Test Specifications: Physical Science

General Description of the Physical Science Summative Examination

In 2010 Ohio adopted new rigorous academic content standards for Physical Science. A model curriculum based on these new standards was adopted in 2011.

An achievement examination that aligns to the new standards and model curriculum is mandated by Ohio Revised Code 3301.079. The examination will be administered as a two-part summative test, in a computer-delivered format, to measure progress toward the standards and to provide information to teachers and administrators.

Test Design: Two-Part Summative Exam

The structure of the Physical Science Summative Exam follows the general outline of the summative assessments developed by the Partnership for Assessment of Readiness for College and Careers (PARCC) Consortium for measuring progress toward the Common Core standards in English language arts and mathematics. The Physical Science examination will consist of two parts: a performance-based assessment (PBA) that will be administered approximately three-quarters of the way through the course and an end-of-year examination (EOY) that will be given near the end of the year. Both the PBA and the EOY are fixed forms that are administered in an online format. The PBA is different in that, in addition to technology-enhanced items (graphic-response and short-answer items), it also contains constructed-response items that require the student to type a response into the computer interface. These items are scored by human scorers rather than by computer. The lead time needed to score the items means that the PBA must be administered approximately three-quarters of the way through the year. Outcomes are reported back to schools by the end of the year. After the student has completed both parts of the examination, his or her scores will be combined to yield a comprehensive view of the student's progress.

The two parts of the examination are described in more detail below.

Part I: A Performance-Based Assessment

The Performance-Based Assessment (PBA) will assess the student's knowledge of material from approximately the first three quarters of the course, as specified in this document. The assessment will consist of approximately 9-12 items worth 20 points overall. It will require students to engage with course content at a significant cognitive depth and a meaningful level of analysis. Following the PARCC model, the PBA will present a combination of discrete items and *tasks,* or sets of items linked to stimuli that engage significant content aligned to the model curriculum. An example of a task stimulus might be a set of data tables or charts, a simulation, or a set of passages or maps, linked around a central theme. The sequence of items associated with the stimulus draws the student into deeper analysis and interpretation of the source materials than might ordinarily be possible in a single item. Each task might consist of one or more hand-scored constructed response items or technology-enhanced graphic-response items that require the student to construct, rather than select, a response.

Part II: End-of-Year Examination

The End-of-Year Examination will cover the entire content of the course as specified in this document. It will be administered as close as possible to the end of the course (after approximately 90% of the course). All the items on it will be scored by computer, making possible a very quick return of scores. Like the PBA, the EOY will contain a combination of item types, but approximately fifty percent of the points on the examination will come from selected-response (multiple-choice) items. The remainder will be a combination of technology enhanced items (short-answer and graphic-response items). Some of the items may make up tasks as in the PBA.

Physical Science Summative Exam Blueprint

The test blueprint tables on the following pages display the distribution of item types across the examination. Table 1 displays the two parts of the examination separately. Table 2 lists the physical science topics covered in each reporting category. Table 3 displays the sub-topics that may be included on the Performance-Based Assessment.

Table 1

Subject	**Format**	**Points per Item**	**Min Points**	**Max Points**	**Total Points**
Performance-Based	MC	MC items will not be on the PBA			20
	Graphic-response or Short-answer*	1**, 2, 3	8	12	
	Hand-scored	2 or 4	8	12	
End of Year	MC	1	18	22	36
	Graphic-response or Short-answer*	1, 2, 3	14	18	
	Hand-scored	Hand-scored items will not be on the EOY assessment			

* Each form will have a distribution of both Graphic-response and Short-answer Items.

**1 point Graphic-response/Short-answer items will be on the PBA only as a part of a cluster of items.

Table 2

Reporting Category	Format	Points per Item	Total Points
Matter	MC	1	15 - 17
	Graphic-response or Short-answer*	1, 2, 3	
	Hand-scored	2 or 4	
Energy & Waves	MC	1	15 - 17
	Graphic-response or Short-answer*	1, 2, 3	
	Hand-scored	2 or 4	
Forces & Motion	MC	1	15 - 17
	Graphic-response or Short-answer*	1, 2, 3	
	Hand-scored	2 or 4	
The Universe	MC	1	7 - 9
	Graphic-response or Short-answer*	1, 2, 3	
	Human Scored	2 or 4	

* Each form will have a distribution of both Graphic-response and Short-answer Items.

Table 3

Reporting Category	Summary of Sub-Topics Eligible for Use on the Performance-Based Assessment
Matter	Classification of matter
	Atoms
	Periodic trends of the elements
Energy and Waves	Conservation of energy
	Transfer and transformation of energy
	Electricity
Forces and Motion	Motion
	Forces
	Dynamics
The Universe	Not assessed on PBA

Description of Item Types

The several types of items on the examination fall into two categories: those scored by machine and those that require human scorers to evaluate the response.

Machine-scored: Machine-scored items are scored automatically by the testing software to yield an immediate score. The machine-scored items in this examination are multiple-choice, short-answer and graphic-response.

A Multiple-choice item consists of the following:

- a brief statement that orients the student to the context of the question (optional).
- a stimulus (document, data table, graphic, etc.) on which the question is based (optional).
- a question.
- four answer options.

A Short-answer item consists of the following:

- a brief statement that orients the student to the context of the question (optional).
- a stimulus (document, data table, graphic, etc.) to which the question refers (optional).
- a question or prompt.
- a response area. The student types a response to answer the question.

A Graphic-response item consists of the following:

- a brief statement that orients the student to the context of the question (optional).
- a stimulus (document, data table, graphic, etc.) to which the question refers (optional).
- a question or prompt.
- a graphic-response interface on which the student manipulates objects using a computer mouse to create a response to the question. The response interface may be a map, a chart or graph, a picture or a diagram on which the student must position objects correctly.

A Simulation consists of the following:

- an interactive animated graphic interface that simulates an investigative experiment or physical situation. Information is displayed in the form of dynamic maps or illustrations, statistical tables, or charts and graphs. Data inputs can be adjusted by the student to reflect changes in the experimental or situational inputs, and the graphics adjust themselves to account for the new information.

- When a simulation is used as part of a task, it will be accompanied by more than one of the other item types above. The simulation functions as an interactive stimulus that provides information for the student to reflect on, analyze, or synthesize with other knowledge into a cognitively demanding set of answers.

Hand-scored: Hand-scored items are scored against rubrics by trained scorers. The hand-scored tasks on this examination are the constructed response items.

A Short Constructed Response item (SCR) consists of the following:

- a brief statement that orients the student to the context of the questions (optional).
- one or more stimuli (documents, graphics, data displays, etc.) to which the questions refer (optional).
- a question or set of questions that require a detailed written response or responses. The responses are scored according to a rubric or set of rubrics that address multiple dimensions in the student work.

An Extended Constructed Response item (ECR) contains the same components as the SCR but requires a more elaborated response.

Item Specifications: Physical Science

Course Description:

Physical science is a high school level course, which satisfies the Ohio Core science graduation requirements of Ohio Revised Code Section 3313.603. This section of Ohio law requires a three-unit course with inquiry-based laboratory experience that engages students in asking valid scientific questions and gathering and analyzing information.

