# Science and Technology/Engineering (STE)

# Instructional Guidelines: High School Introductory Physics

**Purpose:** The intention of this document is to help provide additional guidance around the instruction and content of the High School Introductory Physics standards. This guidance is aligned with the assessment expectations of the next-generation Introductory Physics MCAS test based on the 2016 Massachusetts Science and Technology/Engineering Curriculum Framework. The information provided in this document is **not an exhaustive list** of what will be assessed on the MCAS Introductory Physics test. This document may be updated as necessary.

**Science and Engineering Practices:** The science and engineering practices are the behaviors or skills students should be practicing in the classroom on a regular basis as a means to explaing phenomena. Multiple practices (such as analyzing data, modeling, and constructing explanations) may be assessed on MCAS with the content of a particular standard, even if that practice is not listed in the standard. Some additional examples of integration of practices and content are included as part of this guide. Helpful resources to learn more about the science and engineering practices: Science and Engineering Practices Matrix, Next Generation Science Standards - NGSS@NSTA, Instructional Leadership for Science Practices, Boston Public Schools Science Department – Practices PD Series (virtual), STEM Teaching Tools.

**Strand Maps/Learning Progressions:** See the strand maps or disclinary core idea (DCI) progression matrix for additional information on the conceptual relationship between standards within and across grades that allow for targeted pre-assessment, contextualization, and/or identification of boundaries for any particular standard that is being taught. This can be an efficient way to visualize how elementary and middle school standards lead to high school standards.

**Reference Sheet:** Students are expected to solve for all variables in the equations listed on the reference sheet, unless otherwise specified. This includes rearranging equations and using scientific notation when appropriate, but does not include trigonometry.

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| PS1. Matter and Its Interactions |
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| **HS-PS1-8. Develop a model to illustrate the energy released or absorbed during the processes of fission, fusion, and radioactive decay.** *Clarification Statements: Examples of models include simple qualitative models, such as pistures or diagrams. Types of radioactive decay include alpha, beta, and gamma. State Assessment Boundary: Quantitative calculations of energy released or absorbed are not expected in state assessment.* |

## Additional Guidelines

**Students should be able to:**

- Create, analyze, and complete models that shows the total number of protons and neutrons is conserved during any nuclear process. The model should include that the number of protons may change, resulting in the type of atom changing.
- Analyze a model to determine whether kinetic and/or electromagnetic energy is released during a fission, fusion, or radioactive decay process. Evidence may include whether photons and/or particles with mass, such as alpha particles, beta particles, or neutrons, are released.
- Communicate differences between nuclear fission and nuclear fusion.
- Construct an explanation about how radioactive decay processes make radioactive atoms with a large number of protons more stable.
- Note: For the MCAS reporting category, this standard will be included with the core idea PS3 (Energy).

| PS2. Motion and Stability: Forces and Interactions |
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| **HS-PS2-1. Analyze data to support the claim that Newton's second law of motion is a mathematical model describing change in motion (the acceleration) of objects when acted on by a net force.** *Clarification Statements: 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, and a moving object being pulled by a constant force. Forces can include contact forces, including friction, and forces acting at a distance, such as gravity and magnetic forces. State Assessment Boundary: Variable forces are not expected in state assessment.*<br>**HS-PS2-10(MA). Use free-body force diagrams, algebraic expressions, and Newton's laws of motion to predict changes to velocity and acceleration for an object moving in one dimension in various situations.** *Clarification Statement: Predictions of changes in motion can be made numerically, graphically, and algebraically using basic equations for velocity, constant acceleration, and Newton's first and second laws. Forces can include contact forces, including friction, and forces acting at a distance, such as gravity and magnetic forces.* |

## Additional Guidelines

**Students should be able to:**

- Communicate an understanding of velocity, speed, acceleration, mass, inertia, weight, displacement (change in position), and distance.
- Analyze and compare the motion of objects using position/distance vs. time, velocity/speed vs. time, and acceleration vs. time graphs.
- Determine whether a net force is acting on an object from a description, graph, or pictorial representation of its motion and determine the relative direction of the net force with respect to the object's motion.
- Construct, interpret, and label free-body force diagrams that model the direction (arrow) and magnitude (length) of specific forces labeled with an appropriate identification or magnitude (e.g., $F_g$ or numerically).

