FREEHOLD REGIONAL HIGH SCHOOL DISTRICT
OFFICE OF CURRICULUM AND INSTRUCTION
SCIENCE DEPARTMENT CURRICULUM

ADVANCED PLACEMENT PHYSICS 2

Grade Level: 11-12

Credits: 5

BOARD OF EDUCATION ADOPTION DATE: August 28, 2024

FREEHOLD REGIONAL HIGH SCHOOL DISTRICT

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Advanced Placement Physics 2		
Course Description		
AP Physics 2 is an algebra-based, introductory college-level physics course. Students cultivate their understanding of Physics through inquiry-based investigations as they explore topics such as fluid statics and dynamics; thermodynamics with kinetic theory; PV diagrams and probability; electrostatics; electrical circuits with capacitors; magnetic fields; electromagnetism; physical and geometric optics; and quantum, atomic, and nuclear physics.		
Course Sequence and Pacing		
Unit Title	**Section Focus**	**Suggested Pacing**
UNIT 9: Thermodynamics	Topic 9.1 Kinetic Theory of Temperature and Pressure Topic 9.2 The Ideal Gas Law Topic 9.3 Thermal Energy Transfer and Equilibrium Topic 9.4 The First Law of Thermodynamics Topic 9.5 Specific Heat and Thermal Conductivity Topic 9.6 Entropy and the Second Law of Thermodynamics	17 Sessions
UNIT 10: Electric Force, Field, and Potential	Topic 10.1 Electric Charge and Electric Force Topic 10.2 Conservation of Electric Charge and the Process of Charging Topic 10.3 Electric Fields Topic 10.4 Electric Potential Energy Topic 10.5 Electric Potential Topic 10.6 Capacitors Topic 10.7 Conservation of Electric Energy	18 Sessions
UNIT 11: Electric Circuits	Topic 11.1 Electric Current Topic 11.2 Simple Circuits Topic 11.3 Resistance, Resistivity, and Ohm's Law Topic 11.4 Electric Power Topic 11.5 Compound Direct Current (DC) Circuits Topic 11.6 Kirchhoff's Loop Rule Topic 11.7 Kirchhoff's Junction Rule Topic 11.8 Resistor-Capacitor (RC) Circuits	18 Sessions
UNIT 12: Magnetism and Electromagnetism	Topic 12.1 Magnetic Fields Topic 12.2 Magnetism and Moving Charges Topic 12.3 Magnetism and Current-Carrying Wires Topic 12.4 Electromagnetic Induction and Faraday's Law	15-16 Sessions
UNIT 13: Geometric Optics	Topic 13.1 Reflection Topic 13.2 Images Formed by Mirrors Topic 13.3 Refraction Topic 13.4 Images Formed by Lenses	11-12 Sessions
UNIT 14: Waves, Sound, and Physical Optics	Topic 14.1 Properties of Wave Pulses and Waves Topic 14.2 Periodic Waves Topic 14.3 Boundary Behavior of Waves and Polarization Topic 14.4 Electromagnetic Waves Topic 14.5 The Doppler Effect Topic 14.6 Wave Interference and Standing Waves Topic 14.7 Diffraction Topic 14.8 Double-Slit Interference and Diffraction Gratings Topic 14.9 Thin-Film Interference	18 Sessions

UNIT 15: Modern Physics	Topic 15.1 Quantum Theory and Wave-Particle Duality Topic 15.2 The Bohr Model of Atomic Structure Topic 15.3 Emission and Absorption Spectra Topic 15.4 Blackbody Radiation Topic 15.5 The Photoelectric Effect Topic 15.6 Compton Scattering Topic 15.7 Fission, Fusion, and Nuclear Decay Topic 15.8 Types of Radioactive Decay	19-20 Sessions

Support Resources

Supporting resources and appendices for this curriculum are available. These include a Resource Catalog of standards-aligned activities, common formative assessment and interdisciplinary items for performance expectations and objectives in this course.

- AP Computer Physics 2 Resource Catalog
- Appendix A: Accommodations and Modifications for Various Student Populations
- Appendix B: Assessment Evidence
- Appendix C: Interdisciplinary Connections

Advanced Placement Physics 2 **UNIT 9: Thermodynamics** **Suggested Unit Pacing: 17 Sessions** **Topic 9.1 Kinetic Theory of Temperature and Pressure**
NJSLS-S Performance Expectations
9.1.A Describe the pressure a gas exerts on its container in terms of atomic motion within that gas.
9.1.B Describe the temperature of a system in terms of the atomic motion within that system.
Standards-Aligned Objectives. Instruction and assessment will align to the following objectives:
Atoms in a gas collide with and exert forces on other atoms in the gas and with the container in which the gas is contained. i. Collisions involving pairs of atoms or an atom and a fixed object, can be described and analyzed using conservation of momentum principles. ii. The pressure exerted by a gas on a surface is the ratio of the sum of the magnitudes of the perpendicular components of the forces exerted by the gas's atoms on the surface to the area of the surface. Relevant equation: $P = F_{\perp}/A$ iii. Pressure exists throughout the gas itself, not just at the boundary between the gas and the container. APP2 9-1[1] Derive a mathematical expression for the pressure of a gas on the walls of its container using impulse and momentum. ($P = (N2mv/At) = 1/3\ (Nmv^2)/V$) APP2 9-1[2] Calculate the pressure of a gas
The temperature of a system is characterized by the average kinetic energy of the atoms within that system. i. The Maxwell-Boltzmann distribution provides a graphical representation of the energies and speeds of atoms at a given temperature. ii. The root-mean-square speed corresponding to the average kinetic energy for an ideal gas is related to the temperature of the gas by Relevant equation: APP2 9-1[3] Describe how the distribution of energies and speeds of an ideal gas change as temperature changes. APP2 9-1[4] Calculate the rms speed of an atom for an ideal gas at a specific temperature APP2 9-1[5] Use semi quantitative reasoning to compare the temperature and rms speed of an ideal gas

Advanced Placement Physics 2 **UNIT 9: Thermodynamics** **Suggested Unit Pacing: 17 Sessions** **Topic 9.2 The Ideal Gas Law**
NJSLS-S Performance Expectations
9.2.A Describe the properties of an ideal gas.
Standards-Aligned Objectives. Instruction and assessment will align to the following objectives:
The classical model of an ideal gas assumes that the instantaneous velocities of atoms are random, the volumes of the atoms are negligible compared to the total volume occupied by the gas, the atoms collide elastically, and the only appreciable forces on the atoms are those that occur during collisions. APP2 9-2[1] Identify the conditions necessary for a gas to be considered "ideal".

An ideal gas is one in which the relationships between pressure, volume, the number of moles or number of atoms, and temperature of a gas can be modeled using the equation $PV = nRT = Nk_bT$. APP2 9-2[2] Apply the Ideal Gas Law to determine the unknown variable for a situation involving an ideal gas.
Graphs modeling the pressure, temperature, and volume of gasses can be used to describe or determine properties of that gas. APP2 9-2[3] Draw and interpret different thermodynamics processes of an ideal gas using P-V graphs
A temperature at which an ideal gas has zero pressure can be extrapolated from a graph of pressure as a function of temperature. APP 2 9-2[4] Interpret pressure as a function of temperature using the ideal gas law

Advanced Placement Physics 2 **UNIT 9: Thermodynamics** **Suggested Unit Pacing: 17 Sessions** **Topic 9.3 Thermal Energy Transfer and Equilibrium**
NJSLS-S Performance Expectations
9.3.A Describe the transfer of energy between two systems in thermal contact due to temperature differences of those two systems.
Standards-Aligned Objectives. Instruction and assessment will align to the following objectives:
Two systems are in thermal contact if the systems may transfer energy by thermal processes. i. Heating is the transfer of energy into a system by thermal processes. ii. Cooling is the transfer of energy out of a system by thermal processes. APP2 9-3[1] Define heating and cooling as a transfer of thermal energy between the system and its environment. APP2 9-3[2] Explain how the heating and cooling process occurs on an atomic/particle level. APP2 9-3[3] Differentiate between heating, cooling, thermal energy, internal energy, and temperature.
The thermal processes by which energy may be transferred between systems at different temperatures are conduction, convection, and radiation. APP2 9-3[4] Differentiate between conduction, convection, and radiation.
Energy is transferred through thermal processes spontaneously from a higher-temperature system to a lower-temperature system. i. In collisions between atoms from different systems, energy is most likely to be transferred from higher-energy atoms to lower-energy atoms. ii. After many collisions of atoms from different systems, the most probable state is one in which both systems have the same temperature. APP2 9-3[5] Explain how the thermal energy of a high temperature system and a low temperature system will change via the collision of atoms/particles. APP2 9-3[6] Predict how the thermal energy of a high temperature system and a low temperature system will change when combined.
Thermal equilibrium results when no net energy is transferred by thermal processes between two systems in thermal contact with each other. APP2 9-3[7] Explain how two systems at different initial temperatures reach thermal equilibrium.

Advanced Placement Physics 2 **UNIT 9: Thermodynamics** **Suggested Unit Pacing: 17 Sessions** **Topic 9.4 The First Law of Thermodynamics**
NJSLS-S Performance Expectations
9.4.A Describe the internal energy of a system.
9.4.B Describe the behavior of a system using thermodynamic processes.
Standards-Aligned Objectives. Instruction and assessment will align to the following objectives:
The internal energy of a system is the sum of the kinetic energy of the objects that make up the system and the potential energy of the configuration of those objects. i. The atoms in an ideal gas do not interact with each other via conservative forces, and the internal structure is not considered. Therefore, an ideal gas does not have internal potential energy. ii. The internal energy of an ideal monatomic gas is the sum of the kinetic energies of the constituent atoms in the gas. Relevant equation: APP2 9-4[1] Differentiate between the kinetic energy of a particle and "n" number of particles with a rms speed. APP2 9-4[2] Justify that the internal energy is dependent on the temperature, not the mass of the particle. *APP2 9-3[3] Differentiate between heating, cooling, thermal energy, internal energy, and temperature.
Changes to a system’s internal energy can result in changes to the internal structure and internal behavior of that system without changing the motion of the system’s center of mass. APP2 9-4[3] Describe the effects a change in a system's energy has on its internal structure and internal behavior as well as how it may affect the motion of its center of mass.
The first law of thermodynamics is a restatement of conservation of energy that accounts for energy transferred into or out of a system by work, heating, or cooling. i. For an isolated system, the total energy is constant. ii. For a closed system, the change in internal energy is the sum of energy transferred to or from the system by heating, or work done on the system. Relevant equation: $\Delta U = Q + W$ iii. The work done on a system by a constant or average external pressure that changes the volume of that system (for example, a piston compressing a gas in a container) is defined as $W = -P\Delta V$. APP2 9-4[4] Represent the transfer of and changes in energies of a system for a thermodynamics process. APP2 9-4[5] Calculate the transfer of and changes in energies of an ideal gas for a thermodynamics process. APP2 9-4[6] Differentiate between the energy transfers into or out an ideal gas when a container expands or contracts. APP2 9-4[7] Calculate the work done on or by the gas given a PV graph.
Pressure-volume graphs (also known as PV diagrams) are representations used to represent thermodynamic processes. i. Lines of constant temperature on a PV diagram are called isotherms. ii. The absolute value of the work done on a gas when the gas expands or compresses is equal to the area underneath the curve of a plot of pressure vs. volume for the gas.

APP2 9-4[8] Draw and interpret P-V graphs representing different thermodynamic processes including isothermal, isobaric, isochoric/isovolumetric, and adiabatic processes. *APP2 9-4[7] Calculate the work done on or by the gas given a PV graph.
Special cases of thermal processes depend on the relationship between the configuration of the system, the nature of the work done on the system, and the system's surroundings. These include constant volume (isovolumetric), constant temperature (isothermal), and constant pressure (isobaric), as well as processes where no energy is transferred to or from the system through thermal processes (adiabatic). *APP2 9-4[8] Draw and interpret P-V graphs representing different thermodynamic processes including isothermal, isobaric, isochoric/isovolumetric, and adiabatic processes.

Advanced Placement Physics 2 **UNIT 9: Thermodynamics** **Suggested Unit Pacing: 17 Sessions** **Topic 9.5 Specific Heat and Thermal Conductivity**
NJSLS-S Performance Expectations
9.5.A Describe the energy required to change the temperature of an object by a certain amount.
9.5.B Describe the rate at which energy is transferred by conduction through a given material.
Standards-Aligned Objectives. Instruction and assessment will align to the following objectives:
The amount of energy required to change the temperature of a material is related to the material's specific heat. Relevant equation: $Q = mc\Delta T$ APP2 9-5[1] Define a substance's specific heat as the amount of energy required to change its temperature.
The specific heat of a material is an intrinsic property of that material that depends on the arrangement and interactions of the atoms that make up the material. APP2 9-5[2] Identify the characteristics of a substance that affect its specific heat (specifically the arrangement and interactions of the atoms that make up the substance)
The rate at which energy is transferred by conduction through a given material is related to the thermal conductivity, the physical dimensions of the material, and the temperature difference across the material. Relevant equation: APP2 9-5[3] Describe how the physical dimension of the material (length and cross sectional area) and the material itself impact the rate at which thermal energy is transferred.
The thermal conductivity of a material is an intrinsic property of that material that depends on the arrangement and interactions of the atoms that make up the material. *APP2 9-5[3] Describe how the physical dimension of the material (length and cross sectional area) and the material itself impact the rate at which thermal energy is transferred.

