Warren County School District

PLANNED INSTRUCTION

COURSE DESCRIPTION

Course Title: AP Physics 2

Course Number: ____________________

Course Prerequisites: appropriate algebra course work

Course Description:

AP Physics 2 is an algebra-based, introductory college-level physics course that explores topics such as fluid statics and dynamics; thermodynamics with kinetic theory; PV diagrams and probability; electrostatics; electrical circuits with capacitors; magnetic fields; electromagnetism; physical and geometric optics; and quantum, atomic, and nuclear physics. Through inquiry-based learning, students will develop scientific critical thinking and reasoning skills

Suggested Grade Level: 10,11,12

Length of Course: ______ One Semester __X__ Two Semesters ______Other (Describe)

Units of Credit: 1 (Insert ***NONE*** if appropriate.)

PDE *Certification and Staffing Policies and Guidelines (CSPG)* Required Teacher Certification(s) (Insert certificate title and CSPG#) **__Physics__ _____ _**

Certification verified by WCSD Human Resources Department:
___X___ Yes ______ No

Board Approved Textbooks, Software, Materials:

TEXTBOOK:

- **Etkina, Eugenia, Michael Gentile, and Alan Van Heuvelen. College Physics. San Francisco, CA: Pearson, 2014. [CR1]**

TEACHING RESOURCES:

- **Christian, Wolfgang, and Mario Belloni. Physlet® Physics: Interactive Illustrations, Explorations and Problems for Introductory Physics. Upper Saddle River, NJ: Prentice Hall, 2004.**

- **Hieggelke, Curtis, David Maloney, Tomas O'Kuma, and Stephen Kanim. E&M TIPERs: Electricity and Magnetism Tasks. Upper Saddle River, NJ: Pearson, 2006.**

- **Knight, Randall D., Brian Jones, and Stuart Field. College Physics: A Strategic Approach. 2nd ed., AP® ed. Boston: Pearson, 2013.**

Publisher:
ISBN #:
Copyright Date:
Date of WCSD Board Approval:

<u>BOARD APPROVAL:</u>

Date Written: ___7/2014________

Date Approved:______________

Implementation Year:_____2014-2015

SPECIAL EDUCATION AND GIFTED REQUIREMENTS

The teacher shall make appropriate modifications to instruction and assessment based on a student's Individual Education Plan (IEP) or Gifted Individual Education Plan (GIEP).

SPECIFIC EDUCATIONAL STANDARDS, ESSENTIAL QUESTIONS, CONTENT, & SKILLS

AP PHYSICS 2 2014

INSTRUCTIONAL STRATEGIES

The AP Physics 2 course is conducted using **inquiry-based instructional strategies** that focus on experimentation to develop students' conceptual understanding of physics principles. The students begin studying a topic by making observations and discovering patterns of natural phenomena. The next steps involve developing, testing and applying models. Throughout the course, the students construct and use multiple representations of physical processes, solve multi-step problems, design investigations, and reflect on knowledge construction through self-assessment rubrics.

In most labs, the students use probeware technology in data acquisition. In the classroom, they use graphing calculators and digital devices for interactive simulations, Physlet-based exercises, collaborative activities and formative assessments.

COURSE SYLLABUS

UNIT 1. ELECTROSTATICS [CR2c]

- Electric Force
- Electric Field
- Electric Potential

Big Ideas 1, 2, 3, 4, 5

Learning Objectives: 1.B.1.1, 1.B.1.2, 1.B.2.2, 1.B.2.3, 1.B.3.1, 2.C.1.1, 2.C.1.2, 2.C.2.1, 2.C.3.1, 2.C.4.1, 2.C.4.2, 2.C.5.1, 2.C.5.2, 2.C.5.3, 2.E.2.1, 2.E.2.2, 2.E.2.3, 2.E.3.1, 2.E.3.2, 3.A.2.1, 3.A.3.2, 3.A.3.3, 3.A.3.4, 3.A.4.1, 3.A.4.2, 3.A.4.3, 3.B.1.3, 3.B.1.4, 3.B.2.1, 3.C.2.1, 3.C.2.2, 3.C.2.3, 3.G.1.2, 3.G.2.1, 4.E.3.1, 4.E.3.2, 4.E.3.3, 4.E.3.4, 4.E.3.5, 5.A.2.1, , 5.B.2.1, 5.C.2.1, 5.C.2.2, 5.C.2.3

