HIGH SCHOOL PHYSICS: MOTION

Standards Bundle

Standards are listed within the bundle. Bundles are created with potential instructional use in mind, based upon the potential for related phenomena that can be used throughout a unit.

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 (SEP: 4; DCI: PS2.A; CCC: Cause/Effect). [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 sliding down a ramp, or a moving object being pulled by a constant force.] *[Assessment Boundary: Assessment is limited to one-dimensional motion and macroscopic objects moving at non-relativistic speeds.]*

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 (SEP: 5; DCI: PS2.A; CCC: Systems). [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.]*

HS-PS2-3 Design, evaluate, and refine a device that minimizes the force on a macroscopic object during a collision (SEP: 6; DCI: PS2.A, ETS1.A, ETS1.C; CCC: Cause/Effect). Alignment may include HS-ETS1-1, HS-ETS1-3 [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.]*

HS-ESS1-4 Use mathematical or computational representations to predict the motion of orbiting objects in the solar system (SEP: 5; DCI: ESS1.B; CCC: Scale/Prop.). [Clarification Statement: Emphasis is on Newtonian gravitational laws governing orbital motions, which apply to human-made satellites as well as planets and moons.] *[Assessment Boundary: Mathematical representations for the gravitational attraction of bodies and Kepler's Laws of orbital motions should not deal with more than two bodies, nor involve calculus.]*

Content Overview

This section provides a generic overview of the content or disciplinary core ideas as an entry point to the standards.

Newton's second law of motion provides a mathematical relationship between a macroscopic object's mass and its acceleration that can be supported through the collection of data. When no outside force acts on a macroscopic system, momentum before and after a collision is always the same and can be calculated through mathematical equations. Newton's laws of motion can be used to design, evaluate, or modify forces during collisions of macroscopic objects.

Momentum is determined by the speed of an object the direction it is traveling (velocity) and the object's mass. Momentum is conserved if there are no new objects added to the system. If a new object is added, then the momentum will change to maintain a balance in the overall system. Devices can be designed and tested, that will use this balance of forces to minimize the effects of a change in momentum on an object.

Laws of motion can also be used to represent and predict the circular motion of objects orbiting in the solar system.

Phenomena

Phenomena can be used at varying levels of instruction. One could be used to anchor an entire unit, while another might be more supplemental for anchoring just a unit. Please remember that phenomena should allow students to engage in the SEP and use the CCC/DCI to understand and explain the phenomenon.

- In driver's education class, stopping times for different types of vehicles are discussed. It is noted that it takes more force for a semi-tractor and trailer to stop than it does for a compact car to stop.
- If a passenger in a car is not wearing a seatbelt, they can be ejected from the car during an accident.
- Following an auto accident, highway patrol officers record many pieces of data about the accident, including things such as the length of skid marks, locations of vehicles, and the sizes of the various vehicles involved. This data is then used to recreate the accident.
- My friends and I like to visit our area's amusement park. Through experience, we found that for our comfort it is important we sit in a certain manner in the ride's cart for rides that spin around.
- I was worried when riding the corkscrew ride with friends that the contents of my pockets might fall out while the ride turned me upside down. My fears were ill-founded.
- Gravity assist can be used to help launch satellites or other space crafts into orbits. For example, if a satellite is moving in the same direction as Jupiter in its orbit, the satellite can increase its speed by 30,000 miles per hour.

Storyline

This section aims to decode not only the DCI connections but also the SEP and CCC in a detailed account of how they possibly fit together in a progression for student learning, including both rationale and context for the bundle.