Physical science introduces students to key concepts and theories that provide a foundation for further study in other sciences and advanced science disciplines. Physical science comprises the systematic study of the physical world as it relates to fundamental concepts about matter, energy and motion. A unified understanding of phenomena in physical, living, Earth and space systems is the culmination of all previously learned concepts related to chemistry, physics, and Earth and space science, along with historical perspective and mathematical reasoning.

Course Content:

The following information may be taught in any order; there is no ODE-recommended sequence.

Study of Matter

- Classification of matter *
  - Heterogeneous vs. homogeneous *
  - Properties of matter *
  - States of matter and its changes*
- Atoms*
  - Models of the atom (components)*
  - Ions (cations and anions)*
  - Isotopes*
- Periodic trends of the elements*
  - Periodic law*
  - Representative groups*
- Bonding and compounds
  - Bonding (ionic and covalent)
  - Nomenclature
- Reactions of matter
  - Chemical reactions
  - Nuclear reactions

Energy and Waves*

- Conservation of energy*
  - Quantifying kinetic energy*
  - Quantifying gravitational/potential energy*
  - Energy is relative*
- Transfer and transformation of energy (including work)*
- Waves
  - Refraction, reflection, diffraction, absorption, superposition
  - Radiant energy and the electromagnetic spectrum
  - Doppler shift
- Thermal energy
- Electricity*
  - Movement of electrons*
  - Current*
  - Electric potential (voltage)*
  - Resistors and transfer of energy*

Forces and Motion*

- Motion*
  - Introduction to one-dimensional vectors*
  - Displacement, velocity (constant, average and instantaneous) and acceleration*
  - Interpreting position vs. time and velocity vs. time graphs*
- Forces*
  - Force diagrams*
  - Types of forces (gravity, friction, normal, tension)*
  - Field model for forces at a distance*
- Dynamics (how forces affect motion)*
  - Objects at rest*

    - Objects moving with constant velocity*
    - Accelerating objects*

The Universe

- History of the universe
- Galaxy formation
- Stars
    - Formation; stages of evolution
    - Fusion in stars

***Content which may be addressed on PBA**

Study of Matter

Sub-Topics:

- **Classification of Matter***
    - Heterogeneous vs. homogeneous*
    - Properties of matter*
    - States of matter and its changes*
- **Atoms***
    - Models of the atom (components)*
    - Ions (cations and anions)*
    - Isotopes*
- **Periodic Trends of the Elements***
    - Periodic law*
    - Representative groups*
- **Bonding and compounds**
    - Bonding (ionic and covalent)
    - Nomenclature
- **Reactions of Matter**
    - Chemical reactions
    - Nuclear reactions

*Content which may be addressed on the PBA

Content Elaboration:

Classification of Matter

Matter was introduced in the elementary grades and the learning progression continued through middle school to include differences in the physical properties of solids, liquids and gases, elements, compounds, mixtures, molecules, kinetic and potential energy and the particulate nature of matter. Content in the chemistry syllabus (e.g., electron configuration, molecular shapes, bond angles) will be developed from concepts in this course.

Matter can be classified in broad categories such as homogeneous and heterogeneous or classified according to its composition or by its chemical (reactivity) and physical properties (e.g., color, solubility, odor, hardness, density, melting point and boiling point, viscosity and malleability).

Solutions are homogenous mixtures of a solute dissolved in a solvent. The amount of a solid solute that can dissolve in a solvent generally increases as the temperature increases since the particles have more kinetic energy to overcome the attractive forces between them. Water is often used as a solvent since so many substances will dissolve in water. Physical properties can be used to separate the substances in mixtures, including solutions.

Phase changes can be represented by graphing the temperature of a sample vs. the time it has been heated. Investigations must include collecting data during heating, cooling and solid-liquid-solid phase changes. At times, the temperature will change steadily, indicating a change in the motion of the particles and the kinetic energy of the substance. However, during a phase change, the temperature of a substance does not change, indicating there is no change in kinetic energy. Since the substance continues to gain or lose energy during phase changes, these changes in energy are potential and indicate a change in the position of the particles. When heating a substance, a phase change will occur when the kinetic energy of the particles is great enough to overcome the attractive forces between the particles; the substance then melts or boils. Conversely, when cooling a substance, a phase change will occur when the kinetic energy of the particles is no longer great enough to overcome the attractive forces between the particles; the substance then condenses or freezes. Phase changes are examples of changes that can occur when energy is absorbed from the surroundings (endothermic) or released into the surroundings (exothermic).

When thermal energy is added to a solid, liquid or gas, most substances increase in volume because the increased kinetic energy of the particles causes an increased distance between the particles. This results in a change in density of the material. Generally, solids have greater density than liquids, which have greater density than gases due to the spacing between the particles. The density of a substance can be calculated from the slope of a mass vs. volume graph. Differences in densities can be determined by interpreting mass vs. volume graphs of the substances.

Atoms

Content introduced in middle school, where the atom was introduced as a small, indestructible sphere, is further developed in the physical science syllabus. Over time, technology was introduced that allowed the atom to be studied in more detail. The atom is composed of protons, neutrons and electrons that have measurable properties, including mass and, in the case of protons and electrons, a characteristic charge. When bombarding thin gold foil with atomic-sized, positively charged, high-speed particles, a few of the particles were deflected slightly from their straight-line path. Even fewer bounced back toward the source. This evidence indicates that most of an atom is empty space with a very small positively charged nucleus. This experiment and other evidence indicate the nucleus is composed of protons and neutrons, and electrons that move about in the empty space that surrounds the nucleus. Additional experimental evidence that led to the development of other historic atomic models will be addressed in the chemistry syllabus.

All atoms of a particular element have the same atomic number; an element may have different isotopes with different mass numbers. Atoms may gain or lose electrons to become anions or cations. Atomic number, mass number, charge and identity of the element can be determined from the numbers of protons, neutrons and electrons. Each element has a unique atomic spectrum that can be observed and used to identify an element. Atomic mass and explanations about how atomic spectra are produced are addressed in the chemistry syllabus.

Periodic Trends of the Elements
Content from the middle school level, specifically the properties of metals and nonmetals and their positions on the periodic table, is further expanded in this course. When elements are listed in order of increasing atomic number, the same sequence of properties appears over and over again; this is the periodic law. The periodic table is arranged so that elements with similar chemical and physical properties are in the same group or family. Metalloids are elements that have some properties of metals and some properties of nonmetals. Metals, nonmetals, metalloids, periods and groups or families including the alkali metals, alkaline earth metals, halogens and noble gases can be identified by their position on the periodic table. Elements in Groups 1, 2 and 17 have characteristic ionic charges that will be used in this course to predict the formulas of compounds. Other trends in the periodic table (e.g., atomic radius, electronegativity, ionization energies) are found in the chemistry syllabus.

