff's loop rule.

$$\Delta V_{loop} = 0$$

**Essential Questions:** Why does a smartphone charge faster when it isn't being used, but slow when it is? How do the outlets in a house work?

**Big Idea:**
1. Change: Interactions produce changes in motion.
2. Force Interactions: Forces characterize interactions between objects or systems.
3. Fields: Fields predict and describe interactions.
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**Unit Assessment:** (What is the authentic evidence that students have achieved the targeted standards/unit objectives?)
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| 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. (HS-PS3-1)<br>The availability of energy limits what can occur in any system. (HS-PS3-1)<br>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). (HS-PS3-4)<br><br>PS3.D: Energy in Chemical Processes<br>Although energy cannot be destroyed, it can be converted to less useful forms—for example, to thermal energy in the surrounding environment. (HS-PS3-3),(HS-PS3-4)<br><br>ETS1.A: Defining and Delimiting an Engineering Problem<br>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. (secondary to HS-PS2-3)<br>Humanity faces major global challenges today, such as the need for supplies of clean water and food or for energy sources that minimize pollution, which can be addressed through engineering. These global challenges also may have manifestations in local communities. (HS-ETS1-1)<br><br>ETS1.B: Developing Possible Solutions<br>When evaluating solutions, it is important to take into account a range of constraints, including cost, safety, reliability, and | analyze, represent, and model data. Simple computational simulations are created and used based on mathematical models of basic assumptions.<br>Use mathematical representations of phenomena to describe explanations. (HS-PS2-2),(HS-PS2-4)<br><br>Constructing Explanations and Designing Solutions<br>Constructing explanations and designing solutions in 9–12 builds on K–8 experiences and progresses to explanations and designs that are supported by multiple and independent student- generated sources of evidence consistent with scientific ideas, principles, and theories.<br>Apply scientific ideas to solve a design problem, taking into account possible unanticipated effects. (HS-PS2-3)<br><br>Obtaining, Evaluating, and Communicating Information<br>Obtaining, evaluating, and communicating information in 9–12 builds on K–8 and progresses to evaluating the validity and reliability of the claims, methods, and designs.<br>Communicate scientific and technical information (e.g. about the process of development and the design and performance of a proposed process or system) in multiple formats (including orally, graphically, textually, and mathematically). | assumptions and approximations inherent in models. (HS- PS3-1)<br>Energy and Matter<br>Changes of energy and matter in a system can be described in terms of energy and matter flows into, out of, and within that system. (HS- PS3-3)<br>Energy cannot be created or destroyed—only moves between one place and another place, between objects and/or fields, or between systems. (HS-PS3-2) | | |

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| Resources: Essential Materials, Supplementary Materials, Links to Best Practices<br>Experimental equipment pertinent to lab activities.<br>Computer Simulations and Software<br>Video Experiments<br>Fundamentals of Physics, Halliday and Resnick | Instructional Adjustments: Modifications, student difficulties, possible misunderstandings<br>Graphic organizers<br>Pre-attentive visual representations<br>Curriculum outline |

Clarification Statement: Assessment and instruction will focus on both qualitative and quantitative predictive models from patterns in data, and analyses of same.

Assessment Boundary: Assessment on topics covered in this and previous section’s standards excluding all topics pertaining to relativistic or quantum mechanics or requiring multivariable calculus.