Advanced Placement Physics 2 **UNIT 9: Thermodynamics** **Suggested Unit Pacing: 17 Sessions**

Topic 9.6 Entropy and the Second Law of Thermodynamics
NJSLS-S Performance Expectations
9.6.A Describe the change in entropy for a given system over time.
Standards-Aligned Objectives. Instruction and assessment will align to the following objectives:
The second law of thermodynamics states that the total entropy of an isolated system can never decrease and is constant only when all processes the system undergoes are reversible. APP2 9-6[1] Describe how the organization of energy or the unavailability of a system's energy to do work changes through thermodynamics processes.
Entropy can be qualitatively described as the tendency of energy to spread or the unavailability of some of the system's energy to do work. i. Localized energy will tend to disperse and spread out. ii. Entropy is a state function and therefore only depends on the current state or configuration of a system, not how the system reached that state. iii. Maximum entropy occurs when a system is in thermodynamic equilibrium. *APP2 9-6[1] Describe how the organization of energy or the unavailability of a system's energy to do work changes through thermodynamics processes.
The change in a system's entropy is determined by the system's interactions with its surroundings. i. Closed systems spontaneously move toward thermodynamic equilibrium. ii. The entropy of a closed system never decreases, but the entropy of an open system can decrease because energy can be transferred into or out of the system. *APP2 9-6[1] Describe how the organization of energy or the unavailability of a system's energy to do work changes through thermodynamics processes.

Topic 10.1 Electric Charge and Electric Force
NJSLS-S Performance Expectations
10.1.A Describe the electric force that results from the interactions between charged objects or systems.
10.1.B Describe the electric and gravitational forces that result from interactions between charged objects with mass.
10.1.C Describe the electric permittivity of a material or medium.
Standards-Aligned Objectives. Instruction and assessment will align to the following objectives:
Charge is a fundamental property of all matter. i. Charge is described as positive or negative. ii. The magnitude of the charge of a single electron or proton, the elementary charge, can be considered to be the smallest divisible amount of charge. iii. The charge of an electron is −e, the charge of a proton is +e, and a neutron has no electric charge. iv. A point charge is a model in which the physical size of a charged object or system is negligible in the context of the situation being analyzed. APP2 10-1[1] Differentiate between the types of charges electron, proton and neutron. APP2 10-1[2] Differentiate between an electron, proton and neutron. APP2 10-1[3] Estimate and Calculate the number of electrons or protons on an object with an excess of charge. APP2 10-1[4] Model the excess charge an object has as a point charge.
Coulomb's law describes the electrostatic force between two charged objects as directly proportional to the magnitude of each of the charges and inversely proportional to the square of the distance between the objects. Relevant equation: APP2 10-1[5] Calculate the force exerted between two objects each with an excess charge. APP2 10-1[6] Predict how the force exerted between two objects, each with an excess charge, will change if the amount of charge and/or distance between each object changes by various factors.
The direction of the electrostatic force depends on the signs of the charges on the interacting objects and is parallel to the line of separation between the objects. i. Two objects with charges of the same sign exert repulsive forces on each other. ii. Two objects with charges of opposite signs exert attractive forces on each other. APP2 10-1[7] Represent and reason the direction of the net electrostatic force on an object with an excess of charge due to a number of other known charged objects.
Electric forces are responsible for some of the macroscopic properties of objects in everyday experiences. However, the large number of particle interactions that occur make it more convenient to treat everyday forces in terms of nonfundamental forces called contact forces, such as normal force, friction, and tension. APP2 10-1[8] Explain how electric forces are responsible for the macroscopic properties of systems using in everyday experiences.
Electrostatic forces can be attractive or repulsive, while gravitational forces are always attractive. APP2 10-1[9] Differentiate between the electric force and gravitational force.
For any two objects that have mass and electric charge, the magnitude of the gravitational force is usually much smaller than the magnitude of the electrostatic force.

APP2 10-1[10] Compare the relative strengths of the electric force and gravitational force for two objects with mass and charge.
Gravitational forces dominate at larger scales even though they are weaker than electrostatic forces, because systems at large scales tend to be electrically neutral. APP2 10-1[11] Explain why gravitational forces are dominant at large distances and electric forces are dominant at small distances.
Electric permittivity is a measurement of the degree to which a material or medium is polarized in the presence of an electric field. APP2 10-1[12] Differentiate between electrical conductors and electrical insulators.
Electric polarization can be modeled as the induced rearrangement of electrons by an external electric field, resulting in a separation of positive and negative charges within a material or medium. APP2 10-1[13] Define electric polarization as the rearrangement of electrons and therefore the separation of positive and negative charges within a material induced by the presence of an external electric field.
Free space has a constant value of electric permittivity, ε_0, that appears in physical relationships. APP2 10-1[14] Identify free space as a vacuum and therefore the absence of matter.
The permittivity of matter has a value different from that of free space that arises from the matter’s composition and arrangement. i. In a given material, electric permittivity is determined by the ease with which electrons can change configurations within the material. ii. Conductors are made from electrically conducting materials in which charge carriers move easily; insulators are made from electrically nonconducting materials in which charge carriers cannot move easily *APP2 10-1[12] Differentiate between electrical conductors and electrical insulators.

Advanced Placement Physics 2 **UNIT 10: Electric Force, Field, and Potential** **Suggested Unit Pacing: 18 Sessions** **Topic 10.2 Conservation of Electric Charge and the Process of Charging**
NJSLS-S Performance Expectations
10.2.A Describe the behavior of a system using conservation of charge.
Standards-Aligned Objectives. Instruction and assessment will align to the following objectives:
The net charge or charge distribution of a system can change in response to the presence of, or changes in, the net charge or charge distribution of other systems. i. The net charge of a system can change due to friction or contact between systems. ii. Induced charge separation occurs when the electrostatic force between two systems alters the distribution of charges within the systems, resulting in the polarization of one or both systems. iii. Induced charge separation can occur in neutral systems. APP2 10-2[1] Differentiate on a microscopic level what it means for an object to be neutral, positively charged, negatively charged and polarized. APP2 10-2[2] Reason how charges move within and transfer between materials. APP2 10-2[3] Represent/sketch/draw how charges transfer or rearrange via contact, induction and/or polarized.

APP2 10-2[4] Predict and justify how charged objects will interact via contact and/or polarized.
Any change to a system’s charge is due to a transfer of charge between the system and its surroundings. i. The charging of a system typically involves the transfer of electrons to and from the system. ii. The net charge of a system will be constant unless there is a transfer of charge to or from the system. *APP2 10-2[2] Reason how charges move within and transfer between materials. *APP2 10-2[3] Represent/sketch/draw how charges transfer or rearrange via contact, induction and/or polarized. *APP2 10-2[4] Predict and justify how charged objects will interact via contact and/or polarized.
Grounding involves electrically connecting a charged system to a much larger and approximately neutral system (e.g., Earth). *APP2 10-2[2] Reason how charges move within and transfer between materials. *APP2 10-2[3] Represent/sketch/draw how charges transfer or rearrange via contact, induction and/or polarized.

Advanced Placement Physics 2 **UNIT 10: Electric Force, Field, and Potential** **Suggested Unit Pacing: 18 Sessions** **Topic 10.3 Electric Fields**
NJSLS-S Performance Expectations
10.3.A Describe the electric field produced by a charged object or configuration of point charges.
10.3.B Describe the electric field generated by charged conductors or insulators.
Standards-Aligned Objectives. Instruction and assessment will align to the following objectives:
Electric fields may originate from charged objects. APP2 10-3[1] Identify the source of an electric field.
The electric field at a given point is the ratio of the electric force exerted on a test charge at that point to the charge of the test charge. Relevant equation: i. A test charge is a point charge of small enough magnitude such that its presence does not significantly affect an electric field in its vicinity. ii. An electric field points away from isolated positive charges and toward isolated negative charges. iii. The electric force exerted on a positive test charge by an electric field is in the same direction as the electric field. The electric force exerted on a negative test charge by an electric field is in the opposite direction of the electric field. APP2 10-3[2] Draw and interpret electric fields produced by a source charge. APP2 10-3[3] Differentiate between a source charge and a test charge. APP2 10-3[4] Calculate the strength and identify the direction of the electric field experienced by a test charge in the presence of a source charge.
The electric field is a vector quantity and can be represented in space using vector field maps. i. The net electric field at a given location is the vector sum of individual electric fields created by nearby charged objects. ii. Electric field maps use vectors to depict the magnitude and direction of the electric field at many locations within a given region.

iii. Electric field line diagrams are simplified models of electric field maps and can be used to determine the relative magnitude and direction of the electric field at any position in the diagram. APP2 10-3[5] Calculate the strength and identify the direction of the net electric field experienced by a test charge in the presence of multiple source charges. APP2 10-3[6] Draw and interpret electric field lines for a single source and multiple sources.
While in electrostatic equilibrium, the excess charge of a solid conductor is distributed on the surface of the conductor, and the electric field within the conductor is zero. i. At the surface of a charged conductor, the electric field is perpendicular to the surface. ii. The electric field outside an isolated sphere with spherically symmetric charge distribution is the same as the electric field due to a point charge with the same net charge as the sphere located at the center of the sphere. Relevant equation: APP2 10-3[7] Describe and sketch the distribution of electric charge for different shaped conducting materials. APP2 10-3[8] Draw the electric field within and around a conducting material.
While in electrostatic equilibrium, the excess charge of an insulator is distributed throughout the interior of the insulator as well as at the surface, and the electric field within the insulator may have a nonzero value. *APP2 10-3[7] Describe and sketch the distribution of electric charge for different shaped conducting materials. *APP2 10-3[8] Draw the electric field within and around a conducting material.

Advanced Placement Physics 2 **UNIT 10: Electric Force, Field, and Potential** **Suggested Unit Pacing: 18 Sessions** **Topic 10.4 Electric Potential Energy**
NJSLS-S Performance Expectations
10.4.A Describe the electric potential energy of a system.
Standards-Aligned Objectives. Instruction and assessment will align to the following objectives:
The electric potential energy of a system of two point charges equals the amount of work required for an external force to bring the point charges to their current positions from infinitely far away. APP2 10-4[1] Reasons that the electric potential energy of two charged objects approaches zero when they are an infinite distance apart. APP2 10-4[2] Describe how the signs of objects with an excess of charge and changes in distances will cause the electric potential energy to change. APP2 10-4[3] Calculate the amount of work done on a system of charged objects to move them to an infinite distance apart.
The general form for the electric potential energy of two charged objects is given by the equation Relevant equation. APP2 10-4[4] Calculate the electrical potential energy of two objects each with an excess charge. APP2 10-4[5] Reasons how the electrical potential energy of a system, each with an excess charge, will change if the amount of charge, the sign of the charge, and/or distance between each object changes by various factors.

The total electric potential energy of a system can be determined by finding the sum of the electric potential energies of the individual interactions between each pair of charged objects in the system. APP2 10-4[6] Calculate the electrical potential energy of a system with multiple objects, each with an excess charge. *APP2 10-4[5] Reasons how the electrical potential energy of a system, each with an excess charge, will change if the amount of charge, the sign of the charge, and/or distance between each object changes by various factors.

Advanced Placement Physics 2 **UNIT 10: Electric Force, Field, and Potential** **Suggested Unit Pacing: 18 Sessions** **Topic 10.5 Electric Potential**
NJSLS-S Performance Expectations
10.5.A Describe the electric potential due to a configuration of charged objects.
10.5.B Describe the relationship between electric potential and electric field.
Standards-Aligned Objectives. Instruction and assessment will align to the following objectives:
Electric potential describes the electric potential energy per unit charge at a point in space. APP2 10-5[1] Describe how spacetime is influenced in terms of electric potential energy per unit charge.
The electric potential due to multiple point charges can be determined by the principle of scalar superposition of the electric potential due to each of the point charges. Relevant equation: APP2 10-5[2] Draw and interpret electric potential field and equipotential lines produced by a source charge. APP2 10-5[3] Differentiate between a source charge and a test charge. APP2 10-5[4] Calculate the strength and identify the direction of the electric potential field experienced by a test charge in the presence of a source charge.
The electric potential difference between two points is the change in electric potential energy per unit charge when a test charge is moved between the two points. Relevant equation: $\Delta V = \Delta U_E/q$ i. Electric potential difference may also result from chemical processes that cause positive and negative charges to separate, such as in a battery. APP2 10-5[5] Calculate and describe the changes in electric potential energy of a system within an electric potential field.
When conductors are in electrical contact, electrons will be redistributed such that the surfaces of the conductors are at the same electric potential. APP2 10-5[6] Reason how electrons redistribute on the surface of a conductor. APP2 10-5[7] Describe how the electric potential of electrons distributed on the surface of a conductor is the same.
The average electric field between two points in space is equal to the electric potential difference between the two points divided by the distance between the two points. Relevant equation:

APP2 10-5[8] Derive a mathematical expression that represents the relationship between electric field and electric potential difference.

Advanced Placement Physics 2
UNIT 10: Electric Force, Field, and Potential **Suggested Unit Pacing: 18 Sessions**
Topic 10.6 Capacitors

NJSLS-S Performance Expectations

10.6.A Describe the physical properties of a parallel-plate capacitor.

Standards-Aligned Objectives. Instruction and assessment will align to the following objectives:

A parallel-plate capacitor consists of two separated parallel conducting surfaces that can hold equal amounts of charge with opposite signs.

APP2 10-6[1] Define a parallel-plate capacitor as two separated parallel conducting surfaces that can hold equal but opposite types of charge.

Capacitance relates the magnitude of the charge stored on each plate to the electric potential difference created by the separation of those charges.
Relevant equation:
$C = Q/\Delta V$
i. The capacitance of a capacitor depends only on the physical properties of the capacitor, such as the capacitor's shape and the material used to separate the plates.
ii. The capacitance of a parallel-plate capacitor is proportional to the area of one of its plates and inversely proportional to the distance between its plates. The constant of proportionality is the product of the dielectric constant, K, of the material between the plates and the electric permittivity of free space, ε_0.
Relevant equation:
$C = K\varepsilon_0(A/d)$

APP2 10-6[2] Identify the variables that affect the capacitance of a capacitor

APP2 10-6[3] Derive a mathematical expression that represents the relationship between capacitance, area of the plates and distance of separation between plates (and characteristics of the materials).