Bonding and Compounds
Middle school content included compounds composed of atoms of two or more elements joined together chemically. In this course, the chemical joining of atoms is studied in more detail. Atoms may be bonded together by losing, gaining or sharing electrons to form molecules or three-dimensional lattices. An ionic bond involves the attraction of two oppositely charged ions, typically a metal cation and a nonmetal anion formed by transferring electrons between the atoms. An ion attracts oppositely charged ions from every direction, resulting in the formation of a three-dimensional lattice. Covalent bonds result from the sharing of electrons between two atoms, usually nonmetals. Covalent bonding can result in the formation of structures ranging from small individual molecules to three-dimensional lattices (e.g., diamond). The bonds in most compounds fall on a continuum between the two extreme models of bonding: ionic and covalent.

Using the periodic table to determine ionic charge, formulas of ionic compounds containing elements from groups 1, 2, 17, hydrogen and oxygen can be predicted. Given a chemical formula, a compound can be named using conventional systems that include Greek prefixes where appropriate. Prefixes will be limited to represent values from one to 10. Given the name of an ionic or covalent substance, formulas can be written. Naming organic molecules is beyond this grade level and is reserved for an advanced chemistry course. Prediction of bond types from electronegativity values, polar covalent bonds, writing formulas and naming compounds that contain polyatomic ions or transition metals will be addressed in the chemistry syllabus.

Reactions of Matter
In middle school, the law of conservation of matter was expanded to chemical reactions, noting that the number and type of atoms and the total mass are the same before and after the reaction. In this course, conservation of matter is expressed by writing balanced chemical equations. At this level, reactants and products can be identified

from an equation and simple equations can be written and balanced given either the formulas of the reactants and products or a word description of the reaction. Stoichiometric relationships beyond the coefficients in a balanced equation and classification of types of chemical reactions are addressed in the chemistry syllabus.

During chemical reactions, thermal energy is either transferred from the system to the surroundings (exothermic) or transferred from the surroundings to the system (endothermic). Since the environment surrounding the system can be large, temperature changes in the surroundings may not be detectable.

While chemical changes involve changes in the electrons, nuclear reactions involve changes to the nucleus and involve much larger energies than chemical reactions. The strong nuclear force is the attractive force that binds protons and neutrons together in the nucleus. While the nuclear force is extremely weak at most distances, over the very short distances present in the nucleus the force is greater than the repulsive electrical forces among protons. When the attractive nuclear forces and repulsive electrical forces in the nucleus are not balanced, the nucleus is unstable. Through radioactive decay, the unstable nucleus emits radiation in the form of very fast-moving particles and energy to produce a new nucleus, thus changing the identity of the element. Nuclei that undergo this process are said to be radioactive. Radioactive isotopes have several medical applications. The radiation they release can be used to kill undesired cells (e.g., cancer cells). Radioisotopes can be introduced into the body to show the flow of materials in biological processes.

For any radioisotope, the half-life is unique and constant. Graphs can be constructed that show the amount of a radioisotope that remains as a function of time and can be interpreted to determine the value of the half-life. Half-life values are used in radioactive dating.

Other examples of nuclear processes include nuclear fission and nuclear fusion. Nuclear fission involves splitting a large nucleus into smaller nuclei, releasing large quantities of energy. Nuclear fusion is the joining of smaller nuclei into a larger nucleus accompanied by the release of large quantities of energy. Nuclear fusion is the process responsible for formation of all the elements in the universe beyond helium and the energy of the sun and the stars.

Further details about nuclear processes including common types of nuclear radiation, predicting the products of nuclear decay, mass-energy equivalence and nuclear power applications are addressed in the chemistry and physics syllabi.

Content Limits:

- Qualitative understanding of solutions (e.g., concentration, solubility, solutes, solvents);
- Kinetic and potential energy as it relates to temperature and phase changes, including heating-cooling curves;

- Density as it is related to phase and temperature changes and mass vs. volume graphs;
- The composition and characteristics of atoms, ions and isotopes, including how they relate to bonding and nuclear reactions;
- Experimental evidence for the existence and composition of the nucleus;
- Periodic law and its implications for the structure of the periodic table;
- Elements within groups/families are chemically similar and have the same number of valence electrons;
- The role of valence electrons in bonding;
- Basic structure of compounds formed from ionic and covalent bonds;
- Chemical formulas and IUPAC names of compounds limited to Greek prefixes 1-10;
- Writing and balancing equations using IUPAC names and formulas for chemical compounds (may include energy release or absorption);
- Conservation of matter as it relates to writing balanced chemical equations;
- Radioactive elements and forces in the nucleus (strong nuclear and electrical);
- Radioactive decay as it relates to half-life graphs, and applications (medical, radioactive dating);
- Definition and examples of nuclear fusion and fission.

Do Not Assess:

- Calculations involving thermal energy;
- Solubility curves;
- Heat of fusion and vaporization;
- Saturation;
- Density interactions not related to mass vs. volume, phase or temperature changes;
- Density calculations involving data not expressed graphically;
- Pressure and phase diagrams;
- Polarity/ions in solution;
- Physical properties of gases, liquids and solids;
- Classifying materials as elements, compounds, and mixtures;
- Classifying properties as chemical or physical;
- Atomic spectra;
- Millikan and Thompson experiments;
- Atomic models other than Rutherford;
- Electron configurations;
- Atomic mass;
- Basic concepts and properties about metals and non-metals;
- Periodic trends such as atomic radius, electronegativity, ionization energies;
- Rote memorization of position of individual elements on the periodic table;
- Classifying intermolecular bonding (e.g. hydrogen bonds, Vander Waals interactions);

- Naming organic molecules;
- Prediction of bond types based on electronegativity values;
- Non-polar and polar covalent bonds;
- Naming compounds that contain polyatomic ions;
- Writing formulas that contain polyatomic ions or elements from Groups 3–16, excluding oxygen;
- Molecular shapes;
- Bond angles;
- Common names of compounds (e.g., vinegar, baking soda, lye), except water;
- Lewis diagrams;
- Stoichiometric relationships beyond the coefficients in a balanced equation;
- Classification of types of chemical reactions;
- Elements that form diatomic molecules;
- Mathematics of half-life and nuclear decay beyond graphs that show the amount of a radioisotope that remains as a function of time;
- Common types of nuclear radiation, predicting the products of nuclear decay, mass-energy equivalence, and nuclear power applications;
- Determining whether a particular isotope is stable or unstable.

Stimulus Attributes:

- Tables showing data about the various properties of substances (e.g., boiling point, melting point, mass density);
- Drawing/picture/illustration showing particles in solution under various temperature conditions;
- Drawing/picture/illustration showing particles of gases, liquids, and/or solids in a flexible container under various temperature conditions;
- Graphs showing temperature vs. time data leading to phase change;
- Graphs of mass vs. volume;
- Tables showing data about separation techniques for various substances involving solubility, density, and/or melting and boiling point;
- Drawing/illustration/picture of the Rutherford gold foil experiment;
- Charts with atomic and nuclear data;
- Diagrams of atoms (with all electrons or with only valence electrons);
- Periodic table (entire, or specific groups, families, or elements);
- Images or diagrams of a 3D lattice;
- Tables and graphs showing data (e.g., mass, time, energy released) for various types of radioactive isotopes;
- Word descriptions of chemical reactions (single or double replacement);
- Diagrams or illustrations of nuclear fission or fusion.

