FOLSOM CORDOVA UNIFIED SCHOOL DISTRICT

Advanced Placement Physics 2

Date: January 2019 | **Course Length: 2 Semesters**
Proposed Grade Level(s): 11-12 | **Subject Area: Physical Science**
Grading: A - F | **Credits: 5 per semester**

Prerequisite(s): Completion of AP Physics 1; completion or concurrent enrollment in Pre-Calculus or Trigonometry.
Intent to Pursue 'A-G' College Prep Status: **Yes**
A-G Course Identifier: D- Laboratory science

COURSE DESCRIPTION:

AP Physics 2 is an algebra-based, introductory college-level physics course. This course is useful for potential engineering, pre-med, science, and computer science majors, as well as anyone interested in physics. The course covers fluids; thermodynamics; electrical force, field, and potential; electric circuits; magnetism and electromagnetic induction; geometric and physical optics; and quantum, atomic and nuclear physics. This course will prepare the student to take the Advanced Placement Examination for Physics 2. This course meets UC/CSU (Laboratory Science-d) requirements. AP Physics allows time for thorough, in-depth, student-centered inquiry activities allowing students to carry out careful experiments and design laboratory practical work to answer real world questions.

GENERAL GOALS/ESSENTIAL QUESTIONS:

- To provide further challenges and opportunities for gifted and advanced students in their high school curriculum.
- To provide students the opportunity to receive college credit for coursework completed in high school.
- To increase student knowledge and skills in the study of physics, including fluids, thermodynamics, electromagnetic force, optics and modern nuclear physics.
- To use hands-on experience to devise a scientific model and to use that model to predict physical behavior.
- To learn to think using critical thinking processes.

COMMON CORE STATE STANDARDS FOR SCIENCE & TECHNICAL SUBJECTS (11^{th} -12^{th})

Key Ideas and Details

1. Cite specific textual evidence to support analysis of science and technical texts, attending to important distinctions the author makes and to any gaps or inconsistencies in the account.
2. Determine the central ideas or conclusions of a text; summarize complex concepts, processes, or information presented in a text by paraphrasing them in simpler but still accurate terms.
3. Follow precisely a complex multistep procedure when carrying out experiments, taking measurements, or performing technical tasks; analyze the specific results based on explanations in the text.

Craft and Structure

4. Determine the meaning of symbols, key terms, and other domain-specific words and phrases as they are used in a specific scientific or technical context relevant to *grades 11-12 texts and topics*.

5. Analyze how the text structures information or ideas into categories or hierarchies, demonstrating understanding of the information or ideas.
6. Analyze the author's purpose in providing an explanation, describing a procedure, or discussing an experiment in a text, identifying important issues that remain unresolved.

Integration of Knowledge and Ideas

7. Integrate and evaluate multiple sources of information presented in diverse formats and media (e.g., quantitative data, video, multimedia) in order to address a question or solve a problem.
8. Evaluate the hypotheses, data, analysis, and conclusions in a science or technical text, verifying the data when possible and corroborating or challenging conclusions with other sources of information.
9. Synthesize information from a range of sources (e.g., texts, experiments, simulations) into a coherent understanding of a process, phenomenon, or concept, resolving conflicting information when possible.

Reading Range / Text Complexity

10. By the end of grade 12, read and comprehend science/technical texts in the grades 11-CCR text complexity band independently and proficiently.

DETAILED UNITS OF INSTRUCTION:

**See Appendix A for an elaboration on the learning outcomes*

Unit 1 Fluids

- Properties of Fluids - Gases and Liquids
- Hydrostatic Pressure
- Buoyancy (Archimedes' Principle)
- Fluid Flow Continuity (Conservation of Mass)
- Conservation of Energy and Bernoulli's Principle

Learning Outcomes*: 1.E.1.1, 1.E.1.2, 3.C.4.1, 3.C.4.2, 5.B.10.1, 5.B.10.2, 5.B.10.3, 5.B.10.4, 5.F.1.1

Unit 2 Thermodynamics

- Temperature
- Pressure
- Heat/energy transfer
- Ideal gases
- Kinetic Theory
- Laws of Thermodynamics
- Entropy
- PV diagrams
- Probability and thermal equilibrium

Learning Outcomes*: 1.E.3.1, 4.C.3.1, 5.A.2.1, 5.B.4.1, 5.B.4.2, 5.B.5.4, 5.B.5.5, 5.B.5.6, 5.B.6.1, 5.B.7.1, 5.B.7.2, 5.B.7.3, 7.A.1.1, 7.A.1.2, 7.A.2.1, 7.A.2.2, 7.A.3.1, 7.A.3.2, 7.A.3.3, 7.B.1.1, 7.B.2.1

Unit 3 Electric Force, Field and Potential

- Elementary charges and fundamental particles
- Charging and redistribution of charge
- Electric force (Coulomb's Law) and electric field
- Electric potential, potential difference and potential energy
- Electric dipoles

Learning Outcomes*: 1.B.1.1, 1.B.1.2, 1.B.2.2, 1.B.2.3, 1.B.3.1, 2.C.1.1, 2.C.1.2, 2.C.2.1, 2.C.3.1, 2.C.4.1, 2.C.4.2, 2.C.5.1, 2.C.5.2, 2.C.5.3, 2.E.2.1, 2.E.2.2, 2.E.2.3, 2.E.3.1, 2.E.3.2, 3.A.2.1, 3.A.3.2, 3.A.3.3, 3.A.3.4, 3.A.4.1, 3.A.4.2, 3.A.4.3, 3.B.1.3, 3.B.1.4, 3.B.2.1, 3.C.2.1, 3.C.2.2, 3.C.2.3, 3.G.1.2, 3.G.2.1, 3.G.3.1, 4.E.3.1, 4.E.3.2, 4.E.3.3, 4.E.3.4, 4.E.3.5, 5.A.2.1