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| PS2. Motion and Stability: Forces and Interactions |
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| **HS-PS2-2. Use mathematical representations to show that the total momentum of a system of interacting objects is conserved when there is no net force on the system.** *Clarification Statement: Emphasis is on the qualitative meaning of the conservation of momentum and the quantitative understanding of the conservation of linear momentum in interactions involving elastic and inelastic collisions between two objects in one dimension.*<br><br>**HS-PS2-3. Apply scientific principles of motion and momentum to design, evaluate, and refine a device that minimizes the force on a macroscopic object during a collision.*** *Clarification Statement: Both qualitative evaluations and algebraic manipulations may be used.* |

## Additional Guidelines

**Students should be able to:**

- Compare the motion of two objects before and after they collide or separate, both qualitatively and quantitatively in one-dimentional scenarios.
- Apply the impulse-momentum relationship, both qualitatively and quantitatively.
- Compare the magnitude and direction of the forces involved when two objects interact, including applying Newton's $3^{rd}$ Law to help understand situations that involve collisions.

| PS2. Motion and Stability: Forces and Interactions |
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| **HS-PS2-4. Use mathematical representations of Newton's law of gravitation and Coulomb's law to both qualitatively and quantitatively describe and predict the effects of gravitational and electrostatic forces between objects.** *Clarification Statement: Emphasis is on the relative changes when distance, mass or charge, or both are changed. State Assessment Boundaries: State assessment will be limited to systems with two objects. Permittivity of free space is not expected in state assessment.* |

## Additional Guidelines

**Students should be able to:**

- Calculate the gravitational force or the electrostatic force acting on an object and determine the direction of the force, including scenarios using scientific notation but excluding scenarios that require rearranging equations.
- Analyze and compare systems of two objects with different charges and distances apart to compare the magnitude of the electrostatic forces.

| PS2. Motion and Stability: Forces and Interactions |
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| **HS-PS2-5. Provide evidence that an electric current can produce a magnetic field and that a changing magnetic field can produce an electric current.** *Clarification Statement: Examples of evidence can include movement of a magnetic compass when placed in the vicinity of a current-carrying wire, and a magnet passing through a coil that turns on the light of a Faraday flashlight. State Assessment Boundary: Explanations of motors or generators are not expected in state assessment.* |

## Additional Guidelines

**Students should be able to:**

- Construct an explanation about how electricity is generated and how electricity can be converted into mechanical energy.
- Interpret a model to show how magnetic fields and electrical currents are used in technology, such as a compass, an ammeter, a generator, or a motor.

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| PS2. Motion and Stability: Forces and Interactions |
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| **HS-PS2-9(MA). Evaluate simple series and parallel circuits to predict changes to voltage, current, or resistance when simple changes are made to a circuit.** *Clarification Statements: Predictions of changes can be represented numerically, graphically, or algebraically using Ohm's law. Simple changes to a circuit may include adding a component, changing the resistance of a load, and adding a parallel path, in circuits with batteries and common loads. Simple circuits can be represented in schematic diagrams. State Assessment Boundary: Use of measurement devices and predictions of changes in power are not expected in state assessment.* |

## Additional Guidelines

**Students should be able to:**

- Construct models of series and parallel circuits that use common schematic symbols such as wires, batteries, resistors, switches, and light bulbs.
- Calculate the total resistance of a series circuit by adding the resistances of each element.
- From an investigation, qualitatively determine how placing a resistor anywhere in a combination circuit will affect the total resistance of the circuit.
- Communicate how the brightness of a light bulb will change when simple changes are made to a circuit, such as adding another light bulb in series or parallel.