Response Attributes:

Machine-scored

Response options may include, but are not limited to, the following:

- Visually representing particles in solution under various concentration and temperature conditions;
- Designing a strategy or process to separate mixtures based on solubility, density, and/or boiling/melting point of the components;
- Given melting and boiling point data, graphing temperature vs. time through phase changes;
- Interpreting and extrapolating from a given graph of mass vs. volume;
- Given data, determining values for various atomic properties (e.g., atomic number, mass number);
- Creating diagrams of atomic models, including ions and isotopes;
- Given elemental properties, determining which elements belong in the same group;
- Predicting an unknown element's properties based on the properties of elements near it in the periodic table;
- Determining the chemical names of simple ionic and covalent compounds given their formulas (or vice versa);
- Creating a model of atoms involved in various chemical bonds;
- Given a pair of elements, determining if the bond would be covalent or ionic (e.g., metal-nonmetal, nonmetal-nonmetal);
- Given elements, determining the formula for appropriate ionic compounds and name the compounds;
- Given an ionic formula with an unknown, identifying the group's name, ion's charge, and/or the group's location on the periodic table (e.g., XF_2);
- Given compounds, describing how the bonds are formed in terms of electrons;
- Balancing chemical reactions (if given information about energy change, identify as endo- or exothermic);
- Interpreting a nuclear decay graph;
- Comparing nuclear fusion and nuclear fission;
- Describing how position on the periodic table determines the types of bonds that will form between various atoms;
- Given half-life data of radioactive elements, evaluating which elements are appropriate for various applications and justify this using evidence;
- Describing the advantages and disadvantages of radioisotope applications.

Distractors may include, but are not limited to, the following:

- Common misconceptions:
    - Particle size and temperature change during phase changes.
    - Melting and freezing don't happen at the same temperature.
    - Density is equivalent to weight or mass.

- During phase change a substance is either completely in one phase or another.
- New substances are formed in all solutions.
- Concentration can only be changed by varying the solute.
- Solutions can only be a solid dissolved in a liquid.
- Ions are formed by changing protons.
- Neutrons are negative.
- Mass number and atomic number are the same.
- Mass number is number of neutrons.
- The number of electrons and protons have to be equal in an atom.
- The number of protons and neutrons have to be equal in an atom.
- Positive ions have extra electrons.
- Confusing groups and periods.
- Halogens have a +7 charge as opposed to –1.
- Covalent bonds transfer charges and ionic bonds share charges.
- Using charges as subscript.
- Using Greek prefixes for all compounds.

Hand-scored

Responses may include, but are not limited to, the following:

- Supporting, with evidence, whether particular regions of a heating-cooling graph involve kinetic or potential energy;
- Designing a solution to a real-world problem involving mixtures that need to be separated based on solubility, density, and/or boiling/melting point;
- Comparing the strengths and weaknesses of designs to determine the identity of an unknown substance based on solubility, density, and/or boiling/melting point;
- Designing an experiment to determine the relative concentrations of solutions;
- Given data, justifying conclusions from the results of an experiment (e.g., Rutherford gold foil experiment, periodic trends).

Energy and Waves

Sub-Topics:

- **Conservation of Energy***
    - Quantifying kinetic energy*
    - Quantifying gravitational potential energy*
    - Energy is relative*
- **Transfer and transformation of energy (including work)***
- **Waves**
    - Refraction, reflection, diffraction, absorption, superposition
    - Radiant energy and the electromagnetic spectrum
    - Doppler shift
- **Thermal Energy**
- **Electricity***
    - Movement of electrons*
    - Current*
    - Electric potential (voltage)*
    - Resistors and transfer of energy*

*Content which may be addressed on the PBA

Content Elaboration:

Building upon knowledge gained in elementary and middle school, major concepts about energy and waves are further developed. Conceptual knowledge will move from qualitative understandings of energy and waves to ones that are more quantitative using mathematical formulas, manipulations and graphical representations.

Conservation of Energy

Energy content learned in middle school, specifically conservation of energy and the basic differences between kinetic and potential energy, is elaborated on and quantified in this course. Energy has no direction and has units of Joules (J). Kinetic energy, E_k, can be mathematically represented by $E_k = ½mv^2$. Gravitational potential energy, E_g, can be mathematically represented by $E_g = mgh$. The amount of energy of an object is measured relative to a reference that is considered to be at a point of zero energy. The reference may be changed to help understand different situations. Only the change in the amount of energy can be measured absolutely. The conservation of energy and equations for kinetic and gravitational potential energy can be used to calculate values associated with energy (i.e., height, mass, speed) for situations involving energy transfer and transformation. Opportunities to quantify energy from data collected in experimental situations (e.g., a swinging pendulum, a car travelling down an incline) must be provided.

Transfer and Transformation of Energy

In middle school, concepts of energy transfer and transformation were addressed, including conservation of energy, conduction, convection, and radiation, the transformation of electrical energy, and the dissipation of energy into thermal energy. Work also was introduced as a method of energy transfer into or out of the system when an outside force moves an object over a distance. In this course, these concepts are further developed. As long as the force, $\boldsymbol{F}$, and displacement, $\boldsymbol{\Delta x}$, are in the same direction, work, W, can be calculated from the equation $W = \boldsymbol{F\Delta x}$. Energy transformations for a phenomenon can be represented through a series of pie graphs or bar graphs. Equations for work, kinetic energy and potential energy can be combined with the law of conservation of energy to solve problems. When energy is transferred from one system to another, some of the energy is transformed to thermal energy. Since thermal energy involves the random movement of many trillions of subatomic particles, it is less able to be organized to bring about further change. Therefore, even though the total amount of energy remains constant, less energy is available for doing useful work.

Waves

As addressed in middle school, waves transmit energy from one place to another, can transfer energy between objects and can be described by their speed, wavelength, frequency and amplitude. The relationship between speed, wavelength and frequency also was addressed in middle school Earth and Space Science as the motion of seismic waves through different materials is studied.

In elementary and middle school, reflection and refraction of light were introduced, as was absorption of radiant energy by transformation into thermal energy. In this course, these processes are addressed from the perspective of waves and expanded to include other types of energy that travel in waves. When a wave encounters a new material, the new material may absorb the energy of the wave by transforming it to another form of energy, usually thermal energy. Waves can be reflected off solid barriers or refracted when a wave travels from one medium into another medium. Waves may undergo diffraction around small obstacles or openings. When two waves traveling through the same medium meet, they pass through each other then continue traveling through the medium as before. When the waves meet, they undergo superposition, demonstrating constructive and destructive interference. Sound travels in waves and undergoes reflection, refraction, interference and diffraction. In the physics syllabus, many of these wave phenomena will be studied further and quantified.