Unit 4 Electric Circuits

- Electric resistance
- Ohm's Law
- DC circuits with resistors only
- Kirchoff's Laws
- Series, parallel and combination circuits
- Capacitance
- DC circuits with resistors and capacitors

Learning Outcomes*: 1.E.2.1, 4.E.4.1, 4.E.4.2, 4.E.4.3, 4.E.5.1, 4.E.5.2, 4.E.5.3, 5.B.9.4, 5.B.9.5, 5.B.9.6, 5.B.9.7, 5.B.9.8, 5.C.3.4, 5.C.3.5, 5.C.3.6, 5.C.3.7

Unit 5 Magnetism & Electromagnetic Induction

- Magnetic field
- Magnetic force on a charged particle
- Magnetic force on a current-carrying wire
- Magnetic flux
- Electromagnetic induction: Faraday's Law
- Lenz's Law
- Motional EMF

Learning Outcomes*: 2.C.4.1, 2.D.1.1, 2.D.2.1, 2.D.3.1, 2.D.4.1, 3.A.2.1, 3.A.3.2, 3.A.3.3, 3.A.4.1, 3.A.4.2, 3.A.4.3, 3.C.3.1, 3.C.3.2, 4.E.1.1, 4.E.2.1

Unit 6 Geometric and Physical Optics

- Nature of light and electromagnetism
- Reflection, mirrors and critical angle
- Refraction and lenses
- Total internal reflection
- Thin film interference
- Polarization
- Interference and diffraction

Learning Outcomes*: 6.A.1.2, 6.A.1.3, 6.A.2.2, 6.B.3.1, 6.C.1.1, 6.C.1.2, 6.C.2.1, 6.C.3.1, 6.C.4.1, 6.E.1.1, 6.E.2.1, 6.E.3.1, 6.E.3.2, 6.E.3.3, 6.E.4.1, 6.E.4.2, 6.E.5.1, 6.E.5.2, 6.F.1.1, 6.F.2.1

Unit 7 Quantum, Atomic and Nuclear Physics

- Brief history and development of modern physics in the late 19th and early 20th centuries
- Fundamental forces
- Theory of photons and photoelectric effect
- Radioactivity, nuclear reactions, radiations and half life
- Mass-energy equivalence
- Quantized energy states for electrons in atoms
- Energies of photon emission and absorption
- Wave particle duality, de Broglie wavelength
- Electron diffraction

Learning Outcomes*: 1.A.2.1, 1.A.4.1, 1.C.4.1, 1.D.1.1, 1.D.3.1, 4.C.4.1, 5.B.8.1, 5.B.11.1, 5.C.1.1, 5.D.1.6, 5.D.1.7, 5.D.2.5, 5.D.2.6, 5.D.3.2, 5.D.3.3, 5.G.1.1, 6.F.3.1, 6.F.4.1, 6.G.1.1, 6.G.2.1, 6.G.2.2, 7.C.1.1, 7.C.2.1, 7.C.3.1, 7.C.4.1

TEXTBOOKS and RESOURCE MATERIALS:

Textbook
Knight, R, Jones, B. and Field, S. *College Physics: A Strategic Approach*. Boston, MA: Pearson Education. Third Edition. 2015.

Supplement(s)
Advanced Physics Experiments. Pasco Scientific. 2014
College Board Classroom Resources (Curriculum Modules, Focus Materials, Articles)
(https://apcentral.collegeboard.org/courses/ap-physics-2/classroom-resources?course=ap-physics-2)

SUBJECT AREA CONTENT STANDARDS TO BE ADDRESSED:

The basis for this course are the AP Physics 2 standards developed by the College Board. However, the skill set required in writing, reading, communicating, and thinking critically is practiced regularly and reinforces those standards found in the Common Core ELA Standards. The skills practiced and reinforced through the AP Physics curriculum also support the Common Core Math Standards. In addition, several of the Next Generation Science Standards are also addressed the AP Physics 2 curriculum.

Next Generation Science Standards

Earth and Space Sciences

- HS-ESS1-1. Develop a model based on evidence to illustrate the life span of the sun and the role of nuclear fusion in the sun's core to release energy that eventually reaches Earth in the form of radiation.
- HS-ESS2-3. Develop a model based on evidence of Earth's interior to describe the cycling of matter by thermal convection.

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Physical Science

- HS-PS1-8. Develop models to illustrate the changes in the composition of the nucleus of the atom and the energy released during the processes of fission, fusion, and radioactive decay.

- HS-PS2-4. Use mathematical representations of Newton's Law of Gravitation and Coulomb's Law to describe and predict the gravitational and electrostatic forces between objects.
- HS-PS2-5. Plan and conduct an investigation to provide evidence that an electric current can produce a magnetic field and that a changing magnetic field can produce an electric current.
- HS-PS3-4. Plan and conduct an investigation to provide evidence that the transfer of thermal energy when two components of different temperature are combined within a closed system results in a more uniform energy distribution among the components in the system (second law of thermodynamics).
- HS-PS3–5. Develop and use a model of two objects interacting through electric or magnetic fields to illustrate the forces between objects and the changes in energy of the objects due to the interaction.

- HS-PS4-1. Use mathematical representations to support a claim regarding relationships among the frequency, wavelength, and speed of waves traveling in various media.
- HS-PS4-3. Evaluate the claims, evidence, and reasoning behind the idea that electromagnetic radiation can be described either by a wave model or a particle model, and that for some situations one model is more useful than the other.

Engineering Design

- HS-ETS1-2. Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering.