## Targeted State Standards:

(NJSLS/HS-PS2-1) Analyze data to support the claim that Newton's second law of motion describes the mathematical relationship among the net force on a macroscopic object, its mass, and its acceleration.
(NJSLS/HS-PS2-2) Use mathematical representations to support the claim that the total momentum of a system of objects is conserved when there is no net force on the system.
(NJSLS/HS-PS2-3) Apply scientific and engineering ideas to design, evaluate, and refine a device that minimizes the force on a macroscopic object during a collision.
(NJSLS/HS-PS2-4) Use mathematical representations of Newton's Law of Gravitation and Coulomb's Law to describe and predict the gravitational and electrostatic forces between objects.
(NJSLS/HS-PS2-5) 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.
(NJSLS/HS-PS2-6) Communicate scientific and technical information about why the molecular-level structure is important in the functioning of designed materials.
(NJSLS/HS-PS3-1) Create a computational model to calculate the change in the energy of one component in a system when the change in energy of the other component(s) and energy flows in and out of the system are known.
(NJSLS/HS-PS3-2) Develop and use 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 position of particles (objects).
(NJSLS/HS-PS3-3) Design, build, and refine a device that works within given constraints to convert one form of energy into another form of energy.
(NJSLS/HS-PS3-5) 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.
(NJSLS/HS-PS4-1) Use mathematical representations to support a claim regarding relationships among the frequency, wavelength, and speed of waves traveling in various media.
(NJSLS/HS-PS4-2) Evaluate questions about the advantages of using digital transmission and storage of information.
(NJSLS/HS-PS4-3) 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.
(NJSLS/HS-PS4-4) Evaluate the validity and reliability of claims in published materials of the effects that different frequencies of electromagnetic radiation have when absorbed by matter.
(NJSLS/HS-PS4-5) 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.
(NJSLS/HS-ESS1-4) Use mathematical or computational representations to predict the motion of orbiting objects in the solar system.
(NJSLS/HS-ETS1-1) Analyze a major global challenge to specify qualitative and quantitative criteria and constraints for solutions that account for societal needs and wants.
(NJSLS/HS-ETS1-2) Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering.
(NJSLS/HS-ETS1-3) Evaluate a solution to a complex real-world problem based on prioritized criteria and trade-offs that account for a range of constraints, including cost, safety, reliability, and aesthetics, as well as possible social, cultural, and environmental impacts.
(NJSLS/HS-ETS1-4) Use a computer simulation to model the impact of proposed solutions to a complex real-world problem with numerous criteria and constraints on interactions within and between systems relevant to the problem
(WHST.9-12.7) Conduct short as well as more sustained research projects to answer a question (including a self-generated question) or solve a problem; narrow or broaden the inquiry when appropriate; synthesize multiple sources on the subject, demonstrating understanding of the subject under investigation.
(WHST.11-12.8) Gather relevant information from multiple authoritative print and digital sources, using advanced searches effectively; assess the strengths and limitations of each source in terms of the specific task, purpose, and audience; integrate information into the text selectively to maintain the flow of ideas, avoiding plagiarism and overreliance on any one source and following a standard format for citation.
(SL.11-12.5) Make strategic use of digital media (e.g., textual, graphical, audio, visual, and interactive elements) in presentations to enhance understanding of findings, reasoning, and evidence and to add interest.
(WHST.9-12.7) Conduct short as well as more sustained research projects to answer a question (including a self-generated question) or solve a problem; narrow or broaden the inquiry when appropriate; synthesize multiple sources on the subject, demonstrating understanding of the subject under investigation.
(HSN-Q.A.1) Use units as a way to understand problems and to guide the solution of multi-step problems; choose and interpret units consistently in formulas; choose and interpret the scale and the origin in graphs and data displays.
(HSN-Q.A.2) Define appropriate quantities for the purpose of descriptive modeling.
(HSN-Q.A.3) Choose a level of accuracy appropriate to limitations on measurement when reporting quantities.
(8.1.12.A.2) Produce and edit a multi-page digital document for commercial or professional audience and present it to peers and/or professionals in that related area for review.
(8.1.12.A.5) Create a report from a relational database consisting of at least two tables and describe the process, and explain the report results.
(CRP4) Communicate clearly and effectively with reason
(CRP8). Utilize critical thinking to make sense of problems and persevere in solving them.
(CRP11) Use technology to enhance productivity.

## Unit Objectives/Enduring Understandings: (Students will be able to.....)

- Magnetic fields are created by changing electric fields and exert magnetic force on changing electric fields.

$\mu_o = 4\pi \, x \, 10^{-7} Tm/A$ $\quad B = \frac{\mu_o I}{2\pi r}$ $\quad F_m = qv \, x \, B$ $\quad F_m = Il \, x \, B$

Similarly, a changing magnetic flux over time creates a voltage.

$$\Phi_B = BA = \oint BdA \qquad \varepsilon = \frac{d\Phi_B}{dt}$$

- The speed of light/EM waves is c=299792458 m/s regardless of observer's frame of reference. This makes space and time dependent on velocity.

$$\gamma = \frac{1}{\sqrt{1-v^2/c^2}} \qquad L = L_0/\gamma \qquad \Delta t = \Delta t_0\gamma \qquad u = \frac{v+u\prime}{1+vu\prime/c^2}$$

$$E = mc^2 \qquad E = \sqrt{p^2c^2 + m_0^2c^4} \qquad m = m_0\gamma$$

- Light has wave and particle characteristics, as does everything else. It has a quantized energy like a particle. It also has a frequency and can interfere like a wave. It has neither a position and momentum simultaneously with precision, nor an energy and duration. This is described by Heisenberg's uncertainty principle. Evidence for this is shown in the double slit experiment, blackbody radiation's 'ultraviolet catastrophe', and the photoelectric effect.

$$E_{photon} = hf \qquad K_{max} = E_{photon} - \phi_{work}$$

$$\lambda = \frac{h}{p} \qquad \Delta p\Delta x \geq \frac{h}{4\pi} \qquad \Delta E\Delta t \geq \frac{h}{4\pi} \qquad h = 6.63x10^{-34}Js = 4.14x10^{-15}eVs$$

**Essential Questions:** How do we communicate quickly and share information "instantly" with each other to become more of a global society? How can we depend less on non-renewable energy sources to become a more responsible society?

**Big Idea:**

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