UNIT 2. ELECTRIC CIRCUITS [CR2d]

- Electric resistance
- Ohm's Law
- DC circuits with resistors only
- Kirchhoff's Laws
- Series, parallel and series-parallel circuits
- Capacitance
- DC circuits with resistors and capacitors

Big Ideas 1, 4, 5

Learning Objectives: 1.E.2.1, 4.E.4.1, 4.E.4.2, 4.E.4.3, 4.E.5.1, 4.E.5.2, 4.E.5.3, 5.B.9.4, 5.B.9.5, 5.B.9.6, 5.B.9.7, 5.B.9.8, 5.C.3.4, 5.C.3.5, 5.C.3.6, 5.C.3.7

UNIT 3. MAGNETISM AND ELECTROMAGNETIC INDUCTION [CR2e]

- Magnetic field
- Magnetic force on a charged particle
- Magnetic force on a current-carrying wire
- Magnetic flux
- Electromagnetic induction: Faraday's Law

- Lenz's law
- Motional *emf*

Big Ideas 1, 2, 3, 4

Learning Objectives: 2.C.4.1, 2.D.1.1, 2.D.2.1, 2.D.3.1, 2.D.4.1, 3.A.2.1, 3.A.3.2, 3.A.3.3, 3.A.4.1, 3.A.4.2, 3.A.4.3, 3.C.3.1, 3.C.3.2, 4.E.1.1, 4.E.2.1

UNIT 4. THERMODYNAMICS [CR2a]

- Kinetic theory
- Ideal gases
- First law of thermodynamics
- Thermodynamic processes and PV diagrams
- Heat engines
- Carnot cycle
- Efficiency
- Second law of thermodynamics: entropy

Big Ideas 1, 4, 5, 7

Learning Objectives: 1.E.3.1, 4.C.3.1, 5.A.2.1, 5.B.4.1, 5.B.4.2, 5.B.5.4, 5.B.5.5, 5.B.5.6, 5.B.6.1, 5.B.7.1, 5.B.7.2, 5.B.7.3, 7.A.1.1, 7.A.1.2, 7.A.2.1, 7.A.2.2, 7.A.3.1, 7.A.3.2, 7.A.3.3, 7.B.1.1, 7.B.2.1

UNIT 5. FLUIDS [CR2b]

- Density
- Pressure: atmospheric and fluid pressure
- Pascal's principle
- Buoyant force
- Archimedes' principle
- Flow rate
- Continuity equation
- Bernoulli's principle

Big Ideas 1, 3, 5

Learning Objectives: 1.E.1.1, 1.E.1.2, 3.C.4.1, 3.C.4.2, 5.B.10.1, 5.B.10.2, 5.B.10.3, 5.B.10.4, 5.F.1.1

UNIT 6. GEOMETRIC AND PHYSICAL OPTICS [CR2f]

- Reflection
- Image formation by flat and curved mirrors
- Refraction and Snell's Law

- Image formation by thin lenses
- Interference and diffraction
- Double slit, single slit and diffraction grating interference
- Thin film interference

Big Idea 6

Learning Objectives: 6.A.1.2, 6.A.1.3, 6.A.2.2, 6.B.3.1, 6.C.1.1, 6.C.1.2, 6.C.2.1, 6.C.3.1, 6.C.4.1, 6.E.1.1, 6.E.2.1, 6.E.3.1, 6.E.3.2, 6.E.3.3, 6.E.4.1, 6.E.4.2, 6.E.5.1, 6.E.5.2, 6.F.1.1, 6.F.2.1

UNIT 7. QUANTUM PHYSICS, ATOMIC AND NUCLEAR PHYSICS [CR2g]

- Atoms, atomic mass, mass number and isotopes
- Atomic energy levels
- Absorption and emission spectra
- Models of light: wave and particle
- Photoelectric effect
- DeBroglie wavelength
- Wave function graphs
- Mass-energy equivalence
- Radioactive decay: alpha, beta and gamma decay
- Half life
- Conservation of nucleon number: fission and fusion