Radiant energy travels in waves and does not require a medium. Sources of light energy (e.g., the sun, a light bulb) radiate energy continually in all directions. Radiant energy has a wide range of frequencies, wavelengths and energies arranged into the electromagnetic spectrum. The electromagnetic spectrum is divided into bands: radio (lowest energy), microwaves, infrared, visible light, X-rays and gamma rays (highest energy) that have different applications in everyday life. Radiant energy of the entire electromagnetic spectrum travels at the same speed in a vacuum. Specific frequency, energy or wavelength ranges of the electromagnetic spectrum are not required. However, the relative positions of the different bands, including the colors of visible light, are important (e.g., ultraviolet has more energy than microwaves). Radiant energy exhibits wave behaviors including reflection, refraction, absorption, superposition and diffraction, depending in part on the nature of the medium. For opaque objects (e.g., paper, a chair, an apple), little if any radiant energy is transmitted into the new material. However the radiant energy can be absorbed, usually increasing the thermal energy of the object and/or the radiant energy can be reflected. For rough objects, the reflection in all directions forms a diffuse reflection and for smooth shiny objects, reflections can result in clear images. Transparent materials transmit most of the energy through the material but smaller amounts of energy may be absorbed or reflected.

Changes in the observed frequency and wavelength of a wave can occur if the wave source and the observer are moving relative to each other. When the source and the observer are moving toward each other, the wavelength is shorter and the observed frequency is higher; when the source and the observer are moving away from each other, the wavelength is longer and the observed frequency is lower. This phenomenon is called the Doppler shift and can be explained using diagrams. This phenomenon is important to current understanding of how the universe was formed and will be applied in later sections of this course. Calculations to measure the apparent change in frequency or wavelength are not appropriate for this course.

Thermal Energy
In middle school, thermal energy is introduced as the energy of movement of the particles that make up matter. Processes of heat transfer, including conduction, convection and radiation, are studied. In other sections of this course, the role of thermal energy during heating, cooling and phase changes is explored conceptually and graphically. In this course, rates of thermal energy transfer and thermal equilibrium are introduced.

Thermal conductivity depends on the rate at which thermal energy is transferred from one end of a material to another. Thermal conductors have a high rate of thermal energy transfer and thermal insulators have a slow rate of thermal energy transfer. The rate at which thermal radiation is absorbed or emitted by a system depends on its temperature, color, texture and exposed surface area. All other things being equal, in a given amount of time, black rough surfaces absorb more thermal energy than smooth white surfaces. An object or system is continually absorbing and emitting thermal radiation. If the object or system absorbs more thermal energy than it emits and there is no change in phase, the temperature increases. If the object or system emits more thermal energy than is absorbed and there is no change in phase, the temperature decreases. For an object or system in thermal equilibrium, the amount of thermal energy absorbed is equal to the amount of thermal energy emitted; therefore, the temperature remains constant. In chemistry, changes in thermal energy are quantified for substances that change their temperature.

Electricity
In earlier grades, these concepts were introduced: electrical conductors and insulators; and a complete loop is needed for an electrical circuit that may be parallel or in a series. In this course, circuits are explained by the flow of electrons, and current, voltage and resistance are introduced conceptually to explain what was observed in middle school.

The differences between electrical conductors and insulators can be explained by how freely the electrons flow throughout the material due to how firmly electrons are held by the nucleus.

By convention, electric current is the rate at which positive charge flows in a circuit. In reality, it is the negatively charged electrons that are actually moving. Current is measured in amperes (A), which is equal to one coulomb of charge per second (C/s). In an electric circuit, the power source supplies the electrons already in the circuit with electric potential energy by doing work to separate opposite charges. For a battery, the energy is provided by a chemical reaction that separates charges on the positive and negative sides of the battery. This separation of charge is what causes the electrons to flow in the circuit. These electrons then transfer energy to other objects and transform electrical energy into other forms (e.g., light, sound, heat) in the resistors. Current continues to flow, even after the electrons transfer their energy. Resistors oppose the rate of charge flow in the circuit. The potential difference or voltage across an energy source is a measure of potential energy in Joules supplied to each coulomb of charge. The volt (V) is the unit of potential difference and is equal to one Joule of energy per coulomb of charge (J/C). Potential difference across the circuit is a property of the energy source and does not depend upon the devices in the circuit. These concepts can be used to explain why current will increase as the potential difference increases and as the resistance decreases. Experiments, investigations and testing (3-D or virtual) must be used to construct a variety of circuits, and measure and compare the potential difference (voltage) and current. Electricity concepts are dealt with conceptually in this course. Calculations with circuits will be addressed in the physics syllabus.

Content Limits:

Note: Symbols for all physical quantities will be referenced by name (e.g., gravitational potential energy, E_g).

Note: For testing purposes, the acceleration due to Earth's gravity will be provided, and the value will be 10 m/s^2 or N/kg.

- Calculations involving the equations of gravitational potential (E_g) and kinetic energy (E_k) (e.g., find m, v, or h), in scenarios involving conservation of energy in a closed system;
- Calculations involving the equations of gravitational potential (E_g), kinetic energy (E_k), and/or work (W) (e.g., find m, v, h, F, or Δx) in scenarios where an outside force is acting on a system;
- Conceptual understanding of dissipations of energy from systems due to transformation into thermal energy;
- Characteristics and behaviors (e.g., superposition/interference, diffraction) of waves as a form of energy transfer;
- Relative energies, frequencies, and wavelengths of the different bands of the electromagnetic spectrum, including the colors of visible light (e.g., ultraviolet has more energy than microwaves);
- Change in frequency and wavelength due to the Doppler effect;

- Thermal conductivity as it relates to rates of thermal energy transfer and thermal equilibrium;
- Radiant energy interactions with objects influencing the rate of thermal absorption and emission (e.g., temperature, color, texture, and exposed surface area in the system);
- The origin, motion, and energy of electrons in circuits;
- The role of batteries as energy sources and resistors as energy dissipaters in circuits;
- Conceptual understanding of potential difference (i.e., voltage);
- Current and resistance and the relationship between them.

Do Not Assess:

- Value of the acceleration due to gravity at Earth’s surface (*g*);
- Solving for velocity from kinetic energy (avoid the square root);
- Calculations of work from a force at an angle to motion (force can be in the opposite direction of motion);
- Basic conceptual understandings of conservation of energy (middle school);
- Conduction, convection, and radiation;
- Calculations involving dissipation of energy into thermal energy, beyond what can be done through conservation of energy;
- Basic conceptual understanding of work;
- Basic wave properties such as speed, wavelength, frequency, and amplitude;
- The relationship between speed, wavelength, and frequency;
- Advanced details (e.g. resonance, diffraction patterns, wave/particle duality) and calculations involved in wave phenomena;
- Specific values of frequency, energy or wavelength ranges of parts of the electromagnetic spectrum;
- Basics of reflection, refraction, diffusion, transmission, and absorption of light and sound not related to waves;
- Doppler effect calculations to measure the apparent change in frequency or wavelength;
- Classifying materials as thermal conductors and thermal insulators;
- Specific and latent heat calculations;
- Thermal energy as the energy of movement of the particles that make up matter;
- Basic concepts of electrical conductors and insulators;
- Basic concepts of electrical circuits (e.g., open vs. closed circuits, structural differences between parallel and series circuits);
- Calculations of electrical properties.