The electric field between two charged parallel plates with uniformly distributed electric charge, such as in a parallel-plate capacitor, is constant in both magnitude and direction, except near the edges of the plates.
i. The magnitude of the electric field between two charged parallel plates, where the plate separation is much smaller than the dimensions of the plates, can be described with the equation
$E_C = Q/(K\varepsilon_0 A)$.
ii. A charged particle between two oppositely charged parallel plates undergoes constant acceleration and therefore its motion shares characteristics with the projectile motion of an object with mass in the gravitational field near Earth's surface.

APP2 10-6[4] Calculate the electric field between two charged parallel plates with uniform distribution of charge.

APP2 10-6[5] Predict the motion of a charged particle between two equal but oppositely charged parallel plates.

The electric potential energy stored in a capacitor is equal to the work done by an external force to separate that amount of charge on the capacitor.

APP2 10-6[6] Determine the electric potential energy stored in a capacitor.

The electric potential energy stored in a capacitor is described by the equation $U_C = (1/2)Q\Delta V$.

*APP2 10-6[6] Determine the electric potential energy stored in a capacitor.

Adding a dielectric between two plates of a capacitor changes the capacitance of the capacitor and induces an electric field in the dielectric in the opposite direction to the field between the plates.

APP2 10-6[7] Describe how the presence of a dielectric (electrical insulator) may affect the capacitance of a capacitor

Advanced Placement Physics 2
UNIT 10: Electric Force, Field, and Potential **Suggested Unit Pacing: 18 Sessions**
Topic 10.7 Conservation of Electric Energy

NJSLS-S Performance Expectations

10.7.A Describe changes in energy in a system due to a difference in electric potential between two locations.

Standards-Aligned Objectives. Instruction and assessment will align to the following objectives:

When a charged object moves between two locations with different electric potentials, the resulting change in the electric potential energy of the object-field system is given by the following equation.
Relevant equation:
$\Delta U_E = q\Delta V$

APP2 10-7[1] Calculate the change in electric potential energy for a charge that has changed locations within the electric potential field.

The movement of a charged object between two points with different electric potentials results in a change in kinetic energy of the object consistent with the conservation of energy.

APP2 10-7[2] Apply the law of conservation of energy to determine the change in a charged object's kinetic energy between two points with different electric potentials.

Advanced Placement Physics 2

UNIT 11: Electric Circuits **Topic 11.1 Electric Current**	**Suggested Unit Pacing: 18 Sessions**

NJSLS-S Performance Expectations
11.1.A Describe the movement of electric charges through a medium.
Standards-Aligned Objectives. Instruction and assessment will align to the following objectives:
Current is the rate at which charge passes through a cross-sectional area of a wire. Relevant equation: $I = \Delta q/\Delta t$ i. Electric charge moves in a circuit in response to an electric potential difference, sometimes referred to as electromotive force, or emf (ε). ii. If the current is zero in a section of wire, the net motion of charge carriers in the wire is also zero, although individual charge carriers will not have zero speed. APP2 11-1[1] Describe current as the rate at which charge passed through the cross section area. APP2 11-1[2] Calculate the amount of charge that passes through a cross sectional area during a given interval of time. APP2 11-1[3] Differentiate between conventional current and the electron flow. APP2 11-1[4] Differentiate between the rms speed of charged particles and conventional current/electron drift.
Although current is not a vector quantity, it does have a direction. The direction of current is associated with what the motion of positive charge would be but not with any coordinate system in space. i. The direction of conventional current is chosen to be the direction in which positive charge would move. ii. In common circuits, current is actually due to the movement of electrons (negative charge carriers). *APP2 11-1[3] Differentiate between conventional current and the electron flow.

UNIT 11: Electric Circuits Topic 11.2 Simple Circuits	Suggested Unit Pacing: 18 Sessions
NJSLS-S Performance Expectations	
11.2.A Describe the behavior of a circuit.	
Standards-Aligned Objectives. Instruction and assessment will align to the following objectives:	
A circuit is composed of electrical loops, which may include circuit elements such as wires, batteries, resistors, lightbulbs, capacitors, switches, ammeters, and voltmeters. APP2 11-2[1] Use electric diagrams and symbols to represent electrical circuits with wires, batteries, lightbulbs, capacitors, switches, ammeters, and voltmeters.	
A closed electrical loop is a closed path through which charges may flow. i. A closed circuit is one in which charges would be able to flow. ii. An open circuit is one in which charges would not be able to flow. iii. A short circuit is one in which charges would be able to flow with no change in potential difference. APP2 11-2[2] Describe and differentiate to the current in closed conducting loop, open conducting loop, and a loop with no or little resistance	
A single circuit element may be part of multiple electrical loops. APP2 11-2[3] Identify the number of closed loops within a complex electrical circuit.	
Circuit schematics are representations used to describe and analyze electric circuits. i. The properties of an electric circuit are dependent on the physical arrangement of its constituent elements. ii. Circuit elements have common symbols that are used to create schematic diagrams. Variable elements are indicated by a diagonal strikethrough arrow across the standard symbol for that element. Circuit Element Diagrams APP2 11-2[4] Differentiate between electrical elements that are variable and those that maintain constant physical values.	

Advanced Placement Physics 2 UNIT 11: Electric Circuits Topic 11.3 Resistance, Resistivity, and Ohm's Law	Suggested Unit Pacing: 18 Sessions
NJSLS-S Performance Expectations	
11.3.A Describe the resistance of an object using physical properties of that object.	
11.3.B Describe the electrical characteristics of elements of a circuit.	
Standards-Aligned Objectives. Instruction and assessment will align to the following objectives:	
Resistance is a measure of the degree to which an object opposes the movement of electric charge. APP2 11-3[1] Describe how resistance will change due to the material of the conductor, the physical dimensions (length and cross sectional area), and the arrangement of electrical elements.	
The resistance of a resistor with uniform geometry is proportional to its resistivity and length and is inversely proportional to its cross-sectional area. Relevant equation:	

$R = \rho l/A$
i. Resistivity is a fundamental property of a material that depends on its atomic and molecular structure and quantifies how strongly the material opposes the motion of electric charge.
ii. The resistivity of a conductor typically increases with temperature.

APP2 11-3[2] Predict how changes in the resistivity, the length of the wire and/or the cross sectional area of the wire will change and by what factor.

APP2 11-3[3] Describe how the resistivity of a conductor increases with temperature.

Ohm's law relates current, resistance, and potential difference across a conductive element of a circuit.
Relevant equation:
$I = \Delta V/R$
i. Materials that obey Ohm's law have constant resistance for all currents and are called ohmic materials.
ii. The resistivity of an ohmic material is constant regardless of temperature.
iii. Resistors can also convert electrical energy to thermal energy, which may change the temperature of both the resistor and the resistor's environment.
iv. The resistance of an ohmic circuit element can be determined from the slope of a graph of the current in the element as a function of the potential difference across the element.

APP2 11-3[4] Predict and describe how changes in voltage and resistance will impact the current through a circuit

APP2 11-3[5] Differentiate between ohmic and non-ohmic resistors including the relationship between resistance, resistivity, and temperature of a material

APP2 11-3[6] Represent an ohmic resistor graphically

Advanced Placement Physics 2 **UNIT 11: Electric Circuits** **Suggested Unit Pacing: 18 Sessions** **Topic 11.4 Electric Power**
NJSLS-S Performance Expectations
11.4.A Describe the transfer of energy into, out of, or within an electric circuit, in terms of power.
Standards-Aligned Objectives. Instruction and assessment will align to the following objectives:
The rate at which energy is transferred, converted, or dissipated by a circuit element depends on the current in the element and the electric potential difference across it. Relevant equation: $P = I\Delta V$ Derived equations: $P = I^2R = (\Delta V)^2/R$ APP2 11-4[1] Predict and/or calculate the rate at which a circuit element dissipates electrical potential energy.
The brightness of a bulb increases with power, so power can be used to qualitatively predict the brightness of bulbs in a circuit. APP2 11-4[2] Predict the brightness of a bulb given its configuration in a circuit.

Advanced Placement Physics 2 **UNIT 11: Electric Circuits** **Suggested Unit Pacing: 18 Sessions** **Topic 11.5 Compound Direct Current (DC) Circuits**
NJSLS-S Performance Expectations
11.5.A Describe the equivalent resistance of multiple resistors connected in a circuit.
11.5.B Describe a circuit with resistive wires and a battery with internal resistance.
11.5.C Describe the measurement of current and potential difference in a circuit.
Standards-Aligned Objectives. Instruction and assessment will align to the following objectives:
Circuit elements may be connected in series and/or in parallel. i. A series connection is one in which any charge passing through one circuit element must proceed through all elements in that connection and has no other path available. The current in each element in series must be the same. ii. A parallel connection is one in which charges may flow through one of two or more paths. Across each path, the potential difference is the same. APP2 11-5[1] Describe, model and calculate the current in a series and parallel circuit.
A collection of resistors in a circuit may be analyzed as though it were a single resistor with an equivalent resistance R_{eq}. i. The equivalent resistance of a set of resistors in series is the sum of the individual resistances. Relevant equation: ii. The inverse of the equivalent resistance of a set of resistors connected in parallel is equal to the sum of the inverses of the individual resistances. Relevant equation: iii. When resistors are connected in parallel, the number of paths available to charges increases, and the equivalent resistance of the group of resistors decreases. APP2 11-5[2] Derive and calculate equivalent resistance of resistance in series and parallel APP2 11-5[3] Reason what happens to the equivalent resistance and subsequent current in a circuit when resistors are in parallel.
Ideal batteries have negligible internal resistance. Ideal wires have negligible resistance. i. The resistance of wires that are good conductors may normally be neglected, because their resistance is much smaller than that of other elements of a circuit. ii. The resistance of wires may only be neglected if the circuit contains other elements that do have resistance. iii. The potential difference a battery would supply if it were ideal is the potential difference measured across the terminals when there is no current in the battery and is sometimes referred to as its emf (ε). APP2 11-5[4] Determine when you can assume that the resistance of wires can be considered negligible.
The internal resistance of a nonideal battery may be treated as the resistance of a resistor in series with an ideal battery and the remainder of the circuit. APP2 11-5[5] Determine the internal resistance of a battery.
When there is current in a nonideal battery with internal resistance r, the potential difference across the terminals of the battery is reduced relative to the potential difference when there is no current in the battery. Derived equation: $\Delta V_{terminal} = \varepsilon - Ir$ *APP2 11-5[5] Determine the internal resistance of a battery.
Ammeters are used to measure current at a specific point in a circuit.

i. Ammeters must be connected in series with the element in which current is being measured. ii. Ideal ammeters have zero resistance so that they do not affect the current in the element that they are in series with. APP2 11-5[6] Describe the purpose of an electric meter (ammeter and voltmeter) and how to connect them to a circuit. APP2 11-5[7] Identify the assumptions made about electric meters and how nonideal meters may affect the properties of a circuit.
Voltmeters are used to measure electric potential difference between two points in a circuit. i. Voltmeters must be connected in parallel with the element across which potential difference is being measured. ii. Ideal voltmeters have an infinite resistance so that no charge flows through them. *APP2 11-5[6] Describe the purpose of an electric meter (ammeter and voltmeter) and how to connect them to a circuit. *APP2 11-5[7] Identify the assumptions made about electric meters and how nonideal meters may affect the properties of a circuit.
Non Ideal ammeters and voltmeters will change the properties of the circuit being measured. *APP2 11-5[6] Describe the purpose of an electric meter (ammeter and voltmeter) and how to connect them to a circuit. *APP2 11-5[7] Identify the assumptions made about electric meters and how nonideal meters may affect the properties of a circuit.

Advanced Placement Physics 2 **UNIT 11: Electric Circuits** **Topic 11.6 Kirchhoff's Loop Rule**	**Suggested Unit Pacing: 18 Sessions**
NJSLS-S Performance Expectations	
11.6.A Describe a circuit or elements of a circuit by applying Kirchhoff's loop rule.	
Standards-Aligned Objectives. Instruction and assessment will align to the following objectives:	
Energy changes in simple electrical circuits may be represented in terms of charges moving through electric potential differences within circuit elements. Relevant equation: $\Delta U_E = q\Delta V$ APP2 11-6[1] Relate and describe how the change in electric potential relates to a change in electrical potential energy for a circuit element	
Kirchhoff's loop rule is a consequence of the conservation of energy *APP2 11-6[1] Relate and describe how the change in electric potential relates to a change in electrical potential energy for a circuit element	
Kirchhoff's loop rule states that the sum of potential differences across all circuit elements in a single closed loop must equal zero. Relevant equation: $\sum \Delta V = 0$ APP2 11-6[2] Derive quantitative expressions for the electric potential difference across the elements in a closed conducting loop.	
The values of electric potential at points in a circuit can be represented by a graph of electric potential as a function of position within a loop. APP2 11-6[3] Draw and interpret graphical representations of the electric potential as a function of position within a loop.	

Advanced Placement Physics 2 **UNIT 11: Electric Circuits** **Suggested Unit Pacing: 18 Sessions** **Topic 11.7 Kirchhoff's Junction Rule**
NJSLS-S Performance Expectations
11.7.A Describe a circuit or elements of a circuit by applying Kirchhoff's junction rule.
Standards-Aligned Objectives. Instruction and assessment will align to the following objectives:
Kirchhoff's junction rule is a consequence of the conservation of electric charge. APP2 11-7[1] Explain how conservation of charge relates to the junction rule.
Kirchhoff's junction rule states that the total amount of charge entering a junction per unit time must equal the total amount of charge exiting that junction per unit time. *Relevant equation:* $\sum I_{in} = \sum I_{out}$ APP2 11-7[2] Sketch/draw on a circuit how a current splits in a junction. APP2 11-7[3] Calculate the currents going into and out of a junction.