ADDITIONAL STANDARDS TO BE ADDRESSED IN THE COURSE:

- Appendix A: Learning Objectives by Big Idea

- AP Physics 2: Course Framework and Sample Exam Questions https://secure-media.collegeboard.org/digitalServices/pdf/ap/ap-physics-2-course-and-exam-description.pdf
  - Science Practices (SP) for AP Physics - pages 11-14
  - Content Area Outlines - pages 16-75

DISTRICT ESLRS TO BE ADDRESSED:

Students will be:

- **Self-Directed Learners:** who are expected to take responsibility for their learning by participating in class activities, labs, and discussions. Students will be expected to keep up with homework and lab prep assignments.
- **Collaborative Workers:** who will participate in cooperative groups for laboratory assignments and in class activities. They will be expected to collaborate with each other in developing class concepts.
- **Effective Communicators:** who will actively participate in class discussions on a regular basis.
- **Quality Producers/ Performers:** who will be guided to be quality performers and producers through ongoing assessment of their class work.
- **Constructive Thinkers:** who will participate in many hands-on activities and labs that require them to analyze their results critically and apply what they have learned to new situations. Students will also develop models to explain physical behaviors and phenomenon.
- **Responsible Citizens:** who will use their knowledge of physics and scientific inquiry to make informed decisions about issues related to physics, the world around them, and their daily lives.

ELECTRIC FORCE, FIELD AND POTENTIAL

BIG IDEA 1: Objects and systems have properties such as mass and charge. Systems may have internal structure.
1.B.1.1: The student is able to make claims about natural phenomena based on conservation of electric charge. **[SP 6.4]**
1.B.1.2: The student is able to make predictions, using the conservation of electric charge, about the sign and relative quantity of net charge of objects or systems after various charging processes, including conservation of charge in simple circuits. **[SP 6.4, 7.2]**
1.B.2.2: The student is able to make a qualitative prediction about the distribution of positive and negative electric charges within neutral systems as they undergo various processes. **[SP 6.4, 7.2]**
1.B.2.3: The student is able to challenge claims that polarization of electric charge or separation of charge must result in a net charge on the object. **[SP6.1]**
1.B.3.1: The student is able to challenge the claim that an electric charge smaller than the elementary charge has been isolated. **[SP 1.5, 6.1, 7.2]**

BIG IDEA 2: Fields existing in space can be used to explain interactions.
2.C.1.1: The student is able to predict the direction and the magnitude of the force exerted on an object with an electric charge q placed in an electric field E using the mathematical model of the relation between an electric force and an electric field: $\vec{F} = q\vec{E}$; a vector relation.**[SP 6.4, 7.2]**
2.C.1.2: The student is able to calculate any one of the variables — electric force, electric charge, and electric field — at a point given the values and sign or direction of the other two quantities.**[SP 2.2]**
2.C.2.1: The student is able to qualitatively and semi-quantitatively apply the vector relationship between the electric field and the net electric charge creating that field. **[SP 2.2, 6.4]**
2.C.3.1: The student is able to explain the inverse square dependence of the electric field surrounding a spherically symmetric electrically charged object. **[SP 6.2]**
2.C.4.1: The student is able to distinguish the characteristics that differ between monopole fields (gravitational field of spherical mass and electrical field due to single point charge) and dipole fields (electric dipole field and magnetic field) and make claims about the spatial behavior of the fields using qualitative or semiquantitative arguments based on vector addition of fields due to each point source, including identifying the locations and signs of sources from a vector diagram of the field. **[SP 2.2, 6.4, 7.2]**
2.C.4.2: The student is able to apply mathematical routines to determine the magnitude and direction of the electric field at specified points in the vicinity of a small set (2–4) of point charges, and express the results in terms of magnitude and direction of the field in a visual representation by drawing field vectors of appropriate length and direction at the specified points. **[SP 1.4, 2.2]**
2.C.5.1: The student is able to create representations of the magnitude and direction of the electric field at various distances (small compared to plate size) from two electrically charged plates of equal magnitude and opposite signs, and is able to recognize that the assumption of uniform field is not appropriate near edges of plates. **[SP 1.1, 2.2]**
2.C.5.2: The student is able to calculate the magnitude and determine the direction of the electric field between two electrically charged parallel plates, given the charge of each plate, or the electric potential difference and plate separation. **[SP 2.2]**
2.C.5.3: The student is able to represent the motion of an electrically charged particle in the uniform field between two oppositely charged plates and express the connection of this motion to projectile motion of an object with mass in the Earth's gravitational field. **[SP 1.1, 2.2, 7.1]**
2.E.1.1: The student is able to construct or interpret visual representations of the isolines of equal gravitational potential energy per unit mass and refer to each line as a gravitational equipotential. **[SP 1.4, 6.4, 7.2]**
2.E.2.1: The student is able to determine the structure of isolines of electric potential by constructing them in a given electric field. **[SP 6.4, 7.2]**

2.E.2.2: The student is able to predict the structure of isolines of electric potential by constructing them in a given electric field and make connections between these isolines and those found in a gravitational field. **[SP 6.4, 7.2**]
2.E.2.3: The student is able to qualitatively use the concept of isolines to construct isolines of electric potential in an electric field and determine the effect of that field on electrically charged objects. **[SP 1.4**]
2.E.3.1: The student is able to apply mathematical routines to calculate the average value of the magnitude of the electric field in a region from a description of the electric potential in that region using the displacement along the line on which the difference in potential is evaluated. **[SP 2.2**]
2.E.3.2: The student is able to apply the concept of the isoline representation of electric potential for a given electric charge distribution to predict the average value of the electric field in the region. **[SP 1.4, 6.4]**