Stimulus Attributes:

- Series of bar graphs representing energy transformations;
- Drawings/illustrations/pictures showing a force being exerted on an object over a distance (e.g., work), labeled to include values for $W = F\Delta x$;

- Graphs and tables showing data from experimental situations involving kinetic energy, gravitational potential energy, and/or work;
- Drawings/illustrations/pictures of constructive and destructive interference (e.g., waves from opposite ends of a spring);
- Drawings/illustrations/pictures of diffraction using wave fronts (e.g., plane wave incident on small opening or corner);
- Diagram of waves emitted by a moving or stationary source;
- Drawings/illustrations/pictures of the electromagnetic spectrum;
- Tables or diagrams showing thermal energy transfer data through various media or materials;
- Circuit diagrams, both parallel and series;
- Drawings/pictures/illustrations of charges within batteries;
- Tables/graphs showing voltage and current data from various circuits.

Response Attributes:

Machine-scored

Response options may include, but are not limited to, the following:

- Given a real-world scenario, calculating values involving work, kinetic energy, and gravitational potential energy;
- Completing bar graphs showing energy transformations and transfers;
- Visually representing diffraction, superposition, constructive and destructive interference;
- Visually representing a change in wavelength due to the Doppler Effect;
- Ordering the electromagnetic spectrum by energy, frequency, or wavelength;
- Conducting an investigation to determine factors influencing the rate at which thermal energy is absorbed and emitted (e.g., temperature, color, texture, and exposed surface area in the system);
- Conducting an investigation involving conservation of energy and/or work;
- Explaining why energy may not appear to be conserved in a real-world example;
- Determining changes in circuit properties (current, voltage) when circuit components or structure are changed and/or explaining these changes based on electron flow and energy transfer;
- Planning an experiment to determine the behavior of waves when interacting with a given surface;
- Planning an investigation to determine factors influencing the rate at which thermal energy is absorbed and emitted (e.g.,

temperature, color, texture, and exposed surface area in the system).

Distractors may include, but are not limited to, the following:

- Common misconceptions:
  - Electrons are “used up” in circuits.
  - The battery supplies all electrons in a circuit.
  - Potential energy only exists for motionless objects.
  - Energy is “used up.”
  - Potential energy is “stored.”
  - Potential energy is absolute.
  - Kinetic energy can be negative.
  - The Doppler effect affects loudness.
  - Work can’t be negative or zero.
  - Work is equivalent to force or labor.
  - Particles travel with sound waves.
  - Destructive interference always destroys the waves involved.
  - Wave properties are the same.
  - Sound and light waves are the same.
  - Radio waves are sound waves.
  - Infrared waves can be seen.

Hand-scored

Responses may include, but are not limited to, the following:

- Planning an experiment to determine the amount of energy transferred through work on a system;
- Designing or improving a system that involves work and energy transformation that meets certain constraints (e.g., height, speed, force, displacement);
- Designing or developing applications of electric circuits to a real-world scenario;
- Explaining observed changes in current and voltage in a circuit in terms of electrons and energy transfer.

Forces and Motion

Sub-Topics:

- **Motion***
  - Introduction to one-dimensional vectors*
  - Displacement, velocity (constant, average and instantaneous) and acceleration*
  - Interpreting position vs. time and velocity vs. time graphs*
- **Forces***
  - Force diagrams*
  - Types of forces (gravity, friction, normal, tension)*
  - Field model for forces at a distance*
- **Dynamics (how forces affect motion)***
  - Objects at rest*
  - Objects moving with constant velocity*
  - Accelerating objects*

*Content which may be addressed on the PBA

Content Elaboration:

Building upon content in elementary and middle school, major concepts of motion and forces are further developed. In middle school, speed has been dealt with conceptually, mathematically and graphically. The concept that forces have both magnitude and direction can be represented with a force diagram, that forces can be added to find a net force and that forces may affect motion has been addressed in middle school. At the high school level, mathematics (including graphing) is used when describing these phenomena, moving from qualitative understanding to one that is more quantitative. For the physical science course, all motion is limited to objects moving in a straight line either horizontally, vertically, up an incline or down an incline, that can be characterized by segments of uniform motion (e.g., at rest, constant velocity, constant acceleration). Motions of two objects may be compared or addressed simultaneously (e.g., when or where would they meet).

Motion

The motion of an object depends on the observer’s frame of reference and is described in terms of distance, position, displacement, speed, velocity, acceleration and time. Position, displacement, velocity and acceleration are all vector properties (magnitude and direction). All motion is relative to whatever frame of reference is chosen, for there is no motionless frame from which to judge all motion. The relative nature of motion will be addressed conceptually, not mathematically. Non-inertial reference frames are excluded. Motion diagrams can be drawn and interpreted to represent the position and velocity of an object. Showing the acceleration on motion diagrams will be reserved for physics.

The displacement or change in position of an object is a vector quantity that can be calculated by subtracting the initial position from the final position ($\boldsymbol{\Delta x} = \boldsymbol{x_f} - \boldsymbol{x_i}$). Displacement can be positive or negative depending upon the direction of motion. Displacement is not always equal to the distance travelled. Examples should be given where the distance is not the same as the displacement.

Velocity is a vector property that represents the rate at which position changes. Average velocity can be calculated by dividing displacement (change in position) by the elapsed time ($\boldsymbol{v_{avg}} = (\boldsymbol{x_f} - \boldsymbol{x_i})/(t_f - t_i)$). Velocity may be positive or negative depending upon the direction of motion and is not always equal to the speed. Provide examples of when the average speed is not the same as the average velocity. Objects that move with constant velocity have the same displacement for each successive time interval. While speeding up or slowing down and/or changing direction, the velocity of an object changes continuously, from instant to instant. The speed of an object at any instant (clock reading) is called instantaneous speed. An object may not travel at this instantaneous speed for any period of time or cover any distance with that particular speed, especially if the speed is continually changing.

Acceleration is a vector property that represents the rate at which velocity changes. Average acceleration can be calculated by dividing the change in velocity divided by elapsed time ($\boldsymbol{a_{avg}} = (\boldsymbol{v_f} - \boldsymbol{v_i})/(t_f - t_i)$). At this grade level, it should be noted that acceleration can be positive or negative, but specifics about what kind of motions produce positive or negative accelerations will be addressed in the physics syllabus. The word “deceleration” should not be used because students tend to associate a negative sign of acceleration only with slowing down. Objects that have no acceleration can either be standing still or be moving with constant velocity (speed and direction). Constant acceleration occurs when the change in an object’s instantaneous velocity is the same for equal successive time intervals.

Motion can be represented by position vs. time and velocity vs. time graphs. Specifics about the speed, direction and change in motion can be determined by interpreting such graphs. For physical science, graphs will be limited to positive x-values and show only uniform motion involving segments of constant velocity or constant acceleration. Motion must be investigated by collecting and analyzing data in the laboratory. Technology can enhance motion exploration and investigation through video analysis, the use of motion detectors and graphing data for analysis.