Big Ideas 1, 3, 4, 5, 6, 7

Learning Objectives: 1.A.2.1, 1.A.4.1, 1.C.4.1, 1.D.1.1, 1.D.3.1, 3.G.3.1, 4.C.4.1, 5.B.8.1, 5.B.11.1, 5.C.1.1, 5.D.1.6, 5.D.1.7, 5.D.2.5, 5.D.2.6, 5.D.3.2, 5.D.3.3, 5.G.1.1, 6.F.3.1, 6.F.4.1, 6.G.1.1, 6.G.2.1, 6.G.2.2, 7.C.1.1, 7.C.2.1, 7.C.3.1, 7.C.4.1

LABORATORY INVESTIGATIONS AND THE SCIENCE PRACTICES

The AP Physics 2 course devotes over **25% of the time** to laboratory investigations. **[CR5]**
The laboratory component of the course allows the students to demonstrate the seven **science practices** through a variety of investigations in all of the foundational principles.
The students use **guided inquiry (GI)** or **open inquiry (OI)** in the design of their laboratory investigations. Some labs focus on investigating a physical phenomenon without having expectations of its outcomes. In other experiments, the student has an expectation of its outcome based on concepts constructed from prior experiences. In application experiments, the students use acquired physics principles to address practical problems.

All investigations are reported in a **laboratory journal**. Students are expected to record their observations, data, and data analyses. Data analyses include identification of the sources and effects of experimental uncertainty, calculations, results and conclusions, and suggestions for further refinement of the experiment as appropriate. **[CR7]**

UNIT	**LAB INVESTIGATION OBJECTIVE(S) CR6a** (Investigation identifier: Guided Inquiry: **GI** Open Inquiry: **OI**) **[CR6b]**	**SCIENCE PRACTICES [CR6b]**
UNIT 1. ELECTROSTATICS	**1. Electrostatics Investigations (GI)** To investigate the behavior of electric charges, charging processes and the distribution of charge on a conducting object.	1.1, 3.1, 4.1, 4.2, 5.1, 5.3, 6.1, 6.2, 6.4, 7.2
	2. The Electroscope (GI) To make qualitative observations of the behavior of an electroscope when it is charged by conduction and by induction.	1.1, 3.1, 4.1, 4.2, 5.1, 5.3, 6.1, 6.2, 6.4, 7.2
	3. Coulomb's Law (OI) To estimate the net charge on identical spherical pith balls by measuring the deflection (angle and separation) between two equally charged pith balls.	1.1, 1.2, 1.4, 1.5, 2.1, 2.2, 3.1, 4.1, 4.2, 4.3, 5.1, 5.3, 6.1, 6.4, 7.2
	4. Electric Field and Equipotentials (GI) To map equipotential isolines around charged conducting electrodes painted with conductive ink and construction of isolines of electric fields.	1.1, 1.2, 1.4, 3.1, 4.1, 4.2, 4.3, 5.1, 6.1, 6.2, 6.4, 7.2
UNIT 2. ELECTRIC CIRCUITS	**5. Resistance and Resistivity (OI)** To explore the microscopic and macroscopic factors that influence the electrical resistance of conducting materials. Students will investigate how geometry affects the resistance of an ionic conductor using Play-Doh™	1.2, 1.4, 2.1, 2.2, 3.1, 3.2, 4.1, 4.2, 4.3, 5.1, 5.2, 5.3, 6.1, 6.2, 6.4, 7.2
	6. DC Circuits: Brightness (GI) To make predictions about the brightness of light bulbs in a variety of DC circuit	1.4, 2.1, 2.2, 3.1, 4.1, 4.2, 4.3, 5.1, 5.3, 6.1, 6.2, 6.4, 7.2