BIG IDEA 3: The interactions of an object with other objects can be described by forces.
3.A.2.1: The student is able to represent forces in diagrams or mathematically using appropriately labeled vectors with magnitude, direction, and units during the analysis of a situation. **[SP 1.1**]
3.A.3.2: The student is able to challenge a claim that an object can exert a force on itself. **[SP 6.1**]
3.A.3.3: The student is able to describe a force as an interaction between two objects and identify both objects for any force. **[SP 1.4]**
3.A.3.4: The student is able to make claims about the force on an object due to the presence of other objects with the same property: mass, electric charge. **[SP 6.1, 6.4]**
3.A.4.1: The student is able to construct explanations of physical situations involving the interaction of bodies using Newton's third law and the representation of action-reaction pairs of forces. **[SP 1.4, 6.2]**
3.A.4.2: The student is able to use Newton's third law to make claims and predictions about the action-reaction pairs of forces when two objects interact. **[SP 6.4, 7.2]**
3.A.4.3: The student is able to analyze situations involving interactions among several objects by using free-body diagrams that include the application of Newton's third law to identify forces. **[SP 1.4]**
3.B.1.3: The student is able to reexpress a free-body diagram representation into a mathematical representation and solve the mathematical representation for the acceleration of the object. **[SP 1.5, 2.2]**
3.B.1.4: The student is able to predict the motion of an object subject to forces exerted by several objects using an application of Newton's second law in a variety of physical situations. **[SP 6.4, 7.2]**
3.B.2.1: The student is able to create and use free-body diagrams to analyze physical situations to solve problems with motion qualitatively and quantitatively. **[SP 1.1, 1.4, 2.2]**
LO 3.C.2.1: The student is able to use Coulomb's law qualitatively and quantitatively to make predictions about the interaction between two electric point charges. **[SP 2.2, 6.4]**
3.C.2.2: The student is able to connect the concepts of gravitational force and electric force to compare similarities and differences between the forces. **[SP 7.2]**
3.C.2.3: The student is able to use mathematics to describe the electric force that results from the interaction of several separated point charges (generally 2 to 4 point charges, though more are permitted in situations of high symmetry). **[SP 2.2]**
3.G.1.2: The student is able to connect the strength of the gravitational force between two objects to the spatial scale of the situation and the masses of the objects involved and compare that strength to other types of forces. **[SP 7.1]**
LO 3.G.2.1: The student is able to connect the strength of electromagnetic forces with the spatial scale of the situation, the magnitude of the electric charges, and the motion of the electrically charged objects involved. [**SP 7.1**]

BIG IDEA 4: Interactions between systems can result in changes in those systems.
4.E.3.1: The student is able to make predictions about the redistribution of charge during charging by friction, conduction, and induction. **[SP 6.4]**
4.E.3.2: The student is able to make predictions about the redistribution of charge caused by the electric field due to other systems, resulting in charged or polarized objects. **[SP 6.4, 7.2]**

4.E.3.3: The student is able to construct a representation of the distribution of fixed and mobile charge in insulators and conductors. **[SP 1.1, 1.4, 6.4]**
4.E.3.4: The student is able to construct a representation of the distribution of fixed and mobile charge in insulators and conductors that predicts charge distribution in processes involving induction or conduction. **[SP 1.1, 1.4, 6.4]**
4.E.3.5: The student is able to plan and/or analyze the results of experiments in which electric charge rearrangement occurs by electrostatic induction, or is able to refine a scientific question relating to such an experiment by identifying anomalies in a data set or procedure. **[SP 3.2, 4.1, 4.2, 5.1, 5.3]**

BIG IDEA 5: Changes that occur as a result of interactions are constrained by conservation laws.
5.A.2.1: The student is able to define open and closed systems for everyday situations and apply conservation concepts for energy, charge, and linear momentum to those situations. **[SP 6.4, 7.2**]
5.B.2.1: The student is able to calculate the expected behavior of a system using the object model (i.e., by ignoring changes in internal structure) to analyze a situation. Then, when the model fails, the student can justify the use of conservation of energy principles to calculate the change in internal energy due to changes in internal structure because the object is actually a system. **[SP 1.4, 2.1**]
5.C.2.1: The student is able to predict electric charges on objects within a system by application of the principle of charge conservation within a system. **[SP 6.4]**
5.C.2.2: The student is able to design a plan to collect data on the electrical charging of objects and electric charge induction on neutral objects and qualitatively analyze that data. **[SP 4.2, 5.1]**
5.C.2.3: The student is able to justify the selection of data relevant to an investigation of the electrical charging of objects and electric charge induction on neutral objects. **[SP 4.1]**

ELECTRIC CIRCUITS

BIG IDEA 1: Objects and systems have properties such as mass and charge. Systems may have internal structure.
1.E.2.1: The student is able to choose and justify the selection of data needed to determine resistivity for a given material. **[SP 4.1**]

BIG IDEA 4: Interactions between systems can result in changes in those systems.
4.E.4.1: The student is able to make predictions about the properties of resistors and/or capacitors when placed in a simple circuit, based on the geometry of the circuit element and supported by scientific theories and mathematical relationships. **[SP 2.2, 6.4]**
4.E.4.2: The student is able to design a plan for the collection of data to determine the effect of changing the geometry and/or materials on the resistance or capacitance of a circuit element and relate results to the basic properties of resistors and capacitors. **[SP 4.1, 4.2]**
4.E.4.3: The student is able to analyze data to determine the effect of changing the geometry and/or materials on the resistance or capacitance of a circuit element and relate results to the basic properties of resistors and capacitors. **[SP 5.1]**
4.E.5.1: The student is able to make and justify a quantitative prediction of the effect of a change in values or arrangements of one or two circuit elements on the currents and potential differences in a circuit containing a small number of sources of emf, resistors, capacitors, and switches in series and/or parallel. **[SP 2.2, 6.4]**
4.E.5.2: The student is able to make and justify a qualitative prediction of the effect of a change in values or arrangements of one or two circuit elements on currents and potential differences in a circuit containing a small number of sources of emf, resistors, capacitors, and switches in series and/or parallel. **[SP 6.1, 6.4]**
4.E.5.3: The student is able to plan data collection strategies and perform data analysis to examine the values of currents and potential differences in an electric circuit that is modified by changing or rearranging circuit elements, including sources of emf, resistors, and capacitors. **[SP 2.2, 4.2, 5.1**]

BIG IDEA 5: Changes that occur as a result of interactions are constrained by conservation laws.

