HS-PS2-1

Students who demonstrate understanding can:

HS-PS2-1. **Analyze data to support the claim that Newton's second law of motion describes the mathematical relationship among the net force on a macroscopic object, its mass, and its acceleration.** [Clarification Statement: Examples of data could include tables or graphs of position or velocity as a function of time for objects subject to a net unbalanced force, such as a falling object, an object rolling down a ramp, or a moving object being pulled by a constant force.] [*Assessment Boundary: Assessment is limited to one-dimensional motion and to macroscopic objects moving at non-relativistic speeds.*]

The performance expectation above was developed using the following elements from *A Framework for K-12 Science Education*:

Science and Engineering Practices

Analyzing and Interpreting Data
Analyzing data in 9–12 builds on K–8 and progresses to introducing more detailed statistical analysis, the comparison of data sets for consistency, and the use of models to generate and analyze data.

- Analyze data using tools, technologies, and/or models (e.g., computational, mathematical) in order to make valid and reliable scientific claims or determine an optimal design solution.

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Connections to Nature of Science

Science Models, Laws, Mechanisms, and Theories Explain Natural Phenomena

- Theories and laws provide explanations in science.
- Laws are statements or descriptions of the relationships among observable phenomena.

Disciplinary Core Ideas

PS2.A: Forces and Motion

- Newton's second law accurately predicts changes in the motion of macroscopic objects.

Crosscutting Concepts

Cause and Effect

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

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

1	Organizing data	
	a	Students organize data that represent the net force on a macroscopic object, its mass (which is held constant), and its acceleration (e.g., via tables, graphs, charts, vector drawings).
2	Identifying relationships	
	a	Students use tools, technologies, and/or models to analyze the data and identify relationships within the datasets, including:
		i. A more massive object experiencing the same net force as a less massive object has a smaller acceleration, and a larger net force on a given object produces a correspondingly larger acceleration; and
		ii. The result of gravitation is a constant acceleration on macroscopic objects as evidenced by the fact that the ratio of net force to mass remains constant.
3	Interpreting data	
	a	Students use the analyzed data as evidence to describe* that the relationship between the observed quantities is accurately modeled across the range of data by the formula $a = F_{net}/m$ (e.g., double force yields double acceleration, etc.).
	b	Students use the data as empirical evidence to distinguish between causal and correlational relationships linking force, mass, and acceleration.
	c	Students express the relationship F_{net}=ma in terms of causality, namely that a net force on an object causes the object to accelerate.

HS-PS2-2

Students who demonstrate understanding can:

HS-PS2-2. **Use mathematical representations to support the claim that the total momentum of a system of objects is conserved when there is no net force on the system.** [Clarification Statement: Emphasis is on the quantitative conservation of momentum in interactions and the qualitative meaning of this principle.] [*Assessment Boundary: Assessment is limited to systems of two macroscopic bodies moving in one dimension.*]

The performance expectation above was developed using the following elements from *A Framework for K-12 Science Education*:

Science and Engineering Practices

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

- Use mathematical representations of phenomena to describe explanations.

Disciplinary Core Ideas

PS2.A: Forces and Motion

- Momentum is defined for a particular frame of reference; it is the mass times the velocity of the object.
- If a system interacts with objects outside itself, the total momentum of the system can change; however, any such change is balanced by changes in the momentum of objects outside the system.

Crosscutting Concepts

Systems and System Models

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

Observable features of the student performance by the end of the course:		
1	Representation	
	a	Students clearly define the system of the two interacting objects that is represented mathematically, including boundaries and initial conditions.
	b	Students identify and describe* the momentum of each object in the system as the product of its mass and its velocity, $p = mv$ (p and v are restricted to one-dimensional vectors), using the mathematical representations.
	c	Students identify the claim, indicating that the total momentum of a system of two interacting objects is constant if there is no net force on the system.
2	Mathematical modeling	
	a	Students use the mathematical representations to model and describe* the physical interaction of the two objects in terms of the change in the momentum of each object as a result of the interaction.
	b	Students use the mathematical representations to model and describe* the total momentum of the system by calculating the vector sum of momenta of the two objects in the system.
3	Analysis	
	a	Students use the analysis of the motion of the objects before the interaction to identify a system with essentially no net force on it.
	b	Based on the analysis of the total momentum of the system, students support the claim that the momentum of the system is the same before and after the interaction between the objects in the system, so that momentum of the system is constant.
	c	Students identify that the analysis of the momentum of each object in the system indicates that any change in momentum of one object is balanced by a change in the momentum of the other object, so that the total momentum is constant.

