Revised:
Board Approved:

AP Physics B Yearly Standards

Units	Priority Standards	Supporting Standards	Science Practices
Unit 1: Fluids	**1.A** The internal structure of a system determines many properties of the system. **1.E** Materials have many macroscopic properties that result from the arrangement and interactions of the atoms and molecules that make up the material. **3.A** All forces share certain common characteristics when considered by observers in inertial reference frames. **3.B** Classically, the acceleration of an object interacting with other objects can be predicted by using $\overline{a} = \frac{\Sigma F}{m}$ **3.C** At the macroscopic level, forces can be categorized as either long-range (action-at-a-distance) forces or contact forces. **5.B** The energy of a system is	**1.A.5.2** Construct representations of how the properties of a system are determined by the interactions of its constituent substructures. [SP 1.1, 1.4, 7.1] **1.E.1.1** 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** 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] **3.A.2.1** Represent forces in diagrams or mathematically using appropriately labeled vectors with magnitude, direction, and units during the analysis of a situation. [SP 1.1]	**1.1** The student can create representations and models of natural or man-made phenomena and systems in the domain. **1.4** The student can use representations and models to analyze situations or solve problems qualitatively and quantitatively.* **7.1** The student can connect phenomena and models across spatial and temporal scales.* **4.1** The student can justify the selection of the kind of data needed to answer a particular scientific question. **4.2** The student can design a plan for collecting data to answer a particular scientific question. **6.4** The student can make claims and predictions about natural phenomena based on scientific theories and models. **6.1** The student can justify claims with evidence.* **6.2** The student can construct explanations of phenomena based on

	conserved. **5.F** Classically, the mass of a system is conserved	**3.A.3.2** Construct an explanation for why an object cannot exert a force on itself. [SP 6.1] **3.A.3.3** Describe a force as an interaction between two objects and identify both objects for any force. [SP 1.4] **3.A.3.4** Make claims about the force on an object due to the presence of other objects with the same properties: mass, electric charge. [SP 6.1, 6.4] **3.A.4.1** 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** Make claims and predictions about the action-reaction pairs of forces when two objects interact using Newton's third law. [SP 6.4, 7.2] **3.A.4.3** 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**	evidence produced through scientific practices **7.2** The student can connect concepts in and across domain(s) to generalize or extrapolate in and/or across enduring understandings and/or big ideas. **1.5** The student can re-express key elements of natural phenomena across multiple representations in the domain. **2.2** The student can apply mathematical routines to quantities that describe natural phenomena **2.1** The student can justify the selection of a mathematical routine to solve problems.

		Re-express 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** 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** 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] **3.C.4.1** Make claims about various contact forces between objects based on the microscopic cause of those forces. [SP 6.1] **3.C.4.2** Explain contact forces (tension, friction, normal, buoyant, spring) as arising from interatomic electric forces and that they therefore have certain directions. [SP 6.2] **5.B.10.1** Make calculations related to a moving fluid using Bernoulli's equation. [SP 2.2] **5.B.10.2** Make calculations related to a moving	

		fluid using Bernoulli's equation and/or the relationship between force and pressure. [SP 2.2] **<u>5.B.10.3</u>** Make calculations related to a moving fluid using Bernoulli's equation and the continuity equation. [SP 2.2] **<u>5.B.10.4</u>** Construct an explanation of Bernoulli's equation in terms of the conservation of energy. [SP 6.2] **<u>5.F.1.1</u>** Make calculations of quantities related to flow of a fluid, using mass conservation principles (the continuity equation). [SP 2.1, 2.2, 7.2]	
Unit 2: Thermodynamics	**<u>1.A</u>** The internal structure of a system determines many properties of the system. **<u>7.A</u>** The properties of an ideal gas can be explained in terms of a small number of macroscopic variables, including temperature and pressure. **<u>3.A</u>** All forces share certain common characteristics when considered by observers in inertial reference frames. **<u>3.B</u>** Classically, the acceleration of an	**<u>1.A.5.2</u>** Construct representations of how the properties of a system are determined by the interactions of its constituent substructures. [SP 1.1, 1.4, 7.1] **<u>7.A.1.1</u>** 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] **<u>7.A.1.2</u>**	**<u>1.1</u>** The student can create representations and models of natural or man-made phenomena and systems in the domain.* **<u>1.4</u>** The student can use representations and models to analyze situations or solve problems qualitatively and quantitatively.* **<u>7.1</u>** The student can connect phenomena and models across spatial and temporal scales.* **<u>2.2</u>** The student can apply mathematical routines to quantities that describe natural phenomena. **<u>3.2</u>** The student can refine scientific questions. **<u>4.2</u>** The student can design a plan for