5.B.9.4: The student is able to analyze experimental data including an analysis of experimental uncertainty that will demonstrate the validity of Kirchhoff's loop rule.**[SP 5.1]**
5.B.9.5: The student is able to use conservation of energy principles (Kirchhoff's loop rule) to describe and make predictions regarding electrical potential difference, charge, and current in steady-state circuits composed of various combinations of resistors and capacitors. **[SP 6.4]**
5.B.9.6: The student is able to mathematically express the changes in electric potential energy of a loop in a multiloop electrical circuit and justify this expression using the principle of the conservation of energy. **[SP 2.1, 2.2]**
5.B.9.7: The student is able to refine and analyze a scientific question for an experiment using Kirchhoff's Loop rule for circuits that includes determination of internal resistance of the battery and analysis of a non-ohmic resistor. **[SP 4.1, 4.2, 5.1, 5.3]**
5.B.9.8: The student is able to translate between graphical and symbolic representations of experimental data describing relationships among power, current, and potential difference across a resistor. **[SP 1.5]**
5.C.3.4: The student is able to predict or explain current values in series and parallel arrangements of resistors and other branching circuits using Kirchhoff's junction rule and relate the rule to the law of charge conservation. **[SP 6.4, 7.2]**
5.C.3.5: The student is able to determine missing values and direction of electric current in branches of a circuit with resistors and NO capacitors from values and directions of current in other branches of the circuit through appropriate selection of nodes and application of the junction rule. **[SP 1.4, 2.2]**
5.C.3.6: The student is able to determine missing values and direction of electric current in branches of a circuit with both resistors and capacitors from values and directions of current in other branches of the circuit through appropriate selection of nodes and application of the junction rule. **[SP 1.4, 2.2]**
5.C.3.7: The student is able to determine missing values, direction of electric current, charge of capacitors at steady state, and potential differences within a circuit with resistors and capacitors from values and directions of current in other branches of the circuit. **[SP 1.4, 2.2**]

MAGNETISM AND ELECROMAGNETIC INDUCTION

BIG IDEA 2: Fields existing in space can be used to explain interactions.
2.C.4.1: The student is able to distinguish the characteristics that differ between monopole fields (gravitational field of spherical mass and electrical field due to single point charge) and dipole fields (electric dipole field and magnetic field) and make claims about the spatial behavior of the fields using qualitative or semiquantitative arguments based on vector addition of fields due to each point source, including identifying the locations and signs of sources from a vector diagram of the field. **[SP 2.2, 6.4, 7.2**]
2.D.1.1: The student is able to apply mathematical routines to express the force exerted on a moving charged object by a magnetic field. **[SP 2.2**]
2.D.2.1: The student is able to create a verbal or visual representation of a magnetic field around a long straight wire or a pair of parallel wires. **[SP 1.1**]
2.D.3.1: The student is able to describe the orientation of a magnetic dipole placed in a magnetic field in general and the particular cases of a compass in the magnetic field of the Earth and iron filings surrounding a bar magnet. **[SP 1.2**]
2.D.4.1: The student is able to use the representation of magnetic domains to qualitatively analyze the magnetic behavior of a bar magnet composed of ferromagnetic material. **[SP 1.4**]

BIG IDEA 3: The interactions of an object with other objects can be described by forces.
3.A.2.1: The student is able to represent forces in diagrams or mathematically using appropriately labeled vectors with magnitude, direction, and units during the analysis of a situation. **[SP 1.1**]
3.A.3.2: The student is able to challenge a claim that an object can exert a force on itself. **[SP** 6.1]
3.A.3.3: The student is able to describe a force as an interaction between two objects and identify both objects for any force. **[SP 1.4]**

3.A.4.1: The student is able to construct explanations of physical situations involving the interaction of bodies using Newton's third law and the representation of action-reaction pairs of forces. **[SP 1.4, 6.2]**
3.A.4.2: The student is able to use Newton's third law to make claims and predictions about the action-reaction pairs of forces when two objects interact. **[SP 6.4, 7.2]**
3.A.4.3: The student is able to analyze situations involving interactions among several objects by using free-body diagrams that include the application of Newton's third law to identify forces. **[SP 1.4]**
3.C.3.1: The student is able to use right-hand rules to analyze a situation involving a current-carrying conductor and a moving electrically charged object to determine the direction of the magnetic force exerted on the charged object due to the magnetic field created by the current-carrying conductor. **[SP 1.4]**
3.C.3.2: The student is able to plan a data collection strategy appropriate to an investigation of the direction of the force on a moving electrically charged object caused by a current in a wire in the context of a specific set of equipment and instruments and analyze the resulting data to arrive at a conclusion. **[SP 4.2, 5.1]**

BIG IDEA 4: Interactions between systems can result in changes in those systems.
4.E.1.1: The student is able to use representations and models to qualitatively describe the magnetic properties of some materials that can be affected by magnetic properties of other objects in the system. **[SP 1.1, 1.4, 2.2**]
4.E.2.1: The student is able to construct an explanation of the function of a simple electromagnetic device in which an induced emf is produced by a changing magnetic flux through an area defined by a current loop (i.e., a simple microphone or generator) or of the effect on behavior of a device in which an induced emf is produced by a constant magnetic field through a changing area. **[SP 6.4**]