	configurations (series, parallel and series-parallel) when some of the bulbs are removed.	
	7. DC Circuits: Resistors (OI) To investigate the behavior of resistors in series, parallel and series-parallel DC circuits. The lab includes measurements of currents and potential differences.	1.2, 1.4, 32.1, 2.2, .1, 4.1, 4.2, 4.3, 5.1, 5.3, 6.1, 6.2, 6.4, 7.2
	8. RC Circuits: Resistors and Capacitors (GI) This investigation consists of two parts: ▪ An observational experiment where the students make qualitative descriptions of the charging and discharging of a capacitor. ▪ To investigate the behavior of resistors in a series-parallel combination with a capacitor in series. Their investigation includes measurement of currents and potential differences.	1.2, 1.4, 2.1, 2.2, 3.1, 4.1, 4.2, 4.3, 5.1, 5.3, 6.1, 6.2, 6.4, 7.2
UNIT 3. MAGNETISM AND ELECTROMAGNETIC INDUCTION	**9. Magnetic Field of the Earth (GI)** To measure the horizontal component of the Earth’s magnetic field using a solenoid and a compass.	1.4, 2.1, 2.2, 3.1, 4.1, 4.2, 4.3, 5.1, 5.3, 6.1, 6.4, 7.2
	10. Magnetic Force on a Current-Carrying Wire (GI) To determine the magnitude and direction of the magnetic force exerted on a current-carrying wire.	1.4, 2.1, 2.2, 3.1, 4.1, 4.2, 4.3, 5.1, 5.3, 6.1, 6.4, 7.2
	11. Electromagnetic Induction (GI) The students move a bar magnet in and out of a solenoid and observe the deflection of the galvanometer. They examine the effects of a changing magnetic field by observing currents induced in a solenoid and determine whether the observations agree with the theory of electromagnetic induction and Lenz' law.	1.1, 1.2, 1.4, 3.1, 3.2, 4.1, 4.2, 4.3, 5.1, 5.3, 6.1, 6.2, 6.4, 7.2

UNIT 4. THERMODYNAMICS	**12. Gas Laws (OI)** To verify the relationships between pressure, temperature and volume of a gas (air).	1.1, 1.4, 2.1, 2.2, 3.1, 4.1, 4.2, 4.3, 5.1, 5.3, 6.1, 6.4, 7.2
	13. Thermal Conductivity (GI) To determine the thermal conductivity of a material by comparing the difference in temperature across one material to the difference in temperature across a second material of known thermal conductivity.	1.4, 2.1, 2.2, 3.1, 4.1, 4.2, 4.3, 5.1, 6.1, 6.2, 6.4, 7.2
	14. Heat Engine (GI) To determine how the work done by an engine that raises mass during each of its cycles is related to the area enclosed by its *P-V* graph.	1.1, 1.2, 1.4, 1.5, 2.1, 2.2, 3.1, 4.1, 4.2, 4.3, 5.1, 6.1, 6.2, 6.4, 7.2
	15. Efficiency of a Hair Dryer (GI) To determine the efficiency of a hair dryer as it dries a wet towel.	1.4, 2.1, 2.2, 3.1, 4.1, 4.2, 4.3, 5.1, 6.1, 6.2, 6.4, 7.2
UNIT 5. FLUIDS	**16. Archimedes' Principle (OI)** To determine the densities of a liquid and two unknown objects by using the method that is attributed to Archimedes.	1.1, 1.4, 2.1, 2.2, 3.1, 4.1, 4.2, 4.3, 5.1, 5.3, 6.1, 6.4, 7.2
	17. Torricelli's Theorem (GI) To determine the exit velocity of a liquid and predict the range attained with holes at varying heights using a clear 2 L plastic bottle.	1.1, 1.4, 2.1, 2.2, 3.1, 4.1, 4.2, 4.3, 5.1, 5.3, 6.1, 6.4, 7.2
	18. Water Fountain Lab (GI) The students design an investigation to determine: ▪ Exit angle and exit speed of the water ▪ Maximum height of water ▪ Radius of the fountain's exit hole ▪ Flow volume rate	1.1, 1.4, 2.1, 2.2, 3.1, 4.1, 4.2, 4.3, 5.1, 5.3, 6.1, 6.4, 7.2
UNIT 6. GEOMETRIC AND PHYSICAL OPTICS	**19. Reflection (GI)** Students design an investigation to answer the following question: "Are there any patterns in	1.1, 1.2, 1.3, 1.4, 3.3, 4.1, 4.2, 4.3, 5.3, 6.1, 6.4, 7.2