Advanced Placement Physics 2 **UNIT 11: Electric Circuits** **Suggested Unit Pacing: 18 Sessions** **Topic 11.8 Resistor-Capacitor (RC) Circuits**
NJSLS-S Performance Expectations
11.8.A Describe the equivalent capacitance of multiple capacitors.
11.8.B Describe the behavior of a circuit containing combinations of resistors and capacitors.
Standards-Aligned Objectives. Instruction and assessment will align to the following objectives:
A collection of capacitors in a circuit may be analyzed as though it were a single capacitor with an equivalent capacitance C_{eq}. i. The inverse of the equivalent capacitance of a set of capacitors connected in series is equal to the sum of the inverses of the individual capacitances. Relevant equation: ii. The equivalent capacitance of a set of capacitors in series is less than the capacitance of the smallest capacitor. iii. The equivalent capacitance of a set of capacitors in parallel is the sum of the individual capacitances. Relevant equation: APP2 11-8[1] Describe, model, and calculate capacitors wired in series and parallel. APP2 11-8[2] Derive and calculate equivalent capacitance of capacitors in series and parallel. APP2 11-8[3] Reason what happens to the equivalent capacitance and subsequent charges stored in the capacitors.
As a result of conservation of charge, each of the capacitors in series must have the same magnitude of charge on each plate. APP2 11-8[4] Reason why capacitors in series have the same magnitude of charge on each plate.
The time constant τ is a significant feature of an RC circuit.

i. The time constant of an RC circuit is a measure of how quickly the capacitor will charge or discharge and is defined as $\tau = R_{eq}C_{eq}$.
ii. For a charging capacitor, the time constant represents the time required for the capacitor's charge to increase from zero to approximately 63 percent of its final asymptotic value.
iii. For a discharging capacitor, the time constant represents the time required for the capacitor's charge to decrease from fully charged to approximately 37 percent of its initial value.

APP2 11-8[5] Plot and describe the voltage and charge as a function of time for the charging and discharging of a capacitor in an RC circuit.

The potential difference across a capacitor and the current in the branch of the circuit containing the capacitor each change over time as the capacitor charges and discharges, but both will reach a steady state after a long time interval.
i. Immediately after being placed in a circuit, an uncharged capacitor acts like a wire, and charge can easily flow to or from the plates of the capacitor.
ii. As a capacitor charges, changes to the potential difference across the capacitor affect the charge on the plates of the capacitor, the current circuit branch in which the capacitor is located, and the electric potential energy stored in the capacitor.
iii. The potential difference across a capacitor, the current in the circuit branch in which the capacitor is located, and the electric potential energy stored in the capacitor all change with respect to time and asymptotically approach steady state conditions.
iv. After a long time, a charging capacitor approaches a state of being fully charged, reaching a maximum potential difference at which there is zero current in the circuit branch in which the capacitor is located.
v. Immediately after a charged capacitor begins discharging, the amount of charge on the capacitor plates and the energy stored in the capacitor begin to decrease.
vi. As a capacitor discharges, the amount of charge on the capacitor, the potential difference across the capacitor, and the current in the circuit branch in which the capacitor is located all decrease until a steady state is reached.
vii.After either charging or discharging for times much greater than the time constant, the capacitor and the relevant circuit branch may be modeled using steady state conditions.

APP2 11-8[6] Identify how an uncharged capacitor behaves the instant the switch is closed.

APP2 11-8[7] Predict how the potential difference across a capacitor and current changes as the capacitor in an RC circuit charges.

APP2 11-8[8] Predict how the potential difference across a capacitor and current changes as the capacitor in an RC circuit discharges.

APP2 11-8[9] Describe what happens to the current when a capacitor is fully charged.

Advanced Placement Physics 2
UNIT 12: Magnetism and Electromagnetism **Suggested Unit Pacing: 15-16 Sessions**
Topic 12.1 Magnetic Fields

NJSLS-S Performance Expectations

12.1.A Describe the properties of a magnetic field.

12.1.B Describe the magnetic behavior of a material as a result of the configuration of magnetic dipoles in the material.

12.1.C Describe the magnetic permeability of a material.

Standards-Aligned Objectives. Instruction and assessment will align to the following objectives:

A magnetic field is a vector field that describes the magnetic force exerted on moving electric charges, electric currents, or magnetic materials.
i. Magnetic fields can be produced by magnetic dipoles or combinations of dipoles, but never by monopoles.
ii. Magnetic dipoles have north and south polarity.

APP2 12-1[1] Describe how magnetic fields are produced by magnetic dipoles.

APP2 12-1[2] Describe how magnetic dipoles have north and south polarity.

A magnetic field is a vector quantity and can be represented using vector field maps.
i. Magnetic field lines form closed loops.
ii. Magnetic fields in a bar magnet form closed loops, with the external magnetic field pointing away from one end (defined as the north pole) and returning to the other end (defined as the south pole).

APP2 12-1[3] Sketch/Draw, represent, and describe magnetic field lines and the magnitude of the field at a specific point.

Magnetic dipoles result from the circular or rotational motion of electric charges. In magnetic materials, this can be the motion of electrons.
i. Permanent magnetism and induced magnetism are system properties that both result from the alignment of magnetic dipoles within a system.
ii. No magnetic north pole is ever found in isolation from a south pole. For example, if a bar magnet is broken in half, both halves are magnetic dipoles.
iii. Magnetic poles of the same polarity will repel; magnetic poles of opposite polarity will attract.
iv. The magnitude of the magnetic field from a magnetic dipole decreases with increasing distance from the dipole.

APP2 12-1[1] Describe and explain how permanent magnetism and induced magnetism are system properties that both result from the alignment of magnetic dipoles within a system.

APP2 12-1[2] Explain what happens to the polarity of a bar magnet if broken in half.

APP2 12-1[3] Predict when magnetic poles will attract or repel from other magnetic materials and/or poles.

APP2 12-1[4] Describe and plot the magnitude of the magnetic field as a function of position.

A magnetic dipole, such as a magnetic compass, placed in a magnetic field will tend to align with the magnetic field.

A material's composition influences its magnetic behavior in the presence of an external magnetic field.
i. Ferromagnetic materials such as iron, nickel, and cobalt can be permanently magnetized by an external field that causes the alignment of magnetic domains or atomic magnetic dipoles.
ii. Paramagnetic materials such as aluminum, titanium, and magnesium interact weakly with an external magnetic field, in that the magnetic dipoles of the material do not remain aligned after the external field is removed.
iii. All materials have the property of diamagnetism, in that their electronic structure creates a usually weak alignment of the dipole moments of the material opposite the external magnetic field.

APP2 12-1[5] Differentiate between ferromagnetic, paramagnetic, and diamagnetic materials.
Earth's magnetic field may be approximated as a magnetic dipole APP2 12-1[6] Justify how Earth's magnetic field may be approximated as a magnetic dipole
Magnetic permeability is a measurement of the amount of magnetization in a material in response to an external magnetic field. APP2 12-1[7] Describe the magnetic permeability of a material and how it affects the strength of the magnetic field.
Free space has a constant value of magnetic permeability, known as the vacuum permeability μ_0, that appears in equations representing physical relationships. *APP2 12-1[7] Describe the magnetic permeability of a material and how it affects the strength of the magnetic fiel
The permeability of matter has values different from that of free space and arises from the matter's composition and arrangement. It is not a constant for a material and varies based on many factors, including temperature, orientation, and strength of the external field. *APP2 12-1 [7] Describe the magnetic permeability of a material and how it affects the strength of the magnetic field.

Advanced Placement Physics 2 **UNIT 12: Magnetism and Electromagnetism** **Topic 12.2 Magnetism and Moving Charges**	**Suggested Unit Pacing: 15-16 Sessions**
NJSLS-S Performance Expectations	
12.2.A Describe the magnetic field produced by moving charged objects.	
12.2.B Describe the force exerted on moving charged objects by a magnetic field.	
12.1.C Describe the magnetic permeability of a material.	
Standards-Aligned Objectives. Instruction and assessment will align to the following objectives:	
A single moving charged object produces a magnetic field. i. The magnetic field at a particular point produced by a moving charged object depends on the object's velocity and the distance between the point and the object. ii. At a point in space, the direction of the magnetic field produced by a moving charged object is perpendicular to both the velocity of the object and the position vector from the object to that point in space and can be determined using the right-hand rule. iii. The magnitude of the magnetic field is a maximum when the velocity vector and the position vector from the object to that point in space are perpendicular. APP2 12-2[1] Calculate and represent how the magnitude and direction of a magnetic field at a specific point in space is created by a moving charged particle.	
APP2 12-2[2] Magnetic forces describe interactions between moving charged objects.	
A magnetic field may exert a force on a charged object moving in that field. i. The magnitude of the force exerted by a magnetic field on a moving charged object is proportional to the magnitude of the charge, the magnitude of the charged object's velocity, and the magnitude of the magnetic field and also depends on the angle between the velocity and magnetic field vectors. Relevant equation: $F_B = qvB\sin\theta$ ii. The direction of the force exerted by a magnetic field on a moving charged object is perpendicular to both the direction of the	

magnetic field and the velocity of the charge, as defined by the right-hand rule.

APP2 12-2[3] Calculate, determine and/or predict magnitude and direction of the force exerted by a magnetic field on a moving charged object moving through a magnetic field

In a region containing both a magnetic field and an electric field, a moving charged object will experience independent forces from each field.

APP2 12-2[4] Describe, predict and/or explain what will happen to a charged object moving in a region containing an electric field and magnetic field.

The Hall effect describes the potential difference created in a conductor by an external magnetic field that has a component perpendicular to the direction of charges moving in the conductor.

APP2 12-2[5] Predict and explain how a potential difference is created in a conductor by an external magnetic field that has a component perpendicular to the direction of charges moving in the conductor.

APP2 12-2[6] Calculate the potential difference created in a conductor by an external magnetic field that has a component perpendicular to the direction of charges moving in the conductor.

Advanced Placement Physics 2
UNIT 12: Magnetism and Electromagnetism **Suggested Unit Pacing: 15-16 Sessions**
Topic 12.3 Magnetism and Current-Carrying Wires

NJSLS-S Performance Expectations

12.3.A Describe the magnetic field produced by a current carrying wire.

12.3.B Describe the force exerted on a current-carrying wire by a magnetic field.

Standards-Aligned Objectives. Instruction and assessment will align to the following objectives:

A current-carrying wire produces a magnetic field.
i. The magnetic field vectors around a long, straight, current-carrying wire are tangent to concentric circles centered on that wire. The field has no component toward, away from, or parallel to the long, straight, current-carrying wire.
ii. At a point in space, the magnitude of the magnetic field due to a long, straight, current-carrying wire is proportional to the magnitude of the current in the wire and inversely proportional to the perpendicular distance from the central axis of the wire to the point.
Relevant equation:

iii. The direction of the magnetic field created by a current-carrying wire is determined with the right-hand rule.
iv. The direction of the magnetic field at the center of a current-carrying loop is directed along the axis of the loop and can be found using the right-hand rule.
v. The magnetic field at a location near two or more current-carrying wires can be determined using vector addition principles.

APP2 12-3[1] Calculate, plot, and/or predict the magnitude of the magnetic field due to a long, straight, current-carrying wire.

APP2 12-3[2] Describe, Sketch/Draw the direction of the magnetic field due to a long, straight, current-carrying wire.

APP2 12-3[3] Calculate and represent the net magnetic field at a specific point in space that created by multiple current-carrying wires.

A magnetic field may exert a force on a current carrying wire.
i. The magnitude of the force exerted by a magnetic field on a current-carrying wire is proportional to the current, the length of the portion of the wire within the magnetic field, and the magnitude of the magnetic field, and also depends on the angle between the direction of the current in the wire and the direction of the magnetic field.
Relevant equation:

$F_B = IlB\sin\theta$ ii. The direction of the force exerted by the magnetic field on a current-carrying wire is determined by the right-hand rule. APP2 12-3[4] Calculate, determine and/or predict the magnitude and direction of the force exerted by a magnetic field on a current carrying wire moving through a magnetic field

Advanced Placement Physics 2 **UNIT 12: Magnetism and Electromagnetism** **Suggested Unit Pacing: 15-16 Sessions** **Topic 12.4 Electromagnetic Induction and Faraday's Law**
NJSLS-S Performance Expectations
12.4.A Describe the induced electric potential difference resulting from a change in magnetic flux.
Standards-Aligned Objectives. Instruction and assessment will align to the following objectives:
Magnetic flux is a description of the amount of the component of a magnetic field that is perpendicular to a cross-sectional area. APP2 12-4[1] Describe and calculate the magnetic flux, the amount of the component of a magnetic field that is perpendicular to a cross-sectional area.
Magnetic flux through a surface is proportional to the magnitude of the component of the magnetic field perpendicular to the surface and to the cross-sectional area of the surface. Relevant equation: $\Phi_B = BA\cos\theta$ i. The area vector is defined to be perpendicular to the plane of the surface and directed outward from a closed surface. ii. The sign of the magnetic flux indicates whether the magnetic field is parallel to or antiparallel to the area vector. APP2 12-4[2] Differentiate the various ways magnetic flux changes
Faraday's law describes the relationship between changing magnetic flux and the resulting induced emf in a system. Relevant equation: APP2 12-4[3] Explain and calculate how a changing magnetic flux and the results in an induced emf in a system-
Lenz's law is used to determine the direction of an induced emf resulting from a changing magnetic flux. Relevant equation: i. An induced emf generates a current that creates a magnetic field that opposes the change in magnetic flux. ii. The right-hand rule is used to determine the relationships between current, emf, and magnetic flux. APP2 12-4[4] Predict and determine the direction of a generated current from an induced emf resulting from a changing magnetic flux.
A common example of electromagnetic induction is a conducting rod on conducting rails in a region with a uniform magnetic field. Derived equation: $\varepsilon = Blv$ APP2 12-4[5] Explain electromagnetic induction for a conducting rod on conducting rails in a region with a uniform magnetic field

Advanced Placement Physics 2
UNIT 13: Geometric Optics **Suggested Unit Pacing: 11-12 Sessions**
Topic 13.1 Reflection

NJSLS-S Performance Expectations

13.1.A Describe light as a ray

13.1.B Describe the reflection of light from a surface.