HS-PS2-3

Students who demonstrate understanding can:

HS-PS2-3. **Apply scientific and engineering ideas to design, evaluate, and refine a device that minimizes the force on a macroscopic object during a collision.*** [Clarification Statement: Examples of evaluation and refinement could include determining the success of the device at protecting an object from damage and modifying the design to improve it. Examples of a device could include a football helmet or a parachute.] [*Assessment Boundary: Assessment is limited to qualitative evaluations and/or algebraic manipulations.*]

The performance expectation above was developed using the following elements from *A Framework for K-12 Science Education*:

Science and Engineering Practices

Constructing Explanations and Designing Solutions

Constructing explanations and designing solutions in 9–12 builds on K–8 experiences and progresses to explanations and designs that are supported by multiple and independent student-generated sources of evidence consistent with scientific ideas, principles, and theories.

- Apply scientific ideas to solve a design problem, taking into account possible unanticipated effects.

Disciplinary Core Ideas

PS2.A: Forces and Motion

- If a system interacts with objects outside itself, the total momentum of the system can change; however, any such change is balanced by changes in the momentum of objects outside the system.

ETS1.A: Defining and Delimiting an Engineering Problem

- Criteria and constraints also include satisfying any requirements set by society, such as taking issues of risk mitigation into account, and they should be quantified to the extent possible and stated in such a way that one can tell if a given design meets them. *(secondary)*

ETS1.C: Optimizing the Design Solution

- Criteria may need to be broken down into simpler ones that can be approached systematically, and decisions about the priority of certain criteria over others (tradeoffs) may be needed. *(secondary)*

Crosscutting Concepts

Cause and Effect

- Systems can be designed to cause a desired effect.

Observable features of the student performance by the end of the course:			
1	Using scientific knowledge to generate the design solution		
	a	Students design a device that minimizes the force on a macroscopic object during a collision. In the design, students:	
		i.	Incorporate the concept that for a given change in momentum, force in the direction of the change in momentum is decreased by increasing the time interval of the collision ($F\Delta t = m\Delta v$); and
		ii.	Explicitly make use of the principle above so that the device has the desired effect of reducing the net force applied to the object by extending the time the force is applied to the object during the collision.
	b	In the design plan, students describe* the scientific rationale for their choice of materials and for the structure of the device.	
2	Describing criteria and constraints, including quantification when appropriate		

	a	Students describe* and quantify (when appropriate) the criteria and constraints, along with the tradeoffs implicit in these design solutions. Examples of constraints to be considered are cost, mass, the maximum force applied to the object, and requirements set by society for widely used collision-mitigation devices (e.g., seatbelts, football helmets).
3	Evaluating potential solutions	
	a	Students systematically evaluate the proposed device design or design solution, including describing* the rationales for the design and comparing the design to the list of criteria and constraints.
	b	Students test and evaluate the device based on its ability to minimize the force on the test object during a collision. Students identify any unanticipated effects or design performance issues that the device exhibits.
4	Refining and/or optimizing the design solution	
	a	Students use the test results to improve the device performance by extending the impact time, reducing the device mass, and/or considering cost-benefit analysis.

HS-PS2-4

Students who demonstrate understanding can:

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

The performance expectation above was developed using the following elements from *A Framework for K-12 Science Education*:

Science and Engineering Practices

Using Mathematics and Computational Thinking

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

- Use mathematical representations of phenomena to describe explanations.