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Analyzing and Interpreting Data ● Analyze data using tools, technologies, and/or models (e.g., computational,	**PS2.A: Forces and Motion** ● Newton's second law accurately predicts changes in the motion of macroscopic objects. ● If a system interacts with objects outside itself, the total momentum of the system can change; however, any such	**Cause and Effect** ● Empirical evidence is required to differentiate between cause and

mathematical) to make valid and reliable scientific claims or determine an optimal design solution. **Constructing Explanations and Designing Solutions** ● Apply scientific ideas to solve a design problem, considering possible unanticipated effects. **Using Mathematics and Computational Thinking** ● Use mathematical representations of phenomena to describe explanations. ● Use mathematical or computational representations of phenomena to describe explanations.	change is balanced by changes in the momentum of objects outside the system. ● Momentum is defined for a particular frame of reference; it is the mass times the velocity of the object. 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 (trade-offs) may be needed. (Secondary) **ESS1.B: Earth and the Solar System** ● Kepler's laws describe common features of the motions of orbiting objects, including their elliptical paths around the sun. Orbits may change due to the gravitational effects from, or collisions with, other objects in the solar system.	correlation and make claims about specific causes and effects. ● Systems can be designed to cause a desired effect. **Systems and System Models** ● When investigating or describing a system, the boundaries and initial conditions of the system need to be defined. **Scale, Proportion, and Quantity** ● Algebraic thinking is used to examine scientific data and predict the effect of a change in one variable on another (e.g., linear growth vs. exponential growth).

Observations and collected data can show the relationship between force, mass, and acceleration. Analysis of this data and observations should provide evidence for patterns within the relationships between force, mass, and acceleration which is Newton's second law of motion that says force equals mass times acceleration. As the force on an object increases, so does the acceleration it experiences. Likewise, the larger the mass of an object, the larger the force required for acceleration.

Conservation of momentum is a concept that can be examined through several methods. Two objects interacting within a system of motion, or cause and effect relationships between the impacts of two objects can both be examined following the Law of Conservation of Momentum. Students will use algebraic thinking to model that the total momentum of two objects colliding is conserved when there is no net force acting on the system. Data involving two objects colliding in either a real-world scenario or a virtual lab can be observed and collected. After the discovery of how the overall system interacts, predictions can be made about the interaction between two new objects. Mathematical representations can be made to describe and/or support the predictions and explanations. To show an understanding of the concept of momentum, specifically that momentum is conserved in a collision, scientific and engineering ideas can be applied to design a device that minimizes the force of a collision on a macroscopic object. Examples of this could include, airbags, springs, restraints, or anything that could increase the length of time the collision occurs. This device will need to be tested and refined based on scientific observations made of the cause-and-effect relationship between the interactions that occur in a collision. The final product should remain within the engineering constraints (financial, societal, or biological) that have been defined.

Newtonian gravitational laws govern the orbital motion of human-made satellites, planets, and moons. Mathematical and computational models can be used to predict the motion of orbiting objects using Kepler's Laws of orbital motion. The motion of these orbiting objects may be changed due to gravitational effects or from collisions within the solar system and through algebraic thinking quantified.

Formative Assessment

Formative assessment is crucial because all learners benefit from timely and focused feedback from others. It promotes self-reflection, self-explanation, and social learning. It can also make learning more relevant. Each of the questions below might be used throughout the formative assessment process. Specific prompts may focus on individual practices, core ideas, or crosscutting concepts, but, together, the components need to support inferences about students' three-dimensional science learning as described in a given bundle, standard, or lesson-level performance expectation.

SEP Analyzing and Interpreting Data

- Analyze the data and identify relationships within the datasets that show 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.
- Analyze the data and identify relationships within the datasets, showing 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.
- Based on the analysis of the total momentum of the system, support the claim that in a system, the momentum is the same before and after the interaction between the objects in the system, so that the momentum of the system is constant.

SEP Constructing Explanations and Designing Solutions

- Determine the best possible design for a solution to minimize the net force on an object under a given set of prioritized constraints and utilize a design matrix to aid in the process of optimization of the design.
- Describe and quantify (when appropriate) the tradeoffs implicit in the design solutions for minimizing harm in collisions. For example, 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 such as seatbelts or football helmets.
- Evaluate systematically the proposed device design including describing the rationales for the design and comparing the design to the list of criteria and constraints.

SEP Using Mathematics and Computational Thinking

- Support the conservation of momentum within a system through mathematical representations.
- Use the mathematical representations to calculate the vector sum of the momenta of the two objects in the system.
- Use mathematical and computational representations to predict interplanetary motion.

CCC Cause and Effect

- According to Newton's second law, what is the effect on the acceleration if the net force is increased and the mass remains constant?
- According to Newton's second law, what is the effect on the net force if the acceleration is increased and the mass remains constant?
- According to Newton's second law, what is the effect on the net force if the mass is increased and the acceleration is kept constant?