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| PS3. Energy |
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| **HS-PS3-1. Use algebraic expressions and the principle of energy conservation to calculate the change in energy of one component of a system when the change in energy of the other component(s) of the system, as well as the total energy of the system including any energy entering or leaving the system, is known. Identify any transformations from one form of energy to another, including thermal, kinetic, gravitational, magnetic, or electrical energy, in the system.** *Clarification Statement: Systems should be limited to two or three components and to thermal energy; kinetic energy; or the energies in gravitational, magnetic, or electric fields.*<br><br>**HS-PS3-2. Develop and use a model to illustrate that energy at the macroscopic scale can be accounted for as either motions of particles and objects or energy stored in fields.** *Clarification Statements: Examples of phenomena at the macroscopic scale could include evaporation and condensation, the conversion of kinetic energy to thermal energy, the gravitational potential energy stored due to position of an object above the Earth, and the energy stored (electrical potential) of a charged object's position within an electrical field. Examples of models could include diagrams, drawings, descriptions, and computer simulations.*<br><br>**HS-PS3-3. Design and evaluate a device that works within given constraints to convert one form of energy into another form of energy.*** *Clarification Statements: Emphasis is on both qualitative and quantitative evaluations of devices. Examples of devices could include Rube Goldberg devices, wind turbines, solar cells, solar ovens, and generators. Examples of constraints could include use of renewable energy forms and efficiency. State Assessment Boundary: Quantitative evaluations will be limited to total output for a given input in state assessment.* |

## Additional Guidelines

**Students should be able to:**

- Compare the amount of kinetic, gravitational potential, and elastic potential energy of an object at different times.
- Calculate the mechanical energy of an object as the sum of the object's kinetic and potential energy.[1]
- Calculate the work done by a force to change an object's energy, including forces that do work perpendicular or parallel to the surface of the Earth.
- Construct a model of the field that exists around one to two masses or one to two charges that shows the direction of the field. Rank different locations in a gravitational or electric field drawing based on the magnitude of the force that would be experienced by a test object, such as a very small mass or a very small positive charge.
- Analyze temperature data to compare the average molecular kinetic energy of different substances and use phase changes as evidence that energy is being added to or removed from a substance.
- Calculate the efficiency of multiple devices and then determine which device should be used in order to meet specific design criteria and constraints.
- Describe design changes that would result in increased energy efficiency of a device, such as design changes that reduce friction.

[1] Guidance on mechanical energy added April 2022

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| PS3. Energy |
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| **HS-PS3-4a. Provide evidence that when two objects of different temperature are in thermal contact within a closed system, the transfer of thermal energy from higher temperature objects to lower temperature objects results in thermal equilibrium, or a more uniform energy distribution among the objects and that temperature changes necessary to achieve thermal equilibrium depend on the specific heat values of the two substances.** *Clarification Statement: Energy changes should be described both quantitatively in a single phase ($Q = mc\Delta T$) and conceptually either in a single phase or during a phase change.* |

## No Additional Guidelines

| PS3. Energy |
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| **HS-PS3-5. Develop and use a model of magnetic or electric fields to illustrate the forces and changes in energy between two magnetically or electrically charged objects changing relative position in a magnetic or electric field, respectively.** *Clarification Statements: Emphasis is on the change in force and energy as objects move relative to each other. Examples of models could include drawings, diagrams, and texts, such as drawings of what happens when two charges of opposite polarity are near each other.* |

## Additional Guidelines

**Students should be able to:**

- Compare the magnitude and direction of the forces between two magnets before and after the position of the magnets has changed. Compare the energy stored in the field between two magnets before and after the position of the magnets has changed.
- Analyze the motion of and compare the forces between two charged particles (with negligible gravitational attraction) that are exerting forces on one another.
- Analyze a model to qualitatively determine if the forces between two particles, the acceleration of each particle, and the velocity of each particle is increasing or decreasing.
- Communicate how the potential energy stored in the field between a system of two charges changes when they are brought closer together or moved farther apart based on their relative signs.