- -

Connections to Nature of Science

Science Models, Laws, Mechanisms, and Theories Explain Natural Phenomena

- Theories and laws provide explanations in science.
- Laws are statements or descriptions of the relationships among observable phenomena.

Disciplinary Core Ideas

PS2.B: Types of Interactions

- Newton's law of universal gravitation and Coulomb's law provide the mathematical models to describe and predict the effects of gravitational and electrostatic forces between distant objects.
- Forces at a distance are explained by fields (gravitational, electric, and magnetic) permeating space that can transfer energy through space. Magnets or electric currents cause magnetic fields; electric charges or changing magnetic fields cause electric fields.

Crosscutting Concepts

Patterns

- Different patterns may be observed at each of the scales at which a system is studied and can provide evidence for causality in explanations of phenomena.

Observable features of the student performance by the end of the course:		
1	Representation	
	a	Students clearly define the system of the interacting objects that is mathematically represented.
	b	Using the given mathematical representations, students identify and describe* the gravitational attraction between two objects as the product of their masses divided by the separation distance squared $\left(F_g = -G\frac{m_1 m_2}{d^2}\right)$, where a negative force is understood to be attractive.
	c	Using the given mathematical representations, students identify and describe* the electrostatic force between two objects as the product of their individual charges divided by the separation distance squared $\left(F_e = k\frac{q_1 q_2}{d^2}\right)$, where a negative force is understood to be attractive.
2	Mathematical modeling	
	a	Students correctly use the given mathematical formulas to predict the gravitational force between objects or predict the electrostatic force between charged objects.
3	Analysis	
	a	Based on the given mathematical models, students describe* that the ratio between gravitational and electric forces between objects with a given charge and mass is a pattern that is independent of distance.

	b	Students describe* that the mathematical representation of the gravitational field $\left(F_g = -G\frac{m_1 m_2}{d^2}\right)$ only predicts an attractive force because mass is always positive.
	c	Students describe* that the mathematical representation of the electric field $\left(F_e = k\frac{q_1 q_2}{d^2}\right)$ predicts both attraction and repulsion because electric charge can be either positive or negative.
	d	Students use the given formulas for the forces as evidence to describe* that the change in the energy of objects interacting through electric or gravitational forces depends on the distance between the objects.

HS-PS2-5

Students who demonstrate understanding can:

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

The performance expectation above was developed using the following elements from *A Framework for K-12 Science Education*:

Science and Engineering Practices

Planning and Carrying Out Investigations
Planning and carrying out investigations to answer questions or test solutions to problems in 9–12 builds on K–8 experiences and progresses to include investigations that provide evidence for and test conceptual, mathematical, physical and empirical models.

- Plan and conduct an investigation individually and collaboratively to produce data to serve as the basis for evidence, and in the design: decide on types, how much, and accuracy of data needed to produce reliable measurements and consider limitations on the precision of the data (e.g., number of trials, cost, risk, time), and refine the design accordingly.

Disciplinary Core Ideas

PS2.B: Types of Interactions

- Newton's law of universal gravitation and Coulomb's law provide the mathematical models to describe and predict the effects of gravitational and electrostatic forces between distant objects. (HS-PS2-4)
- Forces at a distance are explained by fields (gravitational, electric, and magnetic) permeating space that can transfer energy through space. Magnets or electric currents cause magnetic fields; electric charges or changing magnetic fields cause electric fields.

PS3.A: Definitions of Energy

- "Electrical energy" may mean energy stored in a battery or energy transmitted by electric currents. *(secondary)*

Crosscutting Concepts

Cause and Effect

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

Observable features of the student performance by the end of the course:			
1	Identifying the phenomenon to be investigated		
	a	Students describe* the phenomenon under investigation, which includes the following idea: that an electric current produces a magnetic field and that a changing magnetic field produces an electric current.	
2	Identifying the evidence to answer this question		
	a	Students develop an investigation plan and describe* the data that will be collected and the evidence to be derived from the data about 1) an observable effect of a magnetic field that is uniquely related to the presence of an electric current in the circuit, and 2) an electric current in the circuit that is uniquely related to the presence of a changing magnetic field near the circuit. Students describe* why these effects seen must be causal and not correlational, citing specific cause-effect relationships.	
3	Planning for the investigation		
	a	In the investigation plan, students include:	
		i.	The use of an electric circuit through which electric current can flow, a source of electrical energy that can be placed in the circuit, the shape and orientation of the wire, and the types and positions of detectors;
		ii.	A means to indicate or measure when electric current is flowing through the circuit;
		iii.	A means to indicate or measure the presence of a local magnetic field near the circuit; and