CCC Systems and System Models

- How can the relationship between the system of net force, acceleration, and mass be modeled?
- How can a model be used to show that the result of gravitation is a constant acceleration based on macroscopic evidence?
- Within a system how can the conservation of momentum be modeled both conceptually and mathematically?

CCC Scale, Proportion, and Quantity

- According to Kepler's third law of planetary motion, how can you quantify that the square of a revolving body's period of revolution is proportional to the cube of its distance to a gravitational center?
- According to Newton's second law of motion, how can acceleration be calculated if mass and net force are known?
- According to Newton's second law of motion, how can net force be calculated if mass and acceleration are known?

Performance Outcomes

These are statements of how students use knowledge and are similar to the standards in how they blend DCI, SEP, and CCC, but at a smaller grain size. These are potential outcomes for instruction as it plays out in lessons and activities in the classroom. It is important to also think of these as smaller outcomes that build toward the larger goal of mastering the standards.

- **Organize data that represent** the net force on a macroscopic object, that has a *cause-and-effect relationship* to its mass (which is held constant), and its acceleration **into tables, graphs, charts, or vector drawings.**
- *Use tools, technologies, and/or models* **to analyze the data and identify relationships within the datasets,** including a more massive object experiencing the same net force as a less massive object having a smaller acceleration and a larger net force on a given object producing a correspondingly larger acceleration.
- *Use tools, technologies, and/or models* **to analyze the data and identify relationships within the datasets** including 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.
- **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 $a = F_{net}/m$** and *use the data as empirical evidence to show the cause-and-effect relationship* linking force, mass, and acceleration.
- **Express the relationship,** $F_{net}=ma$, in terms of *cause and effect*, namely that a net force on an object causes the object to accelerate.
- *Define the system of the two interacting objects* **that is represented mathematically including boundaries and initial conditions while identifying and describing** 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 vector) **using the mathematical representations** and following the claim that the total momentum of a system of two interacting objects is constant if there is no net force on the system.

- **Use the mathematical representations** *to model and describe the total momentum of the system* by calculating the vector sum of the momenta of the two objects in the system.
- **Based on the analysis of the total momentum** *of the system,* students support the claim that in a system, the momentum is the same before and after the interaction between the objects in the system, so that the momentum of the system is constant.
- **Identify that the analysis of the momentum of each object** *in the system* indicates that any change in the momentum of one object is balanced by and *caused by* a change in the momentum of the other object so that the total momentum is constant.
- **Design a device** that minimizes the force on a macroscopic object during a collision. **In the design, students: incorporate the** *cause and effect* 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 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.
- **Describe and quantify (when appropriate)** *the criteria and constraints of the system*, **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 such as seatbelts or football helmets.
- **Evaluate systematically the proposed device design or design solution's** *cause and effect*, including describing the rationales for the design and comparing the design to the list of criteria and constraints.
- **Identify and describe the following relevant components in the given mathematical** *or model representations* of orbital motion: the trajectories of orbiting bodies, including planets, moons, or human-made spacecraft; each of which depicts a revolving body's eccentricity $e = f/d$, where f is the distance between foci of an ellipse, and d is the ellipse's major axis length which is Kepler's first law of planetary motion.
- **Use the given mathematical or computational representations of orbital motion to depict** *that the quantity* of the square of a revolving body's period of revolution is proportional to the cube of its distance to a gravitational center (T2 ∝ R3), where T is the orbital period and R is the semi-major axis of the orbit, Kepler's third law of planetary motion.
- **Use the given mathematical or computational representation** of Kepler's second law of planetary motion, an orbiting body sweeps out equal areas in equal time, *to predict the quantity of the relationship* between the distance between an orbiting body and its star, and the object's orbital velocity. The closer an orbiting body is to a star, the larger its orbital velocity will be.
- *Use Newton's law of gravitation plus his third law of motion to predict the cause and effect* of how the acceleration of a planet towards the sun varies with its distance from the sun, **and to argue qualitatively** about how this relates to the observed orbits.