	object interacting with other objects can be predicted by using $\overline{a} = \frac{\Sigma F}{m}$ **3.C** At the macroscopic level, forces can be categorized as either long-range (action-at-a-distance) forces or contact forces. **4.C** Interactions with other objects or systems can change the total energy of a system **5.B** The energy of a system is conserved. **5.D** The linear momentum of a system is conserved. **1.E** Materials have many macroscopic properties that result from the arrangement and interactions of the atoms and molecules that make up the material **7.B** The tendency of isolated systems to move toward states with higher disorder is described by probability	Treating a gas molecule as an object (i.e., ignoring its internal structure), analyze qualitatively the collisions with a container wall and determine the cause of pressure, and at thermal equilibrium, 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** 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** Connect the statistical distribution of microscopic kinetic energies of molecules to the macroscopic temperature of the system and relate this to thermodynamic processes. [SP 7.1] **7.A.3.1** Extrapolate from pressure and temperature or volume and temperature data to make the prediction that there is a temperature at which the pressure	collecting data to answer a particular scientific question. **5.1** The student can analyze data to identify patterns or relationships. **6.4** The student can make claims and predictions about natural phenomena based on scientific theories and models **7.2** The student can connect concepts in and across domain(s) to generalize or extrapolate in and/or across enduring understandings and/or big ideas. **6.1** The student can justify claims with evidence.* **6.2** The student can construct explanations of phenomena based on evidence produced through scientific practices. **1.5** The student can re-express key elements of natural phenomena across multiple representations in the domain. **1.2** The student can describe representations and models of natural or man-made phenomena and systems in the domain **2.1** The student can justify the selection of a mathematical routine to solve problems. **4.1** The student can justify the selection of the kind of data needed to answer a particular scientific question.*

		or volume extrapolates to zero. [SP 6.4, 7.2] **7.A.3.2** Design a plan for collecting data to determine the relationships between pressure, volume, and temperature, and/or the amount of an ideal gas; and to refine a scientific question proposing an incorrect relationship between the variables. [SP 3.2, 4.2] **7.A.3.3** 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] **3.A.2.1** 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** Construct an explanation for why an object cannot exert a force on itself. [SP 6.1] **3.A.3.3**	

		Describe a force as an interaction between two objects and identify both objects for any force. [SP 1.4] **3.A.3.4** Make claims about the force on an object due to the presence of other objects with the same properties: mass, electric charge. [SP 6.1, 6.4] **3.A.4.1** 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** Make claims and predictions about the action-reaction pairs of forces when two objects interact using Newton's third law. [SP 6.4, 7.2] **3.A.4.3** 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** Re-express 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** 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** 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] **3.C.4.1** Make claims about various contact forces between objects based on the microscopic cause of those forces. [SP 6.1] **3.C.4.2** Explain contact forces (tension, friction, normal, buoyant, spring) as arising from interatomic electric forces and that they therefore have certain	

		directions. [SP 6.2] **<u>4.C.3.1</u>** Make predictions about the direction of energy transfer due to temperature differences based on interactions at the microscopic level. [SP 6.4] **<u>5.B.2.1</u>** 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, 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] **<u>5.B.4.1</u>** Describe and make predictions about the internal energy of systems. [SP 6.4, 7.2] **<u>5.B.4.2</u>** 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]	