Objects that move with constant velocity and have no acceleration form a straight line (not necessarily horizontal) on a position vs. time graph. Objects that are at rest will form a straight horizontal line on a position vs. time graph. Objects that are accelerating will show a curved line on a position vs. time graph. Velocity can be calculated by determining the slope of a position vs. time graph. Positive slopes on position vs. time graphs indicate motion in a positive direction. Negative slopes on position vs. time graphs indicate motion in a negative direction. While it is important that students can construct graphs by hand, computer graphing programs or graphing calculators also can be used so more time can be spent on graph interpretation and analysis.

Constant acceleration is represented by a straight line (not necessarily horizontal) on a velocity vs. time graph. Objects that have no acceleration (at rest or moving at constant velocity) will have a straight horizontal line for a velocity vs. time graph. Average acceleration can be determined from the slope of a velocity vs. time graph. The details about motion graphs should not be taught as rules to memorize, but rather as generalizations that can be developed from interpreting the graphs.

Forces

Force is a vector quantity, having both magnitude and direction. The (SI) unit of force is a Newton. One Newton of net force will cause a 1 kg object to experience an acceleration of 1 m/s^2. A Newton also can be represented as $kg \cdot m/s^2$. The opportunity to measure force in the lab must be provided (e.g., with a spring scale or a force probe). Normal forces and tension forces are introduced conceptually at this level. These forces and other forces introduced in prior grades (friction, drag, contact, gravitational, electric and magnetic) and can be used as examples of forces that affect motion. Gravitational force (weight) can be calculated from mass, but all other forces will only be quantified from force diagrams that were introduced in middle school. In physical science, only forces in one dimension (positive and negative) will be addressed. The net force can be determined by one-dimensional vector addition. More quantitative study of friction forces, universal gravitational forces, elastic forces and electrical forces will be addressed in the physics syllabus.

Friction is a force that opposes sliding between two surfaces. For surfaces that are sliding relative to each other, the force on an object always points in a direction opposite to the relative motion of the object. In physical science, friction will only be calculated from force diagrams. Equations for static and kinetic friction are found in the physics syllabus.

A normal force exists between two solid objects when their surfaces are pressed together due to other forces acting on one or both objects (e.g., a solid sitting on or sliding across a table, a magnet attached to a refrigerator). A normal force is always a push directed at right angles from the surfaces of the interacting objects. A tension force occurs when a non-slack rope, wire, cord or similar device pulls on another object. The tension force always points in the direction of the pull.

In middle school, the concept of a field as a region of space that surrounds objects with the appropriate property (mass for gravitational fields, charge for electric fields, a magnetic object for magnetic fields) was introduced to explain gravitational, magnetic and electrical forces that occur over a distance. The field concept is further developed in physical science. The stronger the field, the greater the force exerted on objects placed in the field. The field of an object is always there, even if the object is not interacting with anything else. The gravitational force (weight) of an object is proportional to its mass. Weight, $\boldsymbol{F_g}$, can be calculated from the equation $\boldsymbol{F_g} = m\boldsymbol{g}$, where $\boldsymbol{g}$ is the gravitational field strength of an object which is equal to *9.8 N/kg* (m/s^2) on the surface of Earth.

Dynamics (how forces affect motion)
An object does not accelerate (remains at rest or maintains a constant speed and direction of motion) unless an unbalanced net force acts on it. The rate at which an object changes its speed or direction (acceleration) is proportional to the vector sum of the applied forces (net force, F_{net}) and inversely proportional to the mass ($\boldsymbol{a} = \boldsymbol{F}_{net}/m$). When the vector sum of the forces (net force) acting on an object is zero, the object does not accelerate. For an object that is moving, this means the object will remain moving without changing its speed or direction. For an object that is not moving, the object will continue to remain stationary. These laws will be applied to systems consisting of a single object upon which multiple forces act. Vector addition will be limited to one dimension (positive and negative). While both horizontal and vertical forces can be acting on an object simultaneously, one of the dimensions must have a net force of zero.

A force is an interaction between two objects. Both objects in the interaction experience an equal amount of force, but in opposite directions. Interacting force pairs are often confused with balanced forces. Interacting force pairs can never cancel each other out because they always act on different objects. Naming the force (e.g., gravity, friction) does not identify the two objects involved in the interacting force pair. Objects involved in an interacting force pair can be easily identified by using the format “A acts on B so B acts on A.” For example, the truck hits the sign therefore the sign hits the truck with an equal force in the opposite direction. Earth pulls the book down so the book pulls Earth up with an equal force. The focus of the content is to develop a conceptual understanding of the laws of motion to explain and predict changes in motion, not to name or recite a memorized definition. In the physics syllabus, all laws will be applied to systems of many objects.

Content Limits:
- Differences between vector properties (e.g., position, displacement, velocity, and acceleration) and scalar properties (distance and speed);
- Representations of motion including position vs. time graphs, velocity vs. time graphs and motion diagrams;
- Conceptual understanding of normal (for surfaces at any angle) and tension forces;
- Calculations of physical properties from scenarios involving multiple forces acting on an object;
- Conceptual connection between gravitational field strengths and forces that act over a distance;
- Relationship between acceleration, net force ($\boldsymbol{F}_{net}$), and mass (Newton’s Second Law);
- Relationships of the forces between two interacting objects in a system (Newton’s Third Law);
- Differences between balanced forces and interacting force pairs.

Do Not Assess:

- Electric or magnetic fields and/or forces;
- Calculations of average speed;
- Calculations involving the relative nature of motion;
- Non-inertial reference frames;
- Acceleration vectors on motion diagrams;
- Motion graphs with negative y-values or showing non-uniform motion with changing acceleration (showing multiple segments of motion with different sections of uniform accelerations is acceptable);
- Acceleration vs. time graphs;
- Two-dimensional analysis of vectors, unless either the horizontal or vertical component cancels to zero;
- Nonlinear motion;
- Quantitative study of friction forces using coefficients of friction, universal law of gravity, and Hooke’s Law;
- Conceptual understanding of friction, drag, contact forces, gravitational force, electrical forces and magnetic forces taught in previous grades;
- Systems that contain multiple objects on which multiple forces act (e.g., pulleys);
- Terminology associated with Newton’s First, Second, and Third Laws of Motion;
- The terms “action” and “reaction” force (use “interactive force pairs” instead).

Stimulus Attributes:

- Scenarios in which the average speed is not the same as the average velocity (one-dimensional motion);
- Scenarios in which the distance is not the same as the displacement;
- Position vs. time and velocity vs. time graphs;
- Tables or graphs showing data for an object’s motion;
- Motion diagrams;
- Free body diagrams that show normal, tension, friction, drag, applied and/or gravitational forces;
- Drawings/illustrations/pictures of spring scales experiencing different levels of force;
- Tables/graphs showing data for multiple objects within a gravitational field.

Response Attributes:

Machine-scored

Response options may include, but are not limited to, the following:

- Calculating distance and displacement in a real-world scenario;
- Creating, analyzing, and/or interpreting position vs. time, velocity vs. time graphs, and motion diagrams;
- Translating between position vs. time, velocity vs. time graphs, and motion diagrams;

- Calculating displacement, average velocity, and acceleration based on data in graphs;
- Comparing the positions and motion of multiple objects from graphs and tables;
- In a real-world scenario, constructing free body diagrams using information from motion vs. time graphs (or vice versa);
- Calculating force, mass, or acceleration using values drawn from tables/graphs and/or free body diagrams;
- Identifying interactive force pairs, and comparing magnitude and direction, in a real world scenario;
- Explaining why interactive force pairs can never cancel.