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| PS4. Waves and Their Applications in Technologies for Information Transfer |
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| **HS-PS4-1. Use mathematical representations to support a claim regarding relationships among the frequency, wavelength, and speed of waves traveling within various media. Recognize that electromagnetic waves can travel through empty space (without a medium) as compared to mechanical waves that require a medium.** *Clarification Statements: Emphasis is on relationships when waves travel within a medium, and comparisons when a wave travels in different media. Examples of situations to consider could include electromagnetic radiation traveling in a vacuum and glass, sound waves traveling through air and water, and seismic waves traveling through the Earth. Relationships include* $v = \lambda f$, $T = 1/f$, *and the qualitative comparison of the speed of a transverse (including electromagnetic) or longitudinal mechanical wave in a solid, liquid, gas, or vacuum.* |

## Additional Guidelines

**Students should be able to:**

- Differentiate between mechanical and electromagnetic waves in terms of speed, type(s) of wave motion, and whether they have the ability to travel through a vacuum.
- Calculate the frequency, wavelength, or speed of a wave using scientific notation.
- Recognize that the frequency of a sound wave determines the pitch of the sound.
- Recognize that the frequency of a light wave determines its color (if visible) and position in the electromagnetic spectrum.
- Classify ultraviolet, x-ray, and gamma rays as having higher energy and frequency than visible light, and radio, microwave, and infrared waves as having lower energy and frequency than visible light.
- Differentiate between transverse and longitudinal wave motion.

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**PS4. Waves and Their Applications in Technologies for Information Transfer**

**HS-PS4-3. Evaluate the claims, evidence, and reasoning behind the idea that electromagnetic radiation can be described by either a wave model or a particle model, and that for some situations involving resonance, interference, diffraction, refraction, or the photoelectric effect, one model is more useful than the other.** *Clarification Statement: Emphasis is on qualitative reasoning and comparisons of the two models. State Assessment Boundary: Calculations of energy levels or resonant frequencies are not expected in state assessment.*

**HS-PS4-5. Communicate technical information about how some technological devices use the principles of wave behavior and wave interactions with matter to transmit and capture information and energy.*** *Clarification Statements: Emphasis is on qualitative information and descriptions. Examples of technological devices could include solar cells capturing light and converting it to electricity, medical imaging, and communications technology. Examples of principles of wave behavior include resonance, and constructive and destructive interference. State Assessment Boundary: Band theory is not expected in state assessment.*

## Additional Guidelines

**Students should be able to:**

- Support the claim that some experiments indicate light behaves like a wave using evidence, such as:
  - There is an interference pattern created during a double slit experiment.
  - Light diffracts around an obstacle or through an opening.
- Support the claim that some experiments indicate light behaves like a particle using evidence from the photoelectric effect, such as:
  - Light energy is made up of 'packets' of energy known as photons.
  - There is a direct relationship between the energy and the frequency of a photon.
  - When an electron is ejected by a photon, the remaining energy from the photon is transferred to the electron as kinetic energy.
- Create and interpret pictorial models of transverse wave interference. This includes numerically determining the amplitude of a wave pulse before, during, and after interference with another wave pulse.
- Construct an explanation about how an object will vibrate with an increasing amplitude when a force is applied at the object's resonant (natural) frequencies. [2]
- Recognize that the energy of a photon is directly related to the photon's frequency. Note: Calculations of photon energy are not expected.[3]
- Construct an explanation about why light refracts when it travels from one medium to another, with a focus on explaining how the speed of a wave changes when it transitions from one medium to another and that this change in speed causes the wave to change direction.
- Construct an explanation about how various technologies transfer or store information using an understanding of different wave behaviors or the photoelectric effect.
- Given a model or description of a specific technology, apply knowledge of different wave behaviors and the photoelectric effect to analyze the function of that technology.

[2] Guidance on resonance added April 2022

[3] Guidance added April 2022