	the way plane mirrors and curved mirrors reflect light?”	
	20. Concave Mirrors (OI) This investigation has two parts: ▪ To determine the focal length of a concave mirror ▪ To determine two locations where a magnified image can be formed using a concave mirror.	1.1, 1.4, 1.5, 2.1, 2.2, 3.1, 3.2, 4.1, 4.2, 4.3, 5.1, 5.2, 5.3, 6.1, 6.4, 7.2
	21. Index of Refraction (OI) To determine the index of refraction of an acrylic block.	1.1, 1.2, 1.4, 1.5, 2.1, 2.2, 3.1, 4.1, 4.2, 4.3, 5.1, 5.3, 6.1, 6.4, 7.2
	22. Lenses (OI) This investigation is divided into two parts: ▪ To directly determine the focal length of a converging lens directly ▪ To determine the focal length of a diverging lens by combining it with a converging lens.	1.1, 1.4, 1.5, 2.1, 2.2, 3.1, 3.2, 4.1, 4.2, 4.3, 5.1, 5.2, 5.3, 6.1, 6.4, 7.2
	23. Double-Slit Interference and Diffraction (OI) This lab activity consists of three parts where the students design each investigation: ▪ To determine the wavelength of a green laser using a double slit. ▪ The students apply the results of the previous experiment to predict the location of bright and dark fringes when a red laser of known wavelength is used. ▪ The students determine the spacing in a diffraction grating using either the green or the red laser.	1.1, 1.4, 1.5, 2.1, 2.2, 3.1, 3.2, 4.1, 4.2, 4.3, 5.1, 5.2, 5.3, 6.1, 6.4, 7.2
UNIT 7. QUANTUM PHYSICS, ATOMIC	**24. Spectroscopy (GI)** Students use a quantitative analysis	1.2, 3.1, 4.1, 4.2, 4.3, 5.1, 5.3, 6.1, 6.4, 7.2

AND NUCLEAR PHYSICS	spectroscope to analyze flame tests and spectrum tubes.	
	25. Photoelectric Effect (OI) The determine Planck's constant from data collected from a circuit with an LED color strip.	1.1, 1.4, 1.5, 2.1, 2.2, 3.1, 3.2, 4.1, 4.2, 4.3, 5.1, 5.2, 5.3, 6.1, 6.4, 7.2
	26. Radioactive Decay and Half-Life (GI) In this investigation students simulate radioactive decay and determine half-life.	1.1, 1.2, 1.3, 1.4, 2.3, 3.1, 3.2, 4.1, 4.2, 4.3, 5.1, 5.3, 6.1, 6.4, 7.2

INSTRUCTIONAL ACTIVITIES

Throughout the course the students engage in a variety of activities designed to build the students' reasoning skills and deepen their conceptual understanding of physics principles. Students conduct activities and projects that enable them to connect the concepts learned in class to real world applications. Examples of activities are described below.

1. SIMULATION ACTIVITY
Students engage in activities outside of the laboratory experience that support the connection to more than one Learning Objective.

ACTIVITY: Quantum Wave Interference [CR3]
DESCRIPTION:
The PhET Quantum Wave Interference simulation (http://phet.colorado.edu/en/simulation/wave-interference) helps students to visualize the behavior of photons, electrons, and atoms as particles and as waves through a double-slit.
The students work in small groups through a series of 'experiments' that confront students with the basic conflict between the wave model and particle model.
The groups have to gather **evidence** that will allow them to justify how the double slit interference pattern is consistent with both the classical wave view and the photon view. After the class discussion, the students should be able to articulate how the how the wave view is related to the photon view.
Learning Objective 1.D.1.1
The student is able to explain why classical mechanics cannot describe all properties of objects by articulating the reasons that classical mechanics must be refined and an alternative explanation developed when classical particles display wave properties.
Learning Objective 6.G.1.1

The student is able to make predictions about using the scale of the problem to determine at what regimes a particle or wave model is more appropriate.

2. REAL WORLD APPLICATIONS

ACTIVITY 1. Fluid Applications [CR4]
DESCRIPTION:
Students write a series of questions that they wonder about related to buoyancy and density in real world contexts. In teams of two, the students select one research question. They have two class periods to post their results of the research on a Google Doc. Each team presents their information and any sources of data found to the class. Sample questions are:

- How do metal ships float?
- Will a ship full of oil float differently than an empty ship?
- If an oil tanker develops a leak, why does it sink?
- How will a ship float in fresh water as opposed to salt water?
- How and why do hot air balloons work?
- Would hydrogen balloons float better than balloons filled with hot air?