		[SP 1.4, 2.1, 2.2] **5.B.5.4** 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** 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** 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** 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] **<u>5.B.7.1</u>** 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] **<u>5.B.7.2</u>** Create a plot of pressure versus volume for a thermodynamic process from given data. [SP 1.1] **<u>5.B.7.3</u>** Make calculations of internal energy changes, heat, or work, based on conservation of energy principles (i.e., the first law of thermodynamics), using a plot of pressure versus volume for a thermodynamic process. [SP 1.1, 1.4, 2.2] **<u>5.D.1.6</u>** Make predictions of the dynamical properties of a system undergoing a collision by application of the	

		principle of linear momentum conservation and the principle the conservation of energy in situations in which an elastic collision may also be assumed. [SP 6.4] **5.D.1.7** 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** 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**	

		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] **1.E.3.1** Design an experiment, and analyze data from it to examine thermal conductivity. [SP 4.1, 4.2, 5.1] **7.B.1.1** Construct an explanation, based on atomic-scale interactions and probability, of how a system approaches thermal equilibrium when energy is transferred to it or from it in a thermal process. [SP 6.2] **7.B.2.1** 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]	
Unit 3: Electric Force, Field, and	**1.A** The internal structure of a system determines many properties of the	**1.A.5.2** Construct representations of how the properties of	**1.1** The student can create representations and models of natural or man-made phenomena and systems

Potential	system. **1.B** Electric charge is a property of an object or system that affects its interactions with other objects or systems containing charge. **5.C** The electric charge of a system is conserved. **4.E** The electric and magnetic properties of a system can change in response to the presence of, or changes in, other objects or systems. **1.E** Materials have many macroscopic properties that result from the arrangement and interactions of the atoms and molecules that make up the material **3.A** All forces share certain common characteristics when considered by observers in inertial reference frames. **3.B** Classically, the acceleration of an object interacting with other objects can be predicted by using $\overline{a} = \frac{\Sigma F}{m}$	a system are determined by the interactions of its constituent substructures. [SP 1.1, 1.4, 7.1] **1.B.1.1** Make claims about natural phenomena based on conservation of electric charge. [SP 6.4] **1.B.1.2** 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.2.1** Construct an explanation of the two charge model of electric charge based on evidence produced through scientific practices. [SP 6.2] **1.B.2.2** 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** Challenge claims that	in the domain.* **1.4** The student can use representations and models to analyze situations or solve problems qualitatively and quantitatively.* **7.1** The student can connect phenomena and models across spatial and temporal scales.* **6.2** The student can construct explanations of phenomena based on evidence produced through scientific practices. **6.4** The student can make claims and predictions about natural phenomena based on scientific theories and models. **7.2** The student can connect concepts in and across domain(s) to generalize or extrapolate in and/or across enduring understandings and/or big ideas. **4.1** The student can justify the selection of the kind of data needed to answer a particular scientific question. **4.2** The student can design a plan for collecting data to answer a particular scientific question.* **5.1** The student can analyze data to identify patterns or relationships **3.2** The student can refine scientific questions. **5.3** The student can evaluate the evidence provided by data sets in relation to a particular scientific question **6.1** The student can justify claims with evidence.*

	3.C At the macroscopic level, forces can be categorized as either long-range (action-at-a-distance) forces or contact forces **3.G** Certain types of forces are considered fundamental. **2.A** A field associates a value of some physical quantity with every point in space. Field models are useful for describing interactions that occur at a distance (long-range forces) as well as a variety of other physical phenomena **2.C** An electric field is caused by an object with electric charge. **2.E** Physicists often construct a map of isolines connecting points of equal value for some quantity related to a field and use these maps to help visualize the field. **5.B** The energy of a system is conserved.	polarization of electric charge or separation of charge must result in a net charge on the object. [SP 6.1] **1.B.3.1** Construct an explanation that challenges the claim that an electric charge smaller than the elementary charge has been isolated. [SP 1.5, 6.1, 7.2] **5.C.2.1** 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** 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** 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] **4.E.3.1** Make predictions about the redistribution of charge	**1.5** The student can re-express key elements of natural phenomena across multiple representations in the domain.* **2.2** The student can apply mathematical routines to quantities that describe natural phenomena **2.1** The student can justify the selection of a mathematical routine to solve problems