THERMODYNAMICS

BIG IDEA 1: Objects and systems have properties such as mass and charge. Systems may have internal structure.
1.E.3.1: The student is able to design an experiment and analyze data from it to examine thermal conductivity. **[SP 4.1, 4.2, 5.1**]

BIG IDEA 4: Interactions between systems can result in changes in those systems.
4.C.3.1: The student is able to make predictions about the direction of energy transfer due to temperature differences based on interactions at the microscopic level. **[SP 6.4**]

BIG IDEA 5: Changes that occur as a result of interactions are constrained by conservation laws.
5.A.2.1: The student is able to define open and closed systems for everyday situations and apply conservation concepts for energy, charge, and linear momentum to those situations. **[SP 6.4, 7.2**]
5.B.4.1: The student is able to describe and make predictions about the internal energy of systems. **[SP 6.4, 7.2**]
5.B.4.2: The student is able to calculate changes in kinetic energy and potential energy of a system, using information from representations of that system. **[SP 1.4, 2.1, 2.2**]
5.B.5.4: The student is able to make claims about the interaction between a system and its environment in which the environment exerts a force on the system, thus doing work on the system and changing the energy of the system (kinetic energy plus potential energy). **[SP 6.4, 7.2**]
5.B.5.5: The student is able to predict and calculate the energy transfer to (i.e., the work done on) an object or system from information about a force exerted on the object or system through a distance. **[SP 2.2, 6.4**]
5.B.5.6: The student is able to design an experiment and analyze graphical data in which interpretations of the area under a pressure-volume curve are needed to determine the work done on or by the object or system. **[SP 4.2, 5.1**]
5.B.6.1: The student is able to describe the models that represent processes by which energy can be transferred between a system and its environment because of differences in temperature: conduction, convection, and radiation. **[SP 1.2**]

5.B.7.1: The student is able to predict qualitative changes in the internal energy of a thermodynamic system involving transfer of energy due to heat or work done and justify those predictions in terms of conservation of energy principles. **[SP 6.4, 7.2**]
5.B.7.2: The student is able to create a plot of pressure versus volume for a thermodynamic process from given data. **[SP 1.1**]
5.B.7.3: The student is able to use a plot of pressure versus volume for a thermodynamic process to make calculations of internal energy changes, heat, or work, based upon conservation of energy principles (i.e., the first law of thermodynamics). **[SP 1.1, 1.4, 2.2**]

BIG IDEA 7: The mathematics of probability can be used to describe the behavior of complex systems and to interpret the behavior of quantum mechanical systems.
7.A.1.1: The student is able to make claims about how the pressure of an ideal gas is connected to the force exerted by molecules on the walls of the container, and how changes in pressure affect the thermal equilibrium of the system. **[SP 6.4, 7.2]**
7.A.1.2: Treating a gas molecule as an object (i.e., ignoring its internal structure), the student is able to analyze qualitatively the collisions with a container wall and determine the cause of pressure, and at thermal equilibrium, to quantitatively calculate the pressure, force, or area for a thermodynamic problem given two of the variables. **[SP 1.4, 2.2]**
7.A.2.1: The student is able to qualitatively connect the average of all kinetic energies of molecules in a system to the temperature of the system. **[SP 7.1]**
7.A.2.2: The student is able to connect the statistical distribution of microscopic kinetic energies of molecules to the macroscopic temperature of the system and to relate this to thermodynamic processes. **[SP 7.1]**
7.A.3.1: The student is able to extrapolate from pressure and temperature or volume and temperature data to make the prediction that there is a temperature at which the pressure or volume extrapolates to zero. **[SP 6.4, 7.2]**
7.A.3.2: The student is able to design a plan for collecting data to determine the relationships between pressure, volume, and temperature, and amount of an ideal gas, and to refine a scientific question concerning a proposed incorrect relationship between the variables. **[SP 3.2, 4.2]**
7.A.3.3: The student is able to analyze graphical representations of macroscopic variables for an ideal gas to determine the relationships between these variables and to ultimately determine the ideal gas law $PV = nRT$. **[SP 5.1]**
7.B.1.1: The student is able to construct an explanation, based on atomic-scale interactions and probability, of how a system approaches **[SP 6.4, 7.2]**
7.B.2.1: The student is able to connect qualitatively the second law of thermodynamics in terms of the state function called entropy and how it (entropy) behaves in reversible and irreversible processes. **[SP 7.1]**

FLUIDS

BIG IDEA 1: Objects and systems have properties such as mass and charge. Systems may have internal structure.
1.E.1.1: The student is able to predict the densities, differences in densities, or changes in densities under different conditions for natural phenomena and design an investigation to verify the prediction. **[SP 4.2, 6.4**]
1.E.1.2: The student is able to select from experimental data the information necessary to determine the density of an object and/or compare densities of several objects. **[SP 4.1, 6.4**]

BIG IDEA 3: The interactions of an object with other objects can be described by forces.
3.C.4.1: The student is able to make claims about various contact forces between objects based on the microscopic cause of those forces. **[SP 6.1**]
3.C.4.2: The student is able to explain contact forces (tension, friction, normal, buoyant, spring) as arising from interatomic electric forces and that they therefore have certain directions. **[SP 6.2**]