Standards-Aligned Objectives. Instruction and assessment will align to the following objectives:

A light ray is a straight line that is perpendicular to the wavefront of a light wave and points in the direction of travel of the wave.
i. Light rays can be used to determine the behavior of light in geometric optics, where the wave nature of light can be neglected.
ii. Rays are not sufficient to understand the spreading of light. In interference and diffraction, the wave nature of the light is important.
iii. A laser is a common source of a single coherent, monochromatic beam of light that can be modeled as a ray. The wave nature of lasers will be considered in Unit 14.

APP2 13-1[1] Use the ray model of light to predict the behavior of light in geometric objects.

APP2 13-1[2] Differentiate between the ray model and wave model of light

APP2 13-1[3] Identify which model should be used in a specific situation.

Ray diagrams depict the path of light before and after an interaction with matter.

APP2 13-1[4] Draw and interpret ray diagrams to represent the path of light interacting with different optical elements.

Light that is incident on a surface can be reflected.

*APP2 13-1[1] Use the ray model of light to predict the behavior of light in geometric objects.

*APP2 13-1[3] Identify which model should be used in a specific situation.

*APP2 13-1[4] Draw and interpret ray diagrams to represent the path of light interacting with different optical elements.

The law of reflection states that the angle between the incident ray and the normal (the line perpendicular to the surface) is equal to the angle between the reflected ray and the normal.
Relevant equation:
$\theta_i = \theta_r$

APP2 13-1[4] Determine the relationship between the angle of incidence and angle of reflection.

The law of reflection states that the angle between the incident ray and the normal (the line perpendicular to the surface) is equal to the angle between the reflected ray and the normal.
Relevant equation:
$\theta_i = \theta_r$

APP2 13-1[4] Determine the relationship between the angle of incidence and angle of reflection.

Diffuse reflection is the reflection of light from a rough surface and results in light reflected in many different directions, because the line normal to the surface varies over the area over which the light is incident.

APP2 13-1[5] Describe the interaction between light and matter for specific scenarios

Specular reflection is the reflection of light from a smooth surface and results in light uniformly reflected from the surface, because the line normal to the surface has an approximately constant direction over the area the light strikes.

*APP2 13-1[5] Describe the interaction between light and matter for specific scenarios.

Advanced Placement Physics 2 **UNIT 13: Geometric Optics** **Topic 13.2 Images Formed by Mirrors**	**Suggested Unit Pacing: 11-12 Sessions**
NJSLS-S Performance Expectations	
13.2.A Describe the image formed by a mirror.	
13.1.B Describe the reflection of light from a surface.	
Standards-Aligned Objectives. Instruction and assessment will align to the following objectives:	
Incident light rays parallel to the principal axis of a concave (converging) mirror will be reflected toward a common location, called the focal point. APP2 13-2[1] Identify the focal point for an optical element using light rays parallel to the optical element's principal axis.	
Incident light rays parallel to the principal axis of a convex (diverging) mirror will be reflected such that they appear to have originated from a common location behind the mirror, called the focal point. *APP2 13-2[1] Identify the focal point for an optical element using light rays parallel to the optical element's principal axis.	
The focal point of a plane mirror is an infinite distance from the mirror. APP 13-2[2] Differentiate between concave, convex and plane mirrors	
The focal point of a spherical mirror may be approximated as a point located on the principal axis of the mirror halfway between the surface of the mirror and the center of the mirror's radius of curvature. *APP2 13-2[1] Identify the focal point for an optical element using light rays parallel to the optical element's principal axis.	
A real image is formed by a mirror when light rays emanating from a common point are reflected and then intersect at a common point. APP2 13-2[3] Describe the conditions necessary to produce real images and virtual images using a specific optical element.	
A virtual image is formed by a mirror when reflected light rays diverge such that they appear to have originated from a common point. *APP2 13-2[3] Describe the conditions necessary to produce real images and virtual images using a specific optical element.	
The location of an image depends on the focal length of the mirror and the distance between the object and the surface of the mirror. Relevant equation: i. The locations of a mirror's focal point, an object near the mirror, and the image of the object formed by the mirror follow sign conventions that are used to determine those locations relative to the mirror itself. ii. The distance between the image formed and a plane mirror is equal to the distance between the object and the plane mirror. APP2 13-2[4] Derive a mathematical expression to predict the location of an image using the distance of the object (from the surface of the optical element) and the optical element's focal length. APP2 13-2[5] Use the thin lens/mirror equation to determine the image location, object location or focal point when the other	

variables are known.
The magnification of an image formed by a mirror is the ratio of the size of the image produced to the size of the object itself and depends on the locations of the object and image relative to the mirror. Relevant equation: APP2 13-2[6] Determine the relationship between object and image height, object and image location, and optical magnification.
Ray diagrams can be used to determine the location, type, size, and orientation of images formed by mirrors. i. The three principal rays are typically used to find the images formed by mirrors. The principal rays are 1) the ray parallel to the principal axis, 2) the ray that reflects at the center of the mirror where the principal axis intersects the mirror, and 3) the ray that passes through the focal point of the mirror. ii. Images formed by a mirror can be upright or inverted, virtual or real, and reduced, enlarged, or the same size as the object. APP2 13-2[7] Draw and interpret ray diagrams to determine the characteristics of an image formed by an optical element (specifically location, orientation, size and type). APP2 13-2[8] Differentiate between virtual and real images, magnified/enlarged, diminished/reduced and same size images, and upright and inverted images.

Advanced Placement Physics 2 **UNIT 13: Geometric Optics** **Suggested Unit Pacing: 11-12 Sessions** **Topic 13.3 Refraction**
NJSLS-S Performance Expectations
13.3.A Describe the refraction of light between two media.
Standards-Aligned Objectives. Instruction and assessment will align to the following objectives:
Refraction is the change in direction of a light ray as the ray passes from one medium into another. APP2 13-3[1] Identify the conditions necessary for light to undergo refraction.
Refraction is a result of the speed of light changing when light enters a new medium. APP2 13-3[2] Describe the changes that occur to a ray of light as it passes from one medium into another.
The index of refraction of a given medium is inversely proportional to the speed of light in the medium. Relevant equation: $n = c/v$ APP2 13-3[3] Determine a medium's index of refraction, n, by using the ratio of the speed of light in a vacuum, c, to the speed of light in that medium.
Snell's law relates the angles of incidence and refraction of a light ray passing from one medium into another to the indices of refraction of the two media. Relevant equation: $n_1\sin\theta_1 = n_2\sin\theta_2$ i. When a light ray travels from a medium with a higher index of refraction into a medium with a lower index of refraction, the ray refracts away from the normal. ii. When a light ray travels from a medium with a lower index of refraction into a medium with a higher index of refraction, the ray refracts toward the normal. iii. When a light ray is incident along the normal to a surface, the transmitted ray is not refracted.

APP2 13-3[4] Derive a relationship between the indices of refraction and the angles of incidence and refraction for light passing from one medium into another.

APP2 13-3[5] Use Snell's law to predict an index of refraction, angle of incidence or angle of refraction when the other variables are known.

Total internal reflection may occur when light passes from one medium into another medium with a lower index of refraction.
i. Total internal reflection of light occurs beyond a critical angle of incidence.
Derived equation:

ii. For incident rays at the critical angle, the ray refracts at 90 degrees and travels along the surface of the material.
iii. For incident rays beyond the critical angle, all light is reflected (no light is transmitted into the other medium).

APP2 13-3[6] Explain the process and necessary conditions for total internal reflection (T.I.R.) to occur in a medium.

APP2 13-3[7] Determine the critical angle for light passing from one medium into another to result in total internal reflection.

Advanced Placement Physics 2
UNIT 13: Geometric Optics **Suggested Unit Pacing: 11-12 Sessions**
Topic 13.4 Images Formed by Lenses

NJSLS-S Performance Expectations

13.4.A Describe the image formed by a lens.

Standards-Aligned Objectives. Instruction and assessment will align to the following objectives:

Incident light rays parallel to the principal axis of a thin convex (converging) lens will be refracted and converge toward a common location on the transmitted side of the lens, called the focal point.

APP2 13-4[1] Identify the focal point for an optical element using light rays parallel to the optical element's principal axis.
(NOTE: same as APP2 13-2[1])

APP2 13-4[2] Differentiate between concave and convex lenses.

Incident light rays parallel to the principal axis of a thin concave (diverging) lens will be refracted and diverge as if they originated from a focal point on the incident side of the lens.

*APP2 13-4[1] Identify the focal point for an optical element using light rays parallel to the optical element's principal axis.

*APP2 13-4[2] Differentiate between concave and convex lenses.

A real image is formed by a lens when light rays originating from a common point are refracted such that they intersect at another common point.

APP2 13-4[3] Describe the conditions necessary to produce real images and virtual images using a specific optical element.
(NOTE: same as APP2 13-2[3])

A virtual image is formed by a lens when refracted light rays diverge such that they appear to have originated from a common point.

*APP2 13-4[3] Describe the conditions necessary to produce real images and virtual images using a specific optical element.

For a thin lens, the location of an image depends on the focal length of the lens and the distance between the object and the midline of the lens, as given by the thin-lens equation:

Relevant equation i. The locations of a lens’s focal point, an object, and the image of the object formed by the lens follow sign conventions that are used to determine those locations relative to the lens itself. ii. Lenses have a focal point on both sides of the lens that depends on the shape of the respective side of the lens. APP2 13-4[4] Derive a mathematical expression to predict the location of an image using the distance of the object (from the surface of the optical element) and the optical element's focal length. (NOTE: same as APP2 13-2[4]) APP2 13-4[5] Use the thin lens/mirror equation to determine the image location, object location or focal point when the other variables are known. (NOTE: same as APP2 13-2[5])
For a thin lens, the magnification of an image is the ratio of the size of the image produced to the size of the object itself and depends on the locations of the object and image relative to the lens. Relevant equation: APP2 13-4[6] Determine the relationship between object and image height, object and image location, and optical magnification. (NOTE: same as APP2 13-2[6])
Ray diagrams to determine the location, type, size, and orientation of images formed by lenses. i. The three principal rays are typically used to find the images formed by lenses. The principal rays are 1) the ray parallel to the principal axis, 2) the ray that passes through the center of the lens where the principal axis intersects the lens, and 3) the ray that passes through the focal point of the lens. ii. Images formed by a lens can be upright or inverted, virtual or real, and reduced, enlarged, or the same size as the object. APP2 13-4[7] Draw and interpret ray diagrams to determine the characteristics of an image formed by an optical element (specifically location, orientation, size and type) (NOTE: same as APP2 13-2[7]) APP2 13-4[8] Differentiate between virtual and real images, magnified/enlarged, diminished/reduced and same size images, and upright and inverted images. (NOTE: same as APP2 13-2[8])

Advanced Placement Physics 2
UNIT 14: Waves, Sound, and Physical Optics **Suggested Unit Pacing: 18 Sessions**
Topic 14.1 Properties of Wave Pulses and Waves

NJSLS-S Performance Expectations

14.1.A Describe the physical properties of waves and wave pulses.

Standards-Aligned Objectives. Instruction and assessment will align to the following objectives:

Waves transfer energy between two locations without transferring matter between those locations.
i. A wave pulse is a single disturbance that transfers energy without transferring matter between two locations.
ii. A wave is modeled as a continuous, periodic disturbance with well-defined wavelength and frequency.

APP2 14-1[1] Describe the propagation of a wave through a medium.

Mechanical waves or wave pulses require a medium in which to propagate. Electromagnetic waves or wave pulses do not require a medium in which to propagate.

APP2 14-1[2] Compare and contrast between types of waves including mechanical and electromagnetic, pulse and perioding, traveling and standing, and transverse and longitudinal.

APP2 14-1[3] State and Apply that the speed at which a wave or wave pulse propagates through a medium depends on the type of wave and the properties of the medium.
i. The speed of all electromagnetic waves in a vacuum is a universal physical constant, $c = 3.00 \times 10^8$ m/s.
ii. The speed at which a wave pulse or wave propagates along a string is dependent upon the tension in the string, F_T, and the mass per length of the string.
Relevant equation:

iii. In a given medium, the speed of sound waves increases with the temperature of the medium.

APP2 14-1[3] Reason how the speed of a wave will be affected based on the properties of the medium in which the wave propagates.

APP2 14-1[3] State and Apply that the speed at which a wave or wave pulse propagates through a medium depends on the type of wave and the properties of the medium.
i. The speed of all electromagnetic waves in a vacuum is a universal physical constant, $c = 3.00 \times 10^8$ m/s.
ii. The speed at which a wave pulse or wave propagates along a string is dependent upon the tension in the string, F_T, and the mass per length of the string.
Relevant equation:

iii. In a given medium, the speed of sound waves increases with the temperature of the medium.

APP2 14-1[3] Reason how the speed of a wave will be affected based on the properties of the medium in which the wave propagates.

In a transverse wave, the direction of the disturbance is perpendicular to the direction of propagation of the wave.

*APP2 14-1[2] Compare and contrast between types of waves including mechanical and electromagnetic, pulse and perioding, traveling and standing, and transverse and longitudinal.

In a longitudinal wave, the direction of the disturbance is parallel to the direction of propagation of the wave.
i. Sound waves are modeled as mechanical longitudinal waves.
ii. The regions of high and low pressure in a sound wave are called compressions and rarefactions, respectively.

*APP2 14-1[2] Compare and contrast between types of waves including mechanical and electromagnetic, pulse and perioding, traveling and standing, and transverse and longitudinal.