		during charging by friction, conduction, and induction. [SP 6.4] **<u>4.E.3.2</u>** 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] **<u>4.E.3.3</u>** Construct a representation of the distribution of fixed and mobile charge in insulators and conductors. [SP 1.1, 1.4, 6.4] **<u>4.E.3.4</u>** 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] **<u>4.E.3.5</u>** Plan and/or analyze the results of experiments in which electric-charge rearrangement occurs by electrostatic induction, or be 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] **3.A.2.1** 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** Construct an explanation for why an object cannot exert a force on itself. [SP 6.1] **3.A.3.3** Describe a force as an interaction between two objects and identify both objects for any force. [SP 1.4] **3.A.3.4** Make claims about the force on an object due to the presence of other objects with the same properties: mass, electric charge. [SP 6.1, 6.4] **3.A.4.1** 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**	

		Make claims and predictions about the action-reaction pairs of forces when two objects interact using Newton's third law. [SP 6.4, 7.2] **3.A.4.3** 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** Re-express 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** 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** 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] **<u>3.C.2.1</u>** Make predictions about the interaction between two electric point charges, using Coulomb's law qualitatively and quantitatively. [SP 2.2, 6.4] **<u>3.C.2.2</u>** Connect the concepts of gravitational force and electric force to compare similarities and differences between the forces. [SP 7.2] **<u>3.C.2.3</u>** Describe the electric force that results from the interaction of several separated point charges (generally two to four point charges, though more are permitted in situations of high symmetry) using appropriate mathematics. [SP 2.2] **<u>3.G.1.2</u>** 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 with other types of forces. [SP 7.1]	

		3.G.2.1 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] **2.C.1.1** 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: $F=qE$ a vector relation. [SP 6.4, 7.2] **2.C.1.2** 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** 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** Explain the inverse square dependence of the electric field surrounding a spherically symmetric, electrically charged object. [SP 6.2] **2.C.4.1** 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** Apply mathematical routines to determine the magnitude and direction of the electric field at specified points in the	

		vicinity of a small set (two to four) 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** Create representations of the magnitude and direction of the electric field at various distances (small compared with plate size) from two electrically charged plates of equal magnitude and opposite signs, and be 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** 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** 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 Earth's gravitational field. [SP 1.1, 2.2, 7.1] **<u>2.E.1.1</u>** 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] **<u>2.E.2.1</u>** Determine the structure of isolines of electric potential by constructing them in a given electric field. [SP 6.4, 7.2] **<u>2.E.2.2</u>** 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] **<u>2.E.2.3</u>** Construct isolines of electric potential in an electric field,	

		and determine the effect of that field on electrically charged objects, qualitatively using the concept of isolines. [SP 1.4] **2.E.3.1** 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** 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] **5.B.2.1** 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, 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.B.4.1** Describe and make predictions about the internal energy of systems. [SP 6.4, 7.2] **5.B.4.2** 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** 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** 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]	
Unit 4: Circuits	**1.B** Electric charge is a property of an object or system that affects its interactions with other objects or systems containing charge. **1.E** Materials have many macroscopic properties that result from the arrangement and interactions of the atoms and molecules that make up the material. **4.E** The electric and magnetic properties of a system can change in response to the presence of, or changes in, other objects or systems. **5.B** The energy of a system is conserved. **5.C** The electric charge of a system is conserved.	**1.B.1.1** Make claims about natural phenomena based on conservation of electric charge. [SP 6.4] **1.B.1.2** 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.2.1** Construct an explanation of the two charge model of electric charge based on evidence produced through scientific practices. [SP 6.2] **1.B.2.2** 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** Challenge claims that polarization of electric charge or separation of charge must result in a net charge on the object. [SP 6.1] **1.E.2.1** Select and justify the data needed to	**6.1** The student can justify claims with evidence.* **6.2** The student can construct explanations of phenomena based on evidence produced through scientific practices.* **6.4** The student can make claims and predictions about natural phenomena based on scientific theories and models.* **7.2** The student can connect concepts in and across domain(s) to generalize or extrapolate in and/or across enduring understandings and/or big ideas.* **4.1** The student can justify the selection of the kind of data needed to answer a particular scientific question. **2.2** The student can apply mathematical routines to quantities that describe natural phenomena. **4.1** The student can justify the selection of the kind of data needed to answer a particular scientific question. **4.2** The student can design a plan for collecting data to answer a particular scientific question. **5.1** The student can analyze data to identify patterns or relationships. **1.5** The student can re-express key elements of natural phenomena across multiple representations

		determine resistivity for a given material. [SP 4.1] **4.E.4.1** 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** 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** 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** 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]	in the domain. **2.1** The student can justify the selection of a mathematical routine to solve problems **5.3** The student can evaluate the evidence provided by data sets in relation to a particular scientific question **1.4** The student can use representations and models to analyze situations or solve problems qualitatively and quantitatively