Learning Objective 1.E.1.1
The student is able to predict the densities, differences in densities, or changes in densities under different conditions for natural phenomena and design an investigation to verify the prediction.
Learning Objective 1.E.1.2
The student is able to select from experimental data the information necessary to determine the density of an object and/ or compare densities of several objects.
Learning Objective 3.C.4.2
The student is able to explain contact forces (tension, friction, normal, ***buoyant****, spring) as arising from interatomic electric forces and that they therefore have certain directions.*

ACTIVITY 2. Laser Applications
DESCRIPTION:
Students first investigate how a laser works using the PhET Laser simulation (http://phet.colorado.edu/en/simulation/lasers)
The simulation helps the students understand how absorption and spontaneous and stimulated emission work.
Students will be able to explain how these factors: intensity and wavelength of the lamp, the mirror reflectivity, and the lifetimes of the excited states of the atom influence the laser.

After writing their observations they conduct online research to submit a paper that will demonstrate their ability to read and synthesize scientific literature about the applications of lasers in modern medicine. Common research topics of applications include vision correction (LASIK surgery), tattoo removal, and varicose vein treatments.

Learning Objective 5.B.8.1

The student is able to describe emission or absorption spectra associated with electronic or nuclear transitions as transitions between allowed energy states of the atom in terms of the principle of energy conservation, including characterization of the frequency of radiation emitted or absorbed.

3. SCIENTIFIC ARGUMENTATION

In the course, students become familiar with the three components of **scientific argumentation**. The first element is the claim, which is the response to a prediction. A claim provides an explanation for why or how something happens in a laboratory investigation. The second component is the evidence, which supports the claim and consists of the analysis of the data collected during the investigation. The third component consists of questioning, in which students examine and defend one another's claims. Students receive explicit instruction in posing meaningful questions that include questions of clarification, questions that probe assumptions, and questions that probe implications and consequences. As a result of the scientific argumentation process, students are able to revise their claims and make revisions as appropriate. **[CR8]**

ACTIVITY: Nuclear Energy: Friend or Foe

DESCRIPTION:

In addition to the physics concepts, this project requires the evaluation of ethical concerns in order to arrive at a decision regarding nuclear energy. This project is meaningful and engaging to students as it requires the use of **evidence-based reasoning** through **dialogue** and provides a context for understanding scientific information.

Students work in teams of two to investigate the socio-scientific issue about the pros and cons of the use of nuclear energy. The research includes an explanation of the process of nuclear fission, the basic operation of a nuclear reactor, how a chain reaction works and how magnetic and inertial confinements can provide thermonuclear power. Students have to discuss safety, cost-effectiveness, environmental impact including wildlife and human health. The culmination activity is a **debate** moderated by the students themselves.

Learning Objective 5.G.1.1

The student is able to apply conservation of nucleon number and conservation of electric charge to make predictions about nuclear reactions and decays such as fission, fusion, alpha decay, beta decay, or gamma decay.

AP Physics 2 Course Outline

Big Idea 1: Objects and systems have properties such as mass and charge. Systems may have internal structure.

Enduring Understanding 1.A: The internal structure of a system determines many properties of the system.

Essential Knowledge 1.A.2: Fundamental particles have no internal structure.
a. Electrons, neutrinos, photons, and quarks are examples of fundamental particles.
b. Neutrons and protons are composed of quarks.
c. All quarks have electric charges, which are fractions of the elementary charge of the electron. Students will not be expected to know specifics of quark charge or quark composition of nucleons.

Learning Objective (1.A.2.1):
The student is able to construct representations of the differences between a fundamental particle and a system composed of fundamental particles and to relate this to the properties and scales of the systems being investigated. [See Science Practices 1.1 and 7.1]

Essential Knowledge 1.A.3: Nuclei have internal structures that determine their properties.
a. The number of protons identifies the element.
b. The number of neutrons together with the number of protons identifies the isotope.
c. There are different types of radioactive emissions from the nucleus.
d. The rate of decay of any radioactive isotope is specified by its half-life.