Amplitude is the maximum displacement of a wave from its equilibrium position.
i. The amplitude of a longitudinal pressure wave may be determined by the maximum increase or decrease in pressure from equilibrium pressure.
ii. The amplitude of a sound wave is related to the loudness of that sound wave.
iii. The energy carried by a wave increases with increasing amplitude.

APP2 14-1[4] Determine the amplitude of a wave and relate the amplitude to the energy of the wave.

Advanced Placement Physics 2
UNIT 14: Waves, Sound, and Physical Optics **Suggested Unit Pacing: 18 Sessions**
Topic 14.2 Periodic Waves

NJSLS-S Performance Expectations

14.2.A Describe the physical properties of a periodic wave.

Standards-Aligned Objectives. Instruction and assessment will align to the following objectives:

Periodic waves have regular repetitions that can be described using period and frequency.
i. The period is the time for one complete oscillation of the wave.
ii. The frequency is the rate at which the wave repeats.
Relevant equation:
$T= 1/f$
iii. The amplitude of a wave is independent of the period and the frequency of that wave.
iv. The energy of a wave increases with increasing frequency.
v. The frequency of a sound wave is related to its pitch.
vi. Wavelength is the distance between successive corresponding positions (such as peaks or troughs) on a wave.

APP2 14-2[1] Determine the period T of a wave and relate the period to the frequency, f of the wave.

APP2 14-2[2] Determine the wavelength, λ of a wave and identify the parts of a wave that can help determine the length of the wave.

A sinusoidal wave can be described by equations for the displacement from equilibrium at a specific location as a function of time. A wave can also be described by an equation for the displacement from equilibrium at a specific time as a function of position.
Example equations:

APP2 14-2[3] Represent the displacement from equilibrium of a wave physically and mathematically.

For a periodic wave, the wavelength is proportional to the wave’s speed and inversely proportional to the wave’s frequency.
Relevant equation:
$\lambda = v/f$

APP2 14-2[4] Derive a relationship between wavelength, λ speed, v and frequency, f of a wave.

APP2 14-2[5] Use the wave equation to predict the wavelength, speed, frequency or period of a wave when the other variables are known.

Advanced Placement Physics 2 **UNIT 14: Waves, Sound, and Physical Optics** **Suggested Unit Pacing: 18 Sessions** **Topic 14.3 Boundary Behavior of Waves and Polarization**
NJSLS-S Performance Expectations
14.3.A Describe the interaction between a wave and a boundary
Standards-Aligned Objectives. Instruction and assessment will align to the following objectives:
A wave that travels from one medium to another can be transmitted or reflected, depending on the properties of the boundary separating the two media. i. A wave traveling from one medium to another (for example, a wave traveling between low-mass and high-mass strings), will result in reflected and transmitted waves. ii. A reflected wave is inverted if the transmitted wave travels into a medium in which the speed of the wave decreases. iii. A reflected wave is not inverted if the transmitted wave travels into a medium in which the speed of the wave increases. iv. The frequency of a wave does not change when it travels from one medium to another. APP2 14-3[1] Differentiate between wave interactions with barriers: reflection, refraction and diffraction. APP2 14-3[2] Describe the reflection of a wave as it encounters a boundary (change in medium).
Transverse waves that are reflected from a surface, refracted through a medium, or pass through specific openings may be polarized. i. Transverse waves can be polarized and oscillate in a single plane. ii. Longitudinal waves cannot be polarized. APP2 14-3[3] Describe polarization of a wave and the conditions necessary for a wave to be polarized.
Polarization of a wave may result in a reduction of the wave's intensity. i. Intensity is a measure of the amount of power transferred per unit area. ii. The intensity of a wave is the average power per unit area over one period of the wave. APP2 14-3[4] Determine the intensity of a wave and what variables affect the intensity.

Advanced Placement Physics 2 **UNIT 14: Waves, Sound, and Physical Optics** **Suggested Unit Pacing: 18 Sessions** **Topic 14.4 Electromagnetic Waves**
NJSLS-S Performance Expectations
14.4.A Describe the properties of an electromagnetic wave.
Standards-Aligned Objectives. Instruction and assessment will align to the following objectives:
Electromagnetic waves consist of oscillating electric and magnetic fields that are mutually perpendicular. i. Electromagnetic waves are transverse waves because the oscillations of the electric and magnetic fields are perpendicular to the direction of propagation. ii. Electromagnetic waves are commonly assumed to be plane waves, which are characterized by planar wave fronts. APP2 14-4[1] Model electromagnetic waves as oscillating perpendicular electric and magnetic fields that propagate as transverse plane waves.
Electromagnetic waves do not need a medium through which to propagate.

APP2 14-4[2] Justify the claim that electromagnetic waves can propagate through a vacuum.

Categories of electromagnetic waves are characterized by their wavelengths.
i. Categories of electromagnetic waves include (in order of decreasing wavelength, spanning a range from kilometers to picometers) radio waves, microwaves, infrared, visible, ultraviolet, x-rays, and gamma rays.
ii. Visible electromagnetic waves are further broken into categories of color, including (in order of decreasing wavelength) red, orange, yellow, green, blue, and violet.
iii. Visible electromagnetic waves are also called light. Sometimes, electromagnetic waves of all wavelengths are collectively referred to as light or electromagnetic radiation.

APP2 14-4[3] Identify the different parts of the electromagnetic spectrum as categorized by their wavelength, energy and/or frequency.

Advanced Placement Physics 2
UNIT 14: Waves, Sound, and Physical Optics **Suggested Unit Pacing: 18 Sessions**
Topic 14.5 The Doppler Effect

NJSLS-S Performance Expectations

14.5.A Describe the properties of a wave based on the relative motion between the source of the wave and the observer of the wave.

Standards-Aligned Objectives. Instruction and assessment will align to the following objectives:

The Doppler effect is the relationship between the rest frequency of a wave source, the observed frequency of the source, and the relative velocity of the source and the observer.

APP2 14-5[1] Derive a relationship between the frequency of the source, observed frequency of the wave and the relative velocity of the source with respect to the observer.

A greater relative velocity results in a greater measured difference between the observed and rest frequencies.
i. For a wave source moving at the same velocity as the observer, the observed frequency is equal to the rest frequency.
ii. For a wave source moving toward an observer, the observed frequency is greater than the rest frequency. iii. For a wave source moving away from an observer, the observed frequency is less than the rest frequency.

APP2 14-5[2] Reason how the observed frequency will be affected by a source that is approaching an observer and a source that is receding from an observer.

APP2 14-5[3] Determine the Doppler shift for various scenarios.

Advanced Placement Physics 2
UNIT 14: Waves, Sound, and Physical Optics **Suggested Unit Pacing: 18 Sessions**
Topic 14.6 Wave Interference and Standing Waves

NJSLS-S Performance Expectations

14.6.A Describe the net disturbance that occurs when two or more wave pulses or waves overlap.

14.6.B Describe the properties of a standing wave.

Standards-Aligned Objectives. Instruction and assessment will align to the following objectives:

Wave interference is the interaction of two or more wave pulses or waves.

APP2 14-6[1] Define wave interference as the superpositioning of two or more waves that pass through each other in a particular medium.
When two or more wave pulses or waves interact with each other, they travel through each other and overlap rather than bouncing off each other. *APP2 14-6[1] Define wave interference as the superpositioning of two or more waves that pass through each other in a particular medium.
When two or more wave pulses or waves overlap, the resulting displacement can be determined by adding the individual displacements. This is called superposition. *APP2 14-6[1] Define wave interference as the superpositioning of two or more waves that pass through each other in a particular medium. APP2 14-6[2] Determine the amplitude of the resulting wave from two or more superpositioned waves.
Wave interference may be constructive or destructive. i. When the displacements of the superposed wave pulses or waves are in the same direction, the interaction is called constructive interference. ii. When the displacements of the superposed wave pulses or waves are in opposite directions, the interaction is called destructive interference. iii. Two or more traveling wave pulses or waves can interact in such a way as to produce amplitude variations in the resultant wave pulse or wave. *APP2 14-6[2] Determine the amplitude of the resulting wave from two or more superpositioned waves. APP2 14-6[3] Differentiate between constructive and destructive interference.
Visual representations of wave pulses or waves are useful in determining the result of two interacting wave pulses or waves. APP2 14-6[4] Represent wave interference physically and mathematically.
Beats arise from the addition of two waves of slightly different frequency. i. Waves with different frequencies are sometimes in phase and sometimes out of phase at locations along the waves, causing periodic amplitude changes in the resultant wave. ii. The beat frequency is the difference in the frequencies of the two waves. Relevant equation: iii. Tuning forks are devices that are commonly used to demonstrate beat frequencies. APP2 14-6[5] Determine the beat frequency that results from the superpositioning of waves with similar, but not identical, frequencies.
APP2 14-6[7] Describe and Model standing waves can result from interference between two waves that are confined to a region and traveling in opposite directions. i. Standing waves have nodes and antinodes. A node is a point on the standing wave where the amplitude is always zero. An antinode is a point on the standing wave where the amplitude is always at maximum. ii. The possible wavelengths of a standing wave are determined by the size and boundary conditions of the region to which it is confined. iii. Common regions where standing waves can form include pipes with open or closed ends, as well as strings with fixed or loose ends. APP2 14-6[6] Describe the conditions necessary for standing waves to result in different media, such as air columns and strings. APP2 14-6[7] Identify the parts and physical characteristics of a standing wave.

APP2 14-6[8] Determine the relationships between length, wavelength, number of waves, frequency, harmonic, and speed of a standing wave.
For a standing wave, the longest possible wavelength is called the fundamental or first harmonic. The second-longest wavelength is called the second harmonic, and so on. *APP2 14-6[8] Determine the relationships between length, wavelength, number of waves, frequency, harmonic, and speed of a standing wave.
Visual representations of standing waves are useful in determining the relationships between length of the region, wavelength, frequency, wave speed, and harmonic. *APP2 14-6[8] Determine the relationships between length, wavelength, number of waves, frequency, harmonic, and speed of a standing wave.

Advanced Placement Physics 2 **UNIT 14: Waves, Sound, and Physical Optics** **Suggested Unit Pacing: 18 Sessions** **Topic 14.7 Diffraction**
NJSLS-S Performance Expectations
14.7.A Describe the behavior of a wave and the diffraction pattern resulting from a wave passing through a single opening.
Standards-Aligned Objectives. Instruction and assessment will align to the following objectives:
Diffraction is the spreading of a wave around the edges of an obstacle or through an opening. APP2 14-7[1] Differentiate between wave interactions with barriers: reflection, refraction and diffraction. (NOTE: same as APP2 14-3[1])
Diffraction is most pronounced when the size of the opening is comparable to the wavelength of the wave. APP2 14-7[2] Determine the relationship between diffraction, wavelength, and size of the aperture through which the wave is passing.
Diffraction of multiple wavefronts through a single opening leads to observable interference patterns. APP2 14-7[3] Relate the diffraction of multiple wavefronts and the aperture(s) through which the wave passes to observable interference patterns.
For small angles, the distance y from the middle of the central bright fringe of a diffraction pattern to the mth point of minimum brightness produced at a distance of D from a single opening with aperture size a by a wave of wavelength λ passing through the opening can be approximated by Relevant equation APP2 14-7[4] Predict the distance between central maximum and nth maximum in a diffraction or interference pattern, width of aperture, distance between aperture and screen, wavelength, or angle when the other variables are known.
The diffraction pattern produced by a wave passing through an opening depends on the shape of the opening. *APP2 14-7[3] Relate the diffraction of multiple wavefronts and the aperture(s) through which the wave passes to observable interference patterns.
The visual representations of single-slit diffraction patterns are useful in determining the physical properties of the slit and the interacting waves.

APP2 14-7[5] Represent diffraction and interference patterns physically and mathematically.

Advanced Placement Physics 2
UNIT 14: Waves, Sound, and Physical Optics **Suggested Unit Pacing: 18 Sessions**
Topic 14.8 Double-Slit Interference and Diffraction Gratings

NJSLS-S Performance Expectations

14.8.A Describe the behavior of a wave and the diffraction pattern resulting from the wave passing through multiple openings.

Standards-Aligned Objectives. Instruction and assessment will align to the following objectives:

The pattern resulting from a wave interacting with a double slit is caused by a combination of wave diffraction and wave interference.
i. When only considering wave interference, a double slit creates a pattern of uniformly spaced maxima.
ii. The local maxima of an interference pattern can be calculated with the following equation, where y is the distance between the mth bright line and the central maximum (as viewed on a screen at a distance, D, from the slits), and d is the distance between the two slits.
Relevant equation:

iii. When considering wave interference and wave diffraction, a double slit creates a diffraction pattern of maxima and minima superimposed within the envelope created by single-slit diffraction.

APP2 14-8[1] **Relate** the diffraction of multiple wavefronts and the aperture(s) through which the wave passes to observable interference patterns.
(NOTE: same as APP2 14-7[3])

APP2 14-8[2] **Predict** the distance between central maximum and nth maximum in a diffraction or interference pattern, width of aperture, distance between aperture and screen, wavelength, or angle when the other variables are known.
(NOTE: same as APP2 14-7[4])

Interference patterns produced by light interacting with a double slit indicate that light has wave properties. The source of this discovery was Young's double-slit experiment.

APP2 14-8[3] **Support** the claim that light has similar properties to waves.

Visual representations of double-slit diffraction patterns are useful in determining the physical properties of the slits and the interacting waves.

APP2 14-8[4] **Represent** diffraction and interference patterns physically and mathematically.
(NOTE: same as 14-7[5])

A diffraction grating is a collection of evenly spaced parallel slits or openings that produce an interference pattern that is the combination of numerous diffraction patterns superimposed on each other.

*APP2 14-8[1] **Relate** the diffraction of multiple wavefronts and the aperture(s) through which the wave passes to observable interference patterns.

APP2 14-8[5] **Differentiate** between the aperture(s): single slit, double slit and diffraction grating, and their respective patterns.