		4.E.5.2 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** 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] **5.B.9.4** Analyze experimental data including an analysis of experimental uncertainty that will demonstrate the validity of Kirchhoff's loop rule: $\Delta V=0$. [SP 5.1] **5.B.9.5** Describe and make predictions regarding electrical potential difference, charge, and current in steady- state circuits composed of various combinations of resistors and capacitors using conservation of energy principles (Kirchhoff's loop rule). [SP 6.4] **5.B.9.6** Mathematically express the changes in	

		electric potential energy of a loop in a multi loop electrical circuit, and justify this expression using the principle of the conservation of energy. [SP 2.1, 2.2] **5.B.9.7** 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** 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** Predict or describe current values in series and parallel arrangements of resistors and other branching circuits using Kirchhoff's junction rule, and explain the relationship of the rule to the law of charge conservation. [SP 6.4, 7.2] **5.C.3.5** 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] **<u>5.C.3.6</u>** 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] **<u>5.C.3.7</u>** 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]	
Unit 5: Magnetism	**<u>1.A</u>** The internal structure of a system determines many properties of the system. **<u>1.E</u>** Materials have many macroscopic properties that result from the arrangement and interactions of the atoms and molecules that make up the material. **<u>2.A</u>** A field associates a value of some physical quantity with every point in	**<u>1.A.5.2</u>** Construct representations of how the properties of a system are determined by the interactions of its constituent substructures. [SP 1.1, 1.4, 7.1] **<u>2.C.4.1</u>** Distinguish the characteristics that differ between monopole fields (gravitational field of spherical mass and electrical field due to	**<u>1.1</u>** The student can create representations and models of natural or man-made phenomena and systems in the domain. **<u>1.4</u>** The student can use representations and models to analyze situations or solve problems qualitatively and quantitatively.* **<u>7.1</u>** The student can connect phenomena and models across spatial and temporal scales.* **<u>2.2</u>** The student can apply mathematical routines to quantities that describe natural phenomena.

	space. Field models are useful for describing interactions that occur at a distance (long-range forces) as well as a variety of other physical phenomena. **2.C** An electric field is caused by an object with electric charge **2.D** A magnetic field is caused by a magnet or moving electrically charged object. Magnetic fields observed in nature always seem to be produced either by moving charged objects or by magnetic dipoles or combinations of dipoles and never by single poles. **3.C** At the macroscopic level, forces can be categorized as either long-range (action-at-a-distance) forces or contact forces. **3.A** All forces share certain common characteristics when considered by observers in inertial reference frames. **3.B** Classically, the acceleration of an object interacting with other objects can be predicted by using	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** Apply mathematical routines to express the force exerted on a moving charged object by a magnetic field. [SP 2.2] **2.D.2.1** Create a verbal or visual representation of a magnetic field around a straight wire or a pair of parallel wires. [SP 1.1] **2.D.3.1** 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 Earth and iron filings surrounding a bar magnet. [SP 1.2]	**6.4** The student can make claims and predictions about natural phenomena based on scientific theories and models **7.2** The student can connect concepts in and across domain(s) to generalize or extrapolate in and/or across enduring understandings and/or big ideas. **1.2** The student can describe representations and models of natural or man-made phenomena and systems in the domain **4.2** The student can design a plan for collecting data to answer a particular scientific question. **5.1** The student can analyze data to identify patterns or relationships. **6.1** The student can justify claims with evidence.* **6.2** The student can construct explanations of phenomena based on evidence produced through scientific practices