Distractors may include, but are not limited to, the following:

- Common misconceptions:
  - Interactive force pairs act on one object.
  - Normal force and gravitational force are interactive force pairs.
  - Uniform motion requires a force.
  - Mass dominates in force interactions.
  - In a position vs. time graph, a positive slope means the object is going uphill.
  - In a position vs. time graph, a positive slope means acceleration or negative slope means slowing down.
  - In a position vs. time graph, intersecting lines mean equal speed.
  - A horizontal line in any motion graph signifies stopping.
  - The length of the arrow has no meaning in vectors.
  - Zero velocity means zero acceleration.
  - Distance and displacement are equivalent.
  - Speed and velocity are equivalent.

Hand-scored

Responses may include, but are not limited to, the following:

- Given a real-world scenario, interpreting position vs. time, velocity vs. time graphs, and/or motion diagrams;
- Given a real-world context, interpreting position vs. time, velocity vs. time graphs, and/or motion diagrams to create a scenario that explains the forces responsible for the motion;
- Designing an experiment using dynamics to determine a specific force in a given system of forces (e.g., friction force from spring scale);
- Designing or critiquing solutions to engineering problems involving forces and motion;
- Designing an experiment to measure the velocity of objects in a real-world scenario.

The Universe

Sub-Topics:

- History of the Universe
- Galaxy formation
- Stars
    - Formation, stages of evolution
    - Fusion in stars

Content Elaboration:

In early elementary school, observations of the sky and space are the foundation for developing a deeper knowledge of the solar system. In late elementary school, the parts of the solar system are introduced, including characteristics of the sun and planets, orbits and celestial bodies. At the middle school level, energy, waves, gravity and density are emphasized in the physical sciences, and characteristics and patterns within the solar system are found.

In the physical science course, the universe and galaxies are introduced, building upon the previous knowledge about space and the solar system in the earlier grades.

History of the Universe

The Big Bang Model is a broadly accepted theory for the origin and evolution of our universe. It postulates that 12 to 14 billion years ago, the portion of the universe seen today was only a few millimeters across (NASA).

According to the “big bang” theory, the contents of the known universe expanded explosively into existence from a hot, dense state 13.7 billion years ago (NAEP 2009). After the big bang, the universe expanded quickly (and continues to expand) and then cooled down enough for atoms to form. Gravity pulled the atoms together into gas clouds that eventually became stars, which comprise young galaxies. Foundations for the big bang model can be included to introduce the supporting evidence for the expansion of the known universe (e.g., Hubble’s law and red shift or cosmic microwave background radiation). A discussion of Hubble’s law and red shift is found in the *Galaxy Formation* section, below.

Technology provides the basis for many new discoveries related to space and the universe. Visual, radio and x-ray telescopes collect information from across the entire electromagnetic spectrum; computers are used to manage data and complicated computations; space probes send back data and materials from remote parts of the solar system; and accelerators provide subatomic particle energies that simulate conditions in the stars and in the early history of the universe before stars formed.

Galaxy Formation

A galaxy is a group of billions of individual stars, star systems, star clusters, dust and gas bound together by gravity. There are billions of galaxies in the universe, and they are classified by size and shape. The Milky Way is a spiral galaxy. It has more than 100 billion stars and a diameter of more than 100,000 light years. At the center of the Milky Way is a collection of stars bulging outward from the disk, from which extend spiral arms of gas, dust and most of the young stars. The solar system is part of the Milky Way galaxy.

Hubble's law states that galaxies that are farther away have a greater red shift, so the speed at which a galaxy is moving away is proportional to its distance from the Earth. Red shift is a phenomenon due to Doppler shifting, so the shift of light from a galaxy to the red end of the spectrum indicates that the galaxy and the observer are moving farther away from one another. Doppler shifting also is found in the *Energy and Waves* section of this course.

Stars

Early in the formation of the universe, stars coalesced out of clouds of hydrogen and helium and clumped together by gravitational attraction into galaxies. When heated to a sufficiently high temperature by gravitational attraction, stars begin nuclear reactions, which convert matter to energy and fuse the lighter elements into heavier ones. These and other fusion processes in stars have led to the formation of all the other elements. (NAEP 2009). All of the elements, except for hydrogen and helium, originated from the nuclear fusion reactions of stars (College Board Standards for College Success, 2009).

Stars are classified by their color, size, luminosity and mass. A Hertzprung-Russell diagram must be used to estimate the sizes of stars and predict how stars will evolve. Most stars fall on the main sequence of the H-R diagram, a diagonal band running from the bright hot stars on the upper left to the dim cool stars on the lower right.

A star's mass determines the star's place on the main sequence and how long it will stay there. Patterns of stellar evolution are based on the mass of the star. Stars begin to collapse as the core energy dissipates. Nuclear reactions outside the core cause expansion of the star, eventually leading to the collapse of the star.

Note: Names of stars and naming the evolutionary stage of a star from memory will not be assessed. The emphasis is on the interpretation of data (using diagrams and charts) and the criteria and processes needed to make those determinations.

Content Limits:

- Evidence for the Big Bang Model of the Universe (limit to Hubble's Law);
- The relationship between the amount of redshift and the distance from the observer for distant galaxies;
- General understanding of the formation of stars from clouds of hydrogen and helium;
- Fusion in stars and its role in formation of elements;
- The HR diagram as it relates to the characteristics (color, luminosity, temperature, mass, and evolutionary stage) of main sequence of stars;

- Relationship between mass and time spent in the main sequence stage.

Do Not Assess:
- Formation of planets;
- Identifying specific equations of nuclear reactions in stars;
- Calculations of Doppler shift, redshift, and Hubble's Law;
- Microwave background radiation;
- Memorized names of stars or galaxies;
- Evolutionary stages of stars aside from the main sequence.

Stimulus Attributes:
- Data from various technologies that relate to stars or galaxies;
- Comparative spectroscopic data indicating the Doppler shift of various galaxies, given the visible light portion of the EM spectrum with consistent units;
- A Hertzsprung-Russell diagram showing luminosity vs. temperature;
- Tables showing data on various stellar characteristics (e.g., color, size, luminosity, and mass) from different stars.

Response Attributes:

Machine-scored

Response options may include, but are not limited to, the following:

- Analyzing evidence (e.g., atomic spectra of galaxies) supporting the Big Bang Model or Hubble's Law;
- Interpreting the HR diagram in terms of mass, luminosity, temperature and evolutionary stages of the main sequence stars;
- Comparing spectroscopic data indicating the Doppler shift of various galaxies to determine relative motion.

Distractors may include, but are not limited to, the following:

- Common misconceptions:
  - Doppler shift and redshift are different.
  - The size of the universe.
  - The Milky Way Galaxy is the universe.
  - The sun is different from other stars.

Hand-scored

This area will not be assessed on the PBA.