		iv. A design of a system to change the magnetic field in a nearby circuit and a means to indicate or measure when the magnetic field is changing.
	b	In the plan, students state whether the investigation will be conducted individually or collaboratively.
4	Collecting the data	
	a	Students measure and record electric currents and magnetic fields.
5	Refining the design	
	a	Students evaluate their investigation, including an evaluation of:
		i. The accuracy and precision of the data collected, as well as limitations of the investigation; and
		ii. The ability of the data to provide the evidence required.
	b	If necessary, students refine the investigation plan to produce more accurate, precise, and useful data such that the measurements or indicators of the presence of an electric current in the circuit and a magnetic field near the circuit can provide the required evidence.

HS-PS2-6

Students who demonstrate understanding can:

HS-PS2-6. **Communicate scientific and technical information about why the molecular-level structure is important in the functioning of designed materials.*** [Clarification Statement: Emphasis is on the attractive and repulsive forces that determine the functioning of the material. Examples could include why electrically conductive materials are often made of metal, flexible but durable materials are made up of long chained molecules, and pharmaceuticals are designed to interact with specific receptors.] [*Assessment Boundary: Assessment is limited to provided molecular structures of specific designed materials.*]

The performance expectation above was developed using the following elements from *A Framework for K-12 Science Education*:

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Obtaining, Evaluating, and Communicating Information Obtaining, evaluating, and communicating information in 9–12 builds on K–8 and progresses to evaluating the validity and reliability of the claims, methods, and designs. • Communicate scientific and technical information (e.g., about the process of development and the design and performance of a proposed process or system) in multiple formats (including oral, graphical, textual and mathematical).	**PS2.B: Types of Interactions** • Attraction and repulsion between electric charges at the atomic scale explain the structure, properties, and transformations of matter, as well as the contact forces between material objects.	**Structure and Function** • Investigating or designing new systems or structures requires a detailed examination of the properties of different materials, the structures of different components, and connections of components to reveal its function and/or solve a problem.

Observable features of the student performance by the end of the course:			
1	Communication style and format		
	a	Students use at least two different formats (including oral, graphical, textual and mathematical) to communicate scientific and technical information, including fully describing* the structure, properties, and design of the chosen material(s). Students cite the origin of the information as appropriate.	
2	Connecting the DCIs and the CCCs		
	a	Students identify and communicate the evidence for why molecular level structure is important in the functioning of designed materials, including:	
		i.	How the structure and properties of matter and the types of interactions of matter at the atomic scale determine the function of the chosen designed material(s); and
		ii.	How the material's properties make it suitable for use in its designed function.
	b	Students explicitly identify the molecular structure of the chosen designed material(s) (using a representation appropriate to the specific type of communication — e.g., geometric shapes for drugs and receptors, ball and stick models for long-chained molecules).	
	c	Students describe* the intended function of the chosen designed material(s).	
	d	Students describe* the relationship between the material's function and its macroscopic properties (e.g., material strength, conductivity, reactivity, state of matter, durability) and each of the following:	
		i.	Molecular level structure of the material;
		ii.	Intermolecular forces and polarity of molecules; and
		iii.	The ability of electrons to move relatively freely in metals.
	e	Students describe* the effects that attractive and repulsive electrical forces between molecules have on the arrangement (structure) of the chosen designed material(s) of molecules (e.g., solids, liquids, gases, network solid, polymers).	
	f	Students describe* that, for all materials, electrostatic forces on the atomic and molecular scale results in contact forces (e.g., friction, normal forces, stickiness) on the macroscopic scale.	