When white light is incident on a diffraction grating, the center maximum is white and the higher-order maxima disperse white light into a rainbow of colors, with the longest-wavelength light (red) appearing farthest from the central maximum.

APP2 14-8[6] **Explain** the location of different colors from the dispersion of white light through an optical element, such as a prism

or diffraction grating.

Advanced Placement Physics 2 **UNIT 14: Waves, Sound, and Physical Optics** **Suggested Unit Pacing: 18 Sessions** **Topic 14.9 Thin-Film Interference**
NJSLS-S Performance Expectations
14.9.A Describe the behavior of light that interacts with a thin film.
Standards-Aligned Objectives. Instruction and assessment will align to the following objectives:
When light travels from one medium to another, some of the light is transmitted, some is reflected, and some is absorbed. APP2 14-9[1] Differentiate between the transmission, reflection and absorption of light at a change in media (boundary).
The phase change of a reflected ray by using the relative indices of refraction of the materials with which the ray interacts. i. A phase change of 180 degrees occurs when a light ray is reflected from a medium with a greater index of refraction than the medium through which the ray is traveling. ii. No phase change occurs when a light ray is reflected from a medium with a lower index of refraction than the medium through which the ray is traveling. APP2 14-9[2] Determine the phase change of light when it interacts with a thin film.
The phase of a wave does not change when it is refracted as it passes from one medium into another. *APP2 14-9[2] Determine the phase change of light when it interacts with a thin film.
Thin-film interference occurs when light interacts with a medium whose thickness is comparable to the light's wavelength. i. The interactions between the initial reflected light and the light exiting the thin film after being reflected from the second interface exhibit wave interference behavior, resulting in a single wave that is the sum of the two interacting waves. ii. The amount of constructive or destructive interference between the two reflected waves depends on the relationship between the thickness of the film, the wavelength of light, any phase shifts, and the angle at which the incident light strikes the film. APP2 14-9[3] Identify the conditions necessary for thin-film interference. APP2 14-9[4] Relate the thickness of the film, wavelength of light, phase shifts and angle of incidence to the type of interference that occurs for light interacting with a thin film.
Practical examples of thin-film interference include the color variations seen in soap bubbles and oil films, as well as antireflection coatings. i. The spectrum of colors observed in oil films and soap bubbles arises from differences in the thickness of the film. ii. Antireflection coatings eliminate reflected light by applying the relationships between indices of refraction, phase shift, and wave interference to create destructive interference of the light reflected from the two surfaces of the coating. iii. The simplest antireflection coating has a thickness equal to one-quarter of the wavelength of the light in the coating, and the index of refraction of the coating is greater than that of air and less than that of the surface upon which the coating is applied. This assumes incident light is normal to the surface. APP2 14-9[5] Apply thin-film interference to real world examples.

Advanced Placement Physics 2
UNIT 15: Modern Physics **Suggested Unit Pacing: 19-20 Sessions**
Topic 15.1 Quantum Theory and Wave-Particle Duality

NJSLS-S Performance Expectations

15.1.A Describe the properties and behavior of an object that exhibits both particle-like and wave-like behavior.

Standards-Aligned Objectives. Instruction and assessment will align to the following objectives:

Quantum theory was developed to explain observations of matter and energy that could not be explained using classical mechanics. These phenomena include, but are not limited to, atomic spectra, blackbody radiation, and the photoelectric effect. i. Quantum theory is necessary to describe the properties of matter at atomic and subatomic scales. ii. In quantum theory, fundamental particles can exhibit both particle-like and wave-like behavior.

APP2 15-1[1] Identify the limitations of classical mechanics, and therefore the need for quantum theory, for phenomena such as atomic spectra, blackbody radiation and the photoelectric effect.

APP2 15-1[2] Apply both particle and wave models to fundamental particles to predict the behavior of the fundamental particles in different situations.

Light can be modeled both as a wave and as discrete particles, called photons.
i. A photon is a massless, electrically neutral particle with energy proportional to the photon's frequency.
Relevant equations:
$E = hf$
$\lambda = c/f$
ii. Photons travel in straight lines unless they interact with matter

APP2 15-1[3] Apply both particle and wave models to light to predict the behavior of light in different situations.

APP2 15-1[4] Reason, via proportional thinking, how a change in energy, frequency or the speed of light will affect the wavelength of light.

The speed of a photon depends on the medium through which the photon travels.
i. The speed of all photons in free space is equal to the classical speed of light, $c = 3.00 \times 10^8$ m/s.
ii. In general, the speed of photons through a given medium is inversely proportional to the index of refraction of that medium

APP2 15-1[5] Determine the speed of light in a medium based on the index of refraction for a given medium and the speed of light in a vacuum.

Particles can demonstrate wave properties, as shown by variations of Young's double-slit experiment.
i. A wave model of matter is quantified by the de Broglie wavelength, which increases as the momentum of a particle decreases.
Relevant equation:
$\lambda = h/p$
ii. Quantum theory is necessary to describe systems where the de Broglie wavelength is comparable to the size of the system.

APP2 15-1[6] Identify situations in which the de Broglie wavelength of a particle is comparable to the size of the system.

APP2 15-1[7] Calculate the de Broglie wavelength for a particle based on its momentum.

Values of energy and momentum have discrete, or quantized, values for bound systems described by quantum theory.

APP2 15-1[8] Identify the discrete, or quantized value for energy and momentum for bound systems.

Advanced Placement Physics 2 **UNIT 15: Modern Physics** **Suggested Unit Pacing: 19-20 Sessions** **Topic 15.2 The Bohr Model of Atomic Structure**
NJSLS-S Performance Expectations
15.2.A Describe the properties of an atom.
Standards-Aligned Objectives. Instruction and assessment will align to the following objectives:
Atoms have internal structure. i. Atoms consist of a small, positively charged nucleus surrounded by one or more negatively-charged electrons. ii. The nucleus of an atom is made up of protons and neutrons. iii. The number of neutrons and protons in an atom can be represented using nuclear notation. iv. An ion is an atom with a nonzero net electric charge. APP2 15-2[1] Describe the structure of an atom, including the fundamental particles that make up the atom, the charge type and the location of these particles within the atom. APP2 15-2[2] Compare and contrast atoms (element) based on the number of protons, whether it has an unbalanced charge (ion) based on the number of electrons, and whether it is an isotope based on the number of neutrons.
Each atomic element has a unique number of protons. i. The number and arrangements of electrons affects how atoms interact. ii. The total number of neutrons and protons identifies the isotope of an element. iii. The mass of an atom is dominated by the total mass of the protons and neutrons in its nucleus. *APP2 15-2[2] Compare and contrast atoms (element) based on the number of protons, whether it has an unbalanced charge (ion) based on the number of electrons, and whether it is an isotope based on the number of neutrons.
The Bohr model of the atom is based on classical physics and was the historical representation of the atom that led to the description of the hydrogen atom in terms of discrete energy states. i. In the Bohr model of the atom, electrons are modeled as moving around the nucleus in circular orbits determined by the electron's charge and mass, as well as the electric force between the electron and the nucleus. Relevant equations: ii. The standing wave model of electrons accounts for the existence of specific allowed energy states of an electron in an atom, because the electron orbit's circumference must be an integer multiple of the electron's de Broglie wavelength. APP2 15-2[3] Apply Bohr's model of an atom to the hydrogen atom to describe the orbits of electrons around the nucleus of the atom. APP2 15-2[4] Apply de Broglie wavelength of an electron to determine the radius of electron orbit(s) around the nucleus of a hydrogen atom.

Advanced Placement Physics 2 **UNIT 15: Modern Physics** **Suggested Unit Pacing: 19-20 Sessions** **Topic 15.3 Emission and Absorption Spectra**
NJSLS-S Performance Expectations
15.3.A Describe the emission or absorption of photons by atoms.
Standards-Aligned Objectives. Instruction and assessment will align to the following objectives:

Energy transfer occurs when photons are absorbed or emitted by atoms. APP2 15-3[1] Justify if energy is gained or lost when photons are absorbed and/or emitted by atoms. APP2 15-2[2] Compare and contrast atoms (element) based on the number of protons, whether it has an unbalanced charge (ion) based on the number of electrons, and whether it is an isotope based on the number of neutrons.
Energy can only be absorbed or emitted by an atom if the amount of energy being absorbed or emitted corresponds to the energy difference between two atomic energy states. i. An atom in a given energy state may absorb a photon of the appropriate energy and transition to a higher energy state. ii. An atom in an excited energy state may emit a photon of the appropriate energy to spontaneously move to a lower energy state. APP2 15-3[2] Calculate the energy that is gained or lost when photons are absorbed and/or emitted by atoms.
Transitions between two energy states of an atom correspond to the absorption or emission of a photon of a single frequency and, therefore, a single wavelength. APP2 15-3[3] Apply the relationship between energy of a photon, its frequency and its wavelength to determine the frequency and/or wavelength of the photon that is emitted or absorbed when an electron transitions between two energy (orbital) states.
Atoms of each element have a unique set of allowed energy levels and thereby a unique set of absorption and emission frequencies. The unique set of frequencies determines the element's spectrum. i. An emission spectrum can be used to determine the elements in a source of light. ii. An absorption spectrum can be used to determine the elements composing a substance by observing what light the substance has absorbed. APP2 15-3[4] Use atomic spectra to identify elements in a light emitting source. APP2 15-3[5] Differentiate between emission and absorption spectra.
Binding energy is the energy required to remove an electron from an atom, causing the atom to become ionized. An atom in the lowest energy level (ground state) will require the greatest amount of energy to remove the electron from the atom. APP2 15-3[6] Represent the binding energy and energy required to move an electron to different energy states both physically and mathematically.

Advanced Placement Physics 2 **UNIT 15: Modern Physics** **Suggested Unit Pacing: 19-20 Sessions** **Topic 15.4 Blackbody Radiation**
NJSLS-S Performance Expectations
15.4.A Describe the electromagnetic radiation emitted by an object due to its temperature.
Standards-Aligned Objectives. Instruction and assessment will align to the following objectives:
Matter will spontaneously convert some of its internal thermal energy into electromagnetic energy
A blackbody is an idealized model of matter that absorbs all radiation that falls on the body. If the body is in equilibrium at a constant temperature, then it must in turn emit energy. APP2 15-4[1] Define a blackbody radiator as a body that emits the energy in which it absorbs once it is at thermal equilibrium. APP2 15-4[2] Justify if a system could be modeled as a blackbody radiator.

A blackbody will emit a continuous spectrum that only depends on the body's temperature. The radiation emitted by a blackbody is often modeled by plotting intensity per unit wavelength as a function of wavelength. i. The distribution of the intensity of a blackbody's spectrum as a function of temperature cannot be modeled using only classical physics concepts. A blackbody's spectrum is described by Planck's law, which assumes that the energy of light is quantized. ii. The peak wavelength emitted by a blackbody (the wavelength at which the blackbody emits the greatest amount of radiation per unit wavelength) decreases with increasing temperature, as described by Wien's law. Relevant equation: iii. The rate at which energy is emitted (power) by a blackbody is proportional to the surface area of the body and to the temperature of the body raised to the fourth power, as described by the StefanBoltzmann law. Relevant equation: APP2 15-4[3] Draw and interpret a blackbody curve for a radiating source. APP2 15-4[4] Use Wien's Law and the relationship between temperature of the blackbody radiator and its peak wavelength to determine either the temperature or the peak wavelength of the blackbody. APP2 15-4[5] Use Stefan-Boltzmann Law to determine the rate at which energy is emitted from a blackbody radiator.
A blackbody will emit a continuous spectrum that only depends on the body's temperature. The radiation emitted by a blackbody is often modeled by plotting intensity per unit wavelength as a function of wavelength. i. The distribution of the intensity of a blackbody's spectrum as a function of temperature cannot be modeled using only classical physics concepts. A blackbody's spectrum is described by Planck's law, which assumes that the energy of light is quantized. ii. The peak wavelength emitted by a blackbody (the wavelength at which the blackbody emits the greatest amount of radiation per unit wavelength) decreases with increasing temperature, as described by Wien's law. Relevant equation: iii. The rate at which energy is emitted (power) by a blackbody is proportional to the surface area of the body and to the temperature of the body raised to the fourth power, as described by the StefanBoltzmann law. Relevant equation: APP2 15-4[3] Draw and interpret a blackbody curve for a radiating source. APP2 15-4[4] Use Wien's Law and the relationship between temperature of the blackbody radiator and its peak wavelength to determine either the temperature or the peak wavelength of the blackbody. APP2 15-4[5] Use Stefan-Boltzmann Law to determine the rate at which energy is emitted from a blackbody radiator.

Advanced Placement Physics 2 **UNIT 15: Modern Physics** **Suggested Unit Pacing: 19-20 Sessions** **Topic 15.5 The Photoelectric Effect**
NJSLS-S Performance Expectations
15.5.A Describe an interaction between photons and matter using the photoelectric effect.
Standards-Aligned Objectives. Instruction and assessment will align to the following objectives:
The photoelectric effect is the emission of electrons when electromagnetic radiation is incident upon a photoactive material. APP2 15-5[1] Observe the photoelectric effect when light of particular frequency strikes the surface of a photoactive material.
The emission of electrons via the photoelectric effect requires a minimum frequency of incident light, called the threshold frequency. i. Light that is incident on a material and is at the threshold frequency or higher will induce electron emission, regardless of the

number of photons that strike the material.
ii. The energy of the emitted electrons is not dependent on the number of photons that are incident upon the material, which provides evidence that light is a collection of discrete, quantized energy packets called photons.

APP2 15-5[2] Develop a relationship between the emission of electrons from a photoactive material and the minimum frequency of the light required to produce a current.