BIG IDEA 5: Changes that occur as a result of interactions are constrained by conservation laws.
5.B.10.1: The student is able to use Bernoulli's equation to make calculations related to a moving fluid. **[SP 2.2**]
5.B.10.2: The student is able to use Bernoulli's equation and/or the relationship between force and pressure to make calculations related to a moving fluid. **[SP 2.2**]
5.B.10.3: The student is able to use Bernoulli's equation and the continuity equation to make calculations related to a moving fluid. **[SP 2.2**]
5.B.10.4: The student is able to construct an explanation of Bernoulli's equation in terms of the conservation of energy. **[SP 6.2**]
5.F.1.1: The student is able to make calculations of quantities related to flow of a fluid, using mass conservation principles (the continuity equation). **[SP 2.1, 2.2, 7.2**]

GEOMETRIC AND PHYSICAL OPTICS

BIG IDEA 6: Waves can transfer energy and momentum from one location to another without the permanent transfer of mass and serve as a mathematical model for the description of other phenomena.
6.A.1.2: The student is able to describe representations of transverse and longitudinal waves. **[SP 1.2]**
6.A.1.3: The student is able to analyze data (or a visual representation) to identify patterns that indicate that a particular mechanical wave is polarized and construct an explanation of the fact that the wave must have a vibration perpendicular to the direction of energy propagation. **[SP 5.1, 6.2]**
6.A.2.2: The student is able to contrast mechanical and electromagnetic waves in terms of the need for a medium in wave propagation. **[SP 6.4, 7.2**]
6.B.3.1: The student is able to construct an equation relating the wavelength and amplitude of a wave from a graphical representation of the electric or magnetic field value as a function of position at a given time instant and vice versa, or construct an equation relating the frequency or period and amplitude of a wave from a graphical representation of the electric or magnetic field value at a given position as a function of time and vice versa. **[SP 1.5**]
6.C.1.1: The student is able to make claims and predictions about the net disturbance that occurs when two waves overlap. Examples should include standing waves. **[SP 6.4, 7.2]**
6.C.1.2: The student is able to construct representations to graphically analyze situations in which two waves overlap over time using the principle of superposition. **[SP 1.4]**
6.C.2.1: The student is able to make claims about the diffraction pattern produced when a wave passes through a small opening, and to qualitatively apply the wave model to quantities that describe the generation of a diffraction pattern when a wave passes through an opening whose dimensions are comparable to the wavelength of the wave. **[SP 1.4, 6.4, 7.2**]
6.C.3.1: The student is able to qualitatively apply the wave model to quantities that describe the generation of interference patterns to make predictions about interference patterns that form when waves pass through a set of openings whose spacing and widths are small compared to the wavelength of the waves. **[SP 1.4, 6.4**]
6.C.4.1: The student is able to predict and explain, using representations and models, the ability or inability of waves to transfer energy around corners and behind obstacles in terms of the diffraction property of waves in situations involving various kinds of wave phenomena, including sound and light. **[SP 6.4, 7.2**]
6.E.1.1: The student is able to make claims using connections across concepts about the behavior of light as the wave travels from one medium into another, as some is transmitted, some is reflected, and some is absorbed. **[SP 6.4, 7.2**]
6.E.2.1: The student is able to make predictions about the locations of object and image relative to the location of a reflecting surface. The prediction should be based on the model of specular reflection with all angles measured relative to the normal to the surface. **[SP 6.4, 7.2**]
6.E.3.1: The student is able to describe models of light traveling across a boundary from one transparent material to another when the speed of propagation changes, causing a change in the path of the light ray at the boundary of the two media. **[SP 1.1, 1.4]**

6.E.3.2: The student is able to plan data collection strategies as well as perform data analysis and evaluation of the evidence for finding the relationship between the angle of incidence and the angle of refraction for light crossing boundaries from one transparent material to another (Snell's law). **[SP 4.1, 5.1, 5.2, 5.3]**
6.E.3.3: The student is able to make claims and predictions about path changes for light traveling across a boundary from one transparent material to another at non-normal angles resulting from changes in the speed of propagation. **[SP 6.4, 7.2]**
LO 6.E.4.1: The student is able to plan data collection strategies, and perform data analysis and evaluation of evidence about the formation of images due to reflection of light from curved spherical mirrors. **[SP 3.2, 4.1, 5.1, 5.2, 5.3]**
LO 6.E.4.2: The student is able to use quantitative and qualitative representations and models to analyze situations and solve problems about image formation occurring due to the reflection of light from surfaces. **[SP 1.4, 2.2]**
LO 6.E.5.1: The student is able to use quantitative and qualitative representations and models to analyze situations and solve problems about image formation occurring due to the refraction of light through thin lenses. **[SSP 1.4, 2.2]**
LO 6.E.5.2: The student is able to plan data collection strategies, perform data analysis and evaluation of evidence, and refine scientific questions about the formation of images due to refraction for thin lenses. **[SP 3.2, 4.1, 5.1, 5.2, 5.3]**
6.F.1.1: The student is able to make qualitative comparisons of the wavelengths of types of electromagnetic radiation. **[SP 6.4, 7.2**]
6.F.2.1: The student is able to describe representations and models of electromagnetic waves that explain the transmission of energy when no medium is present. **[SP 1.1**]

QUANTUM PHYSICS, ATOMIC AND NUCLEAR PHYSICS

BIG IDEA 1: Objects and systems have properties such as mass and charge. Systems may have internal structure.
1.A.2.1: The student is able to construct representations of the differences between a fundamental particle and a system composed of fundamental particles and to relate this to the properties and scales of the systems being investigated. **[SP 1.1, 7.1**]
1.A.4.1: The student is able to construct representations of the energy-level structure of an electron in an atom and to relate this to the properties and scales of the systems being investigated. **[SP 1.1, 7.1**]
1.C.4.1: The student is able to articulate the reasons that the theory of conservation of mass was replaced by the theory of conservation of mass-energy. **[SP 6.3**]
1.D.1.1: The student is able to explain why classical mechanics cannot describe all properties of objects by articulating the reasons that classical mechanics must be refined and an alternative explanation developed when classical particles display wave properties. **[SP 6.3**]
1.D.3.1: The student is able to articulate the reasons that classical mechanics must be replaced by special relativity to describe the experimental results and theoretical predictions that show that the properties of space and time are not absolute. [Students will be expected to recognize situations in which nonrelativistic classical physics breaks down and to explain how relativity addresses that breakdown, but students will not be expected to know in which of two reference frames a given series of events corresponds to a greater or lesser time interval, or a greater or lesser spatial distance; they will just need to know that observers in the two reference frames can "disagree" about some time and distance intervals.] **[SP 6.3, 7.1**]