	$\overline{a} = \frac{\Sigma F}{m}$ **3.G** Certain types of forces are considered fundamental. **4.E** The electric and magnetic properties of a system can change in response to the presence of, or changes in, other objects or systems.	**2.D.4.1** Qualitatively analyze the magnetic behavior of a bar magnet composed of ferromagnetic material. [SP 1.4] **3.C.3.1** 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** 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] **3.A.2.1** Represent forces in diagrams or mathematically using appropriately labeled vectors with magnitude, direction,	

		and units during the analysis of a situation. [SP 1.1] **<u>3.A.3.2</u>** Construct an explanation for why an object cannot exert a force on itself. [SP 6.1] **<u>3.A.3.3</u>** Describe a force as an interaction between two objects and identify both objects for any force. [SP 1.4] **<u>3.A.3.4</u>** Make claims about the force on an object due to the presence of other objects with the same properties: mass, electric charge. [SP 6.1, 6.4] **<u>3.A.4.1</u>** 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] **<u>3.A.4.2</u>** Make claims and predictions about the action-reaction pairs of forces when two objects interact using Newton's third law. [SP 6.4, 7.2] **<u>3.A.4.3</u>** 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] **<u>3.B.1.3</u>** Re-express 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] **<u>3.B.1.4</u>** 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] **<u>3.B.2.1</u>** 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] **<u>3.G.2.1</u>** 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] **4.E.1.1** 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** 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]	
Unit 6: Optics	**6.A** A wave is a traveling disturbance that transfers energy and momentum. **6.F**	**6.A.1.2** Describe representations of transverse and longitudinal waves. [SP 1.2] **6.A.1.3**	**1.2** The student can describe representations and models of natural or man-made phenomena and systems in the domain **5.1** The student can analyze data to

	Electromagnetic radiation can be modeled as waves or as fundamental particles. **6.B** A periodic wave is one that repeats as a function of both time and position and can be described by its amplitude, frequency, wavelength, speed, and energy. **6.E** The direction of propagation of a wave such as light may be changed when the wave encounters an interface between two media. **6.C** Only waves exhibit interference and diffraction.	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** Contrast mechanical and electromagnetic waves in terms of the need for a medium in wave propagation. [SP 6.4, 7.2] **6.F.1.1** Make qualitative comparisons of the wavelengths of types of electromagnetic radiation. [SP 6.4, 7.2] **6.F.2.1** Describe representations and models of electromagnetic waves that explain the transmission of energy when no medium is present. [SP 1.1] **6.B.3.1** Construct an equation relating the wavelength and amplitude of a wave from a graphical representation of the electric or magnetic field	identify patterns or relationships. **6.2** The student can construct explanations of phenomena based on evidence produced through scientific practices. **6.4** The student can make claims and predictions about natural phenomena based on scientific theories and models. **7.2** The student can connect concepts in and across domain(s) to generalize or extrapolate in and/or across enduring understandings and/or big ideas. **1.1** The student can create representations and models of natural or man-made phenomena and systems in the domain. **1.5** The student can re-express key elements of natural phenomena across multiple representations in the domain. **1.4** The student can use representations and models to analyze situations or solve problems qualitatively and quantitatively.* **4.1** The student can justify the selection of the kind of data needed to answer a particular scientific question. **5.2** The student can refine observations and measurements based on data analysis. **5.3** The student can evaluate the evidence provided by data sets in relation to a particular scientific question **2.2** The student can apply mathematical

		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.E.1.1** 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** 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** Describe models of light traveling across a boundary	routines to quantities that describe natural phenomena. **3.2** The student can refine scientific questions.

		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** 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** 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] **6.E.4.1** 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] **6.E.4.2** 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] **6.E.5.1** 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. [SP 1.4, 2.2] **6.E.5.2** 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.C.1.1** Make claims and predictions about the net disturbance that occurs when two waves	

		overlap. Examples include standing waves. [SP 6.4, 7.2] **6.C.1.2** 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** Make claims about the diffraction pattern produced when a wave passes through a small opening, and 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** 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 with the wavelength of the waves.	