The maximum kinetic energy of an emitted electron is related to the frequency of the incident light and the work function of the material, φ.
i. The work function of a material is the minimum energy required to emit an electron from atoms in the material.
ii. The maximum kinetic energy of an emitted electron is given by the equation Kmax = hf - φ.
iii. In a typical experimental setup to demonstrate the photoelectric effect and determine the work function of a metal, two metal plates are placed in a vacuum chamber and connected to a variable source of potential difference. One of the plates is illuminated by monochromatic light that causes electrons to be ejected and the potential difference between the plates is adjusted until no current is measured in the circuit.

APP2 15-5[3] Use the work function of a photoactive material and the threshold frequency of the photons to determine the kinetic energy of the emitted electron.

APP2 15-5[4] Set up an experiment to demonstrate the work function of a photoactive material.

Advanced Placement Physics 2
UNIT 15: Modern Physics **Suggested Unit Pacing: 19-20 Sessions**
Topic 15.6 Compton Scattering

NJSLS-S Performance Expectations

15.6.A Describe the interaction between photons and matter using Compton scattering.

Standards-Aligned Objectives. Instruction and assessment will align to the following objectives:

In Compton scattering, a photon interacts with a free electron. The Compton effect is when a photon that emerges from the interaction has a lower energy and longer wavelength than the incoming photon. The magnitude of the change is related to the direction of the photon after the collision.

APP2 15-6[1] Apply the conservation of momentum to a collision between a photon and free electron to explain the resulting photon and its direction associated with Compton scattering

Compton scattering provides evidence that light is a collection of discrete, quantized energy packets called photons.
i. Compton scattering can be explained by treating a photon as a particle and applying conservation of energy and conservation of momentum to the collision between the photon and electron.
ii. The transfer of a photon's energy to an electron results in the energy, momentum, frequency, and wavelength of the photon changing.
Relevant equations:
E hf
$\lambda = h/p$

APP2 15-6[2] Explain how Compton scattering provides evidence that photons are discrete, quantized energy packets.

The change in wavelength experienced by a photon after colliding with an electron is related to how much the photon's direction changes.
Relevant equation:

APP2 15-6[1] Apply the conservation of momentum to a collision between a photon and free electron to explain the resulting photon and its direction associated with Compton scattering

Advanced Placement Physics 2 **UNIT 15: Modern Physics** **Suggested Unit Pacing: 19-20 Sessions** **Topic 15.7 Fission, Fusion, and Nuclear Decay**
NJSLS-S Performance Expectations
15.7.A Describe the physical properties that constrain the behavior of interacting nuclei, subatomic particles, and nucleons.
15.7.B Describe the radioactive decay of a given sample of material consisting of a finite number of nuclei.
Standards-Aligned Objectives. Instruction and assessment will align to the following objectives:
The strong force is exerted at nuclear scales and dominates the interactions of nucleons (protons or neutrons). APP2 15-7[1] Identify the type of force that dominates the interactions of nucleons.
Possible nuclear reactions are constrained by the law of conservation of nucleon number. APP2 15-7[2] Apply conservation laws to nucleon numbers to determine possible nuclear reactions.
The behavior of the constituent particles of a nuclear reaction is constrained by laws of conservation of energy, energy-mass equivalence, and conservation of momentum. *APP2 15-7[2] Apply conservation laws to nucleon numbers to determine possible nuclear reactions.
For all nuclear reactions, mass and energy may be exchanged due to mass-energy equivalence. Relevant equation: $E = mc^2$ APP2 15-7[3] Apply mass-energy equivalence to explain changes in an atom's mass.
Energy may be released in nuclear processes in the form of kinetic energy of the products or as photons. *APP2 15-7[3] Apply mass-energy equivalence to explain changes in an atom's mass.
Nuclear fusion is the process by which two or more smaller nuclei combine to form a larger nucleus, as well as subatomic particles. APP2 15-7[4] Differentiate between nuclear fusion, fission, and decay.
Nuclear fission is the process by which the nucleus of an atom splits into two or more smaller nuclei, as well as subatomic particles. *APP2 15-7[4] Differentiate between nuclear fusion, fission, and decay.
Nuclear fission may occur spontaneously or may require an energy input, depending on the binding energy of the nucleus. *APP2 15-7[4] Differentiate between nuclear fusion, fission, and decay.
Radioactive decay is the spontaneous fission of an atomic nucleus. i. The time at which an individual nucleus undergoes radioactive decay is indeterminable, but decay rates can be described using probability. ii. The half-life, $t_{1/2}$, of a radioactive material is the time it takes for half of the initial number of radioactive nuclei to have spontaneously decayed. iii. The decay constant λ can be related to the half-life of a radioactive material with the equation $\lambda = \ln 2/t_{1/2}$ APP2 15-7[5] Describe the process in which an atomic nucleus changes over time through the process of nuclear decay.

APP2 15-7[6] Define the term "half life" as it pertains to an atomic nucleus.

A material's decay constant may be used to predict the number of nuclei remaining in a sample after a period of time, or the age of a material if the initial amount of material is known.
Relevant and derived equations:

APP2 15-7[7] Predict the number of nuclei remaining in a sample after a given period of time.

APP2 15-7[8] Calculate the age of a sample using radioactive dating.

Different unstable elements and isotopes may have vastly different half-lives, ranging from fractions of a second to billions of years.

*APP2 15-7[5] Describe the process in which an atomic nucleus changes over time through the process of nuclear decay.

*APP2 15-7[6] Define the term "half life" as it pertains to an atomic nucleus.

Advanced Placement Physics 2
UNIT 15: Modern Physics **Suggested Unit Pacing: 19-20 Sessions**
Topic 15.8 Types of Radioactive Decay

NJSLS-S Performance Expectations

15.8.A Describe the processes by which individual nuclei decay

Standards-Aligned Objectives. Instruction and assessment will align to the following objectives:

Some processes by which nuclei decay emit subatomic particles with unique properties.
i. An alpha particle, or helium nucleus, consists of two neutrons and two protons and is symbolized by α or He^{2+} .
ii. Neutrinos and antineutrinos are subatomic particles that have no electrical charge, have negligible mass, and are symbolized by ν and ν(bar) , respectively.
iii. Neutrinos and antineutrinos only interact with matter via the weak force and the gravitational force, which results in very little interaction with normal matter.
iv. Positrons, or antielectrons, are subatomic particles that have an electric charge opposite that of an electron, have the same mass as an electron, and are symbolized by e^+ or β^+ .

APP2 15-8[1] Differentiate between alpha, beta, and gamma decay.

APP2 15-8[2] Identify particles based on their characteristics and how they behave in different situations.

Nuclei can undergo radioactive decay via alpha decay, beta-minus decay (β^-), beta-plus decay (β^+), and gamma decay (γ).
i. In all nuclear decays, nucleon number (the number of neutrons and protons), lepton number (the number of electrons and neutrinos), and charge are conserved.
ii. Alpha decay occurs when a nucleus ejects an alpha particle.
iii. Beta-minus decay occurs when a neutron changes to a proton by emitting an electron and antineutrino.
iv. Beta-plus decay occurs when a proton changes to a neutron by emitting a positron and neutrino.
v. Gamma decay occurs after a nucleus has undergone alpha or beta decay and the excited nucleus decays to a lower energy state by emitting a photon.

*APP2 15-8[1] Differentiate between alpha, beta, and gamma decay.

*APP2 15-8[2] Identify particles based on their characteristics and how they behave in different situations.

The type of decay exhibited by a given nucleus is determined by the isotope of the element.

*APP2 15-8[1] Differentiate between alpha, beta, and gamma decay.

*APP2 15-8[2] Identify particles based on their characteristics and how they behave in different situations.

NJSLS Career Awareness, Exploration, Preparation, and Training, and Life Literacies and Key Skills	
9.2.12.CAP.1	Analyze unemployment rates for workers with different levels of education and how the economic, social, and political conditions of a time period are affected by a recession.
9.2.12.CAP.2	Develop college and career readiness skills by participating in opportunities such as structured learning experiences, apprenticeships, and dual enrollment programs.
9.2.12.CAP.3	Investigate how continuing education contributes to one's career and personal growth.
9.2.12.CAP.4	Evaluate different careers and develop various plans (e.g. costs of public, private, training schools) and timetables for achieving them, including educational/training requirements, costs, loans, and debt repayment.
9.2.12.CAP.5	Assess and modify a personal plan to support current interests and postsecondary plans.
9.2.12.CAP.6	Identify transferable skills in career choices and design alternative career plans based on those skills.
9.2.12.CAP.7	Use online resources to examine licensing, certification, and credentialing requirements at the local, state, and national levels to maintain compliance with industry requirements in areas of career interest.
9.2.12.CAP.8	Determine job entrance criteria (e.g., education credentials, math/writing/reading comprehension tests, drug tests) used by employers in various industry sectors.
9.2.12.CAP.9	Locate information on working papers, what is required to obtain them, and who must sign them.
9.2.12.CAP.10	Identify strategies for reducing overall costs of postsecondary education (e.g., tuition assistance, loans, grants, scholarships, and student loans).
9.2.12.CAP.11	Demonstrate an understanding of Free Application for Federal Student Aid (FAFSA) requirements to apply for postsecondary education
9.2.12.CAP.11*	Explain how compulsory government programs (e.g., Social Security, Medicare) provide insurance against some loss of income and benefits to eligible recipients.
9.2.12.CAP.12	Analyze how the economic, social, and political conditions of a time period can affect the labor market.
9.2.12.CAP.13	Analyze and critique various sources of income and available resources (e.g., financial assets, property, and transfer payments) and how they may substitute for earned income.
9.2.12.CAP.14	Demonstrate how exemptions, deductions, and deferred income (e.g. retirement or medical) can reduce taxable income.
9.2.12.CAP.15	Explain why taxes are withheld from income and the relationship of federal, state, and local taxes (e.g. property, income, excise, and sales) and how the money collected is used by local, county, state, and federal governments.
9.2.12.CAP.16	Analyze the impact of the collective bargaining process on benefits, income, and fair labor practice.
9.2.12.CAP.17	Differentiate between taxable and nontaxable income from various forms of employment (e.g. cash business, tips, tax filing and withholding).
9.2.12.CAP.18	Explain the purpose of payroll deductions and why fees for various benefits (e.g., medical benefits) are taken out of pay, including the cost of employee benefits to employers and self-employment income.
9.2.12.CAP.19	Analyze a Federal and State Income Tax Return.
9.2.12.CAP.20	Explain low-cost and low-risk ways to start a business.
9.2.12.CAP.21	Compare risk and reward potential and use the comparison to decide whether starting a business is feasible.
9.2.12.CAP.22	Identify different ways to obtain capital for starting a business.
9.4.12.CI.1	Demonstrate the ability to reflect, analyze and use creative skills and ideas.
9.4.12.CI.2	Identify career pathways that highlight personal talents, skills and abilities.
9.4.12.CI.3	Investigate new challenges and opportunities for personal growth, advancement and transition
9.4.12.CT.1	Identify problem-solving strategies used in the development of an innovative product or practice.
9.4.12.CT.2	Explain the potential benefits of collaborating to enhance critical thinking and problem solving.

9.4.12.CT.3	Collaborate with individuals to analyze a variety of potential solutions to climate change effects and determine why solutions may work better than others (e.g., political. economic, cultural).
9.4.12.CT.4	Enlist input from a variety of stakeholders (e.g., community members, experts in the field) to design a service learning activity that addresses a local or global issue (e.g., environmental justice).
9.4.12.CT.5	Participate in online strategy and planning sessions for course-based, school-based or other project and determine the strategies that contribute to effective outcomes.
9.4.12.DC.1	Explain the beneficial and harmful effects that intellectual property laws can have on the creation and sharing of content.
9.4.12.DC.2	Compare and contrast international differences in copyright laws and ethics.
9.4.12.DC.3	Evaluate the social and economic implications of privacy in the context of safety, law, or ethics.
9.4.12.DC.4	Explain the privacy concerns related to the collection of data (e.g. cookies) and generation of data through automated processes that may not be evident to users.
9.4.12.DC.5	Debate laws and regulations that impact the development and use of software.
9.4.12.DC.6	Select information to post online that positively impacts personal image and future college and career opportunities.
9.4.12.DC.7	Evaluate the influence of digital communities on the nature, content and responsibilities of careers, and other aspects of society.
9.4.12.DC.8	Explain how increased network connectivity and computing capabilities of everyday objects allow for innovative technological approaches to climate protection.
9.4.12.TL.1	Assess digital tools based on features such as accessibility options, capacities and utility for accomplishing a specified task
9.4.12.TL.2	Generate data using formula-based calculations in a spreadsheet and draw conclusions about the data.
9.4.12.TL.3	Analyze the effectiveness of the process and quality of collaborative environments.
9.4.12.TL.4	Collaborate in online learning communities or social networks or virtual worlds to analyze and propose a resolution to a real-world problem.
9.4.12.GCA.1	Collaborate with individuals analyze a variety of potential solutions to climate change effects and determine why solutions may work better than others (e.g., political. economic, cultural).
9.4.12.IML.1	Compare search browsers and recognize features that allow for filtering of information.
9.4.12.IML.2	Evaluate digital sources for timeliness, accuracy, perspective, credibility of the source, and relevance of information, in media, data, or other resources.
9.4.12.IML.3	Analyze data using tools and models to make valid and reliable claims, or to determine optimal design solutions.
9.4.12.IML.4	Assess and critique the appropriateness and impact of existing data visualizations for an intended audience.
9.4.12.IML.5	Evaluate, synthesize and apply information on climate change from various sources appropriately.
9.4.12.IML.6	Use various types of media to produce and store information on climate change for different purposes and audiences with sensitivity to cultural, gender and age diversity.
9.4.12.IML.7	Develop an argument to support a claim regarding a current workplace or societal/ethical issue such as climate change.
9.4.12.IML.9	Evaluate media sources for point of view, bias and motivations.
9.4.12.IML.10	Analyze the decisions creators make to reveal explicit and implicit messages within information and media.

* ID 9.2.12.CAP.11 duplicated in NJDOE NJSLS file page 1 and 2