BIG IDEA 3: The interactions of an object with other objects can be described by forces.
3.G.3.1: The student is able to identify the strong force as the force that is responsible for holding the nucleus together. **[SP 7.2**]

BIG IDEA 4: Interactions between systems can result in changes in those systems.
4.C.4.1: The student is able to apply mathematical routines to describe the relationship between mass and energy and apply this concept across domains of scale. **[SP 2.2, 2.3, 7.2**]

BIG IDEA 5: Changes that occur as a result of interactions are constrained by conservation laws.
5.B.8.1: The student is able to describe emission or absorption spectra associated with electronic or nuclear transitions as transitions between allowed energy states of the atom in terms of the principle of energy conservation, including characterization of the frequency of radiation emitted or absorbed. **[SP 1.2, 7.2**]
5.B.11.1: The student is able to apply conservation of mass and conservation of energy concepts to a natural phenomenon and use the equation $E = mc2$ to make a related calculation. **[SP 2.2, 7.2**]
5.C.1.1: The student is able to analyze electric charge conservation for nuclear and elementary particle reactions and make predictions related to such reactions based upon conservation of charge. **[SP 6.4, 7.2**]
5.D.1.6: The student is able to make predictions of the dynamical properties of a system undergoing a collision by application of the principle of linear momentum conservation and the principle of the conservation of energy in situations in which an elastic collision may also be assumed. **[SP 6.4]**
5.D.1.7: The student is able to classify a given collision situation as elastic or inelastic, justify the selection of conservation of linear momentum and restoration of kinetic energy as the appropriate principles for analyzing an elastic collision, solve for missing variables, and calculate their values. **[SP 2.1, 2.2]**
5.D.2.5: The student is able to classify a given collision situation as elastic or inelastic, justify the selection of conservation of linear momentum as the appropriate solution method for an inelastic collision, recognize that there is a common final velocity for the colliding objects in the totally inelastic case, solve for missing variables, and calculate their values. **[SP 2.1, 2.2]**
5.D.2.6: The student is able to apply the conservation of linear momentum to a closed system of objects involved in an inelastic collision to predict the change in kinetic energy. **[SP 6.4, 7.2]**
5.D.3.2: The student is able to make predictions about the velocity of the center of mass for interactions within a defined one-dimensional system. **[SP 6.4]**
5.D.3.3: The student is able to make predictions about the velocity of the center of mass for interactions within a defined two-dimensional system. **[SP 6.4]**
5.G.1.1: The student is able to apply conservation of nucleon number and conservation of electric charge to make predictions about nuclear reactions and decays such as fission, fusion, alpha decay, beta decay, or gamma decay. **[SP 6.4**]

BIG IDEA 6: Waves can transfer energy and momentum from one location to another without the permanent transfer of mass and serve as a mathematical model for the description of other phenomena.
6.F.3.1: The student is able to support the photon model of radiant energy with evidence provided by the photoelectric effect. **[SP 6.4**]
6.F.4.1: The student is able to select a model of radiant energy that is appropriate to the spatial or temporal scale of an interaction with matter. **[SP 6.4, 7.1**]
6.G.1.1: The student is able to make predictions about using the scale of the problem to determine at what regimes a particle or wave model is more appropriate. **[SP 6.4, 7.1**]
6.G.2.1: The student is able to articulate the evidence supporting the claim that a wave model of matter is appropriate to explain the diffraction of matter interacting with a crystal, given conditions where a particle of matter has momentum corresponding to a de Broglie wavelength smaller than the separation between adjacent atoms in the crystal. **[SP 6.1]**
6.G.2.2: The student is able to predict the dependence of major features of a diffraction pattern (e.g., spacing between interference maxima), based upon the particle speed and de Broglie wavelength of electrons in an electron beam interacting with a crystal. (de Broglie wavelength need not be given, so students may need to obtain it.) **[SP 6.4]**

BIG IDEA 7: The mathematics of probability can be used to describe the behavior of complex systems and to interpret the behavior of quantum mechanical systems.
7.C.1.1: The student is able to use a graphical wave function representation of a particle to predict qualitatively the probability of finding a particle in a specific spatial region. **[SP 1.4**]
7.C.2.1: The student is able to use a standing wave model in which an electron orbit circumference is an integer multiple of the de Broglie wavelength to give a qualitative explanation that accounts for the existence of specific allowed energy states of an electron in an atom. **[SP 1.4**]
7.C.3.1: The student is able to predict the number of radioactive nuclei remaining in a sample after a certain period of time, and also predict the missing species (alpha, beta, gamma) in a radioactive decay. **[SP 6.4**]
7.C.4.1: The student is able to construct or interpret representations of transitions between atomic energy states involving the emission and absorption of photons. [For questions addressing stimulated emission, students will not be expected to recall the details of the process, such as the fact that the emitted photons have the same frequency and phase as the incident photon; but given a representation of the process, students are expected to make inferences such as figuring out from energy conservation that since the atom loses energy in the process, the emitted photons taken together must carry more energy than the incident photon.] **[SP 1.1, 1.2**]