		[SP 1.4, 6.4] **6.C.4.1** 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]	
Unit 7: Quantum, Atomic, and Nuclear Physics	**1.A** The internal structure of a system determines many properties of the system **3.G** Certain types of forces are considered fundamental. **5.C** The electric charge of a system is conserved. **5.D** The linear momentum of a system is conserved. **5.G** Nucleon number is conserved. **5.B** The energy of a system is conserved. **1.C**	**1.A.2.1** Construct representations of the differences between a fundamental particle and a system composed of fundamental particles, and relate this to the properties and scales of the systems being investigated. [SP 1.1, 7.1] **1.A.4.1** Construct representations of the energy-level structure of an electron in an atom, and relate this to the properties and scales of the systems being investigated. [SP 1.1, 7.1] **3.G.3.1**	**1.1** The student can create representations and models of natural or man-made phenomena and systems in the domain. **1.2** The student can describe representations and models of natural or man-made phenomena and systems in the domain **1.4** The student can use representations and models to analyze situations or solve problems qualitatively and quantitatively.* **7.2** The student can connect concepts in and across domain(s) to generalize or extrapolate in and/or across enduring understandings and/or big ideas **7.1** The student can connect phenomena and models across spatial and temporal scales.*

	Objects and systems have properties of inertial mass and gravitational mass that are experimentally verified to be the same and satisfy conservation principles. **4.C** Interactions with other objects or systems can change the total energy of a system. **1.D** Classical mechanics cannot describe all properties of objects. **6.C** Only waves exhibit interference and diffraction. **6.G** All matter can be modeled as waves or particles. **6.F** Electromagnetic radiation can be modeled as waves or as fundamental particles. **7.C** At the quantum scale, matter is described by a wave function, which leads to a probabilistic description of the microscopic world.	Identify the strong force as the force that is responsible for holding the nucleus together. [SP 7.2] **5.C.1.1** Analyze electric charge conservation for nuclear and elementary particle reactions, and make predictions related to such reactions based on conservation of charge. [SP 6.4, 7.2] **5.D.1.6** 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** 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.	**2.2** The student can apply mathematical routines to quantities that describe natural phenomena **2.1** The student can justify the selection of a mathematical routine to solve problems. **6.4** The student can make claims and predictions about natural phenomena based on scientific theories and models. **2.3** The student can estimate numerically quantities that describe natural phenomena **6.3** The student can articulate the reasons that scientific explanations and theories are refined or replaced **6.1** The student can justify claims with evidence. **7.1** The student can connect phenomena and models across spatial and temporal scales

		[SP 2.1, 2.2] **<u>5.D.2.5</u>** 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] **<u>5.D.2.6</u>** 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] **<u>5.D.3.2</u>** Make predictions about the velocity of the center of mass for interactions within a defined one-dimensional system. [SP 6.4] **<u>5.D.3.3</u>** 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** 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] **5.B.2.1** 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, 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.B.4.1** Describe and make predictions about the internal energy of systems. [SP 6.4, 7.2] **5.B.4.2** 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** 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.8.1** 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** Apply conservation of mass and conservation of energy concepts to a natural phenomenon, and use the equation $E=mc^2$ to make a related calculation.	

		[SP 2.2, 7.2] **<u>1.C.4.1</u>** Articulate the reasons that the theory of conservation of mass was replaced by the theory of conservation of mass–energy. [SP 6.3] **<u>4.C.4.1</u>** 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] **<u>1.D.1.1</u>** 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] **<u>1.D.3.1</u>** 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] **6.C.1.1** Make claims and predictions about the net disturbance that occurs when two waves overlap. Examples include standing waves. [SP 6.4, 7.2] **6.C.1.2** 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** Make claims about the diffraction pattern produced when a wave passes through a small opening, and 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** 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 with the wavelength of the waves. [SP 1.4, 6.4] **6.C.4.1** 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.G.1.1**	

		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] **<u>6.G.2.1</u>** 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] **<u>6.G.2.2</u>** Predict the dependence of major features of a diffraction pattern (e.g., spacing between interference maxima) based on 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] **<u>6.F.3.1</u>**	

		Support the photon model of radiant energy with evidence provided by the photoelectric effect. [SP 6.4] **6.F.4.1** 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] **7.C.1.1** 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** 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** 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** 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]	