Essential Knowledge 1.A.4: Atoms have internal structures that determine their properties.
a. The number of protons in the nucleus determines the number of electrons in a neutral atom.
b. The number and arrangements of electrons cause elements to have different properties.
c. The Bohr model based on classical foundations was the historical representation of the atom that led to the description of the hydrogen atom n terms of discrete energy states (represented in energy diagrams by discrete energy levels).
d. Discrete energy state transitions lead to spectra.

Learning Objective (1.A.4.1):
The student is able to construct representations of the energy level structure of an electron in an atom and to relate this to the properties and scales of the systems being investigated. [See Science Practices 1.1 and 7.1]

Essential Knowledge 1.A.5: Systems have properties determined by the properties and interactions of their constituent atomic and molecular substructures. In AP Physics, when the properties of the constituent parts are not important in modeling the behavior of the macroscopic system, the system itself may be referred to as an *object*.

Learning Objective (1.A.5.1):
The student is able to model verbally or visually the properties of a system based on its substructure and to relate this to changes in the system properties over time as external variables are changed. [See Science Practices 1.1 and 7.1]

Learning Objective (1.A.5.2):
The student is able to construct representations of how the properties of a system are determined by the interactions of its constituent substructures. [See Science Practices 1.1, 1.4, and 7.1]

Enduring Understanding 1.B: Electric charge is a property of an object or system that affects its interactions with other objects or systems containing charge.

Essential Knowledge 1.B.1: Electric charge is conserved. The net charge of a system is equal to the sum of the charges of all the objects in the system.

a. An electrical current is a movement of charge through a conductor.
b. A circuit is a closed loop of electrical current.

Learning Objective (1.B.1.1):
The student is able to make claims about natural phenomena based on conservation of electric charge. [See Science Practice 6.4]

Learning Objective (1.B.1.2):
The student is able to make predictions, using the conservation of electric charge, about the sign and relative quantity of net charge of objects or systems after various charging processes, including conservation of charge in simple circuits. [See Science Practices 6.4 and 7.2]

Essential Knowledge 1.B.2: There are only two kinds of electric charge. Neutral objects or systems contain equal quantities of positive and negative charge, with the exception of some fundamental particles that have no electric charge.
a. Like-charged objects and systems repel, and unlike charged objects and systems attract.
b. Charged objects or systems may attract neutral systems by changing the distribution of charge in the neutral system.

Learning Objective (1.B.2.1):
The student is able to construct an explanation of the two-charge model of electric charge based on evidence produced through scientific practices. [See Science Practice 6.2]

Learning Objective (1.B.2.2):
The student is able to make a qualitative prediction about the distribution of positive and negative electric charges within neutral systems as they undergo various processes. [See Science Practices 6.4 and 7.2]

Learning Objective (1.B.2.3):
The student is able to challenge claims that polarization of electric charge or separation of charge must result in a net charge on the object. [See Science Practice 6.1]

Essential Knowledge 1.B.3: The smallest observed unit of charge that can be isolated is the electron charge, also known as the elementary charge.
a. The magnitude of the elementary charge is equal to 1.6×10^{-19} coulombs.
b. Electrons have a negative elementary charge; protons have a positive elementary charge of equal magnitude, although the mass of a proton is much larger than the mass of an electron.

Learning Objective (1.B.3.1):
The student is able to challenge the claim that an electric charge smaller than the elementary charge has been isolated. [See Science Practices 1.5, 6.1, and 7.2]

Enduring Understanding 1.C: Objects and systems have properties of inertial mass and gravitational mass that are experimentally verified to be the same and that satisfy conservation principles.

Essential Knowledge 1.C.4: In certain processes, mass can be converted to energy and energy can be converted to mass according to $E = mc^2$, the equation derived from the theory of special relativity.

Learning Objective (1.C.4.1):

The student is able to articulate the reasons that the theory of conservation of mass was replaced by the theory of conservation of mass-energy. [See Science Practice 6.3]

Enduring Understanding 1.D: Classical mechanics cannot describe all properties of objects.

Essential Knowledge 1.D.1: Objects classically thought of as particles can exhibit properties of waves.
a. This wavelike behavior of particles has been observed, e.g., in a double-slit experiment using elementary particles.
b. The classical models of objects do not describe their wave nature. These models break down when observing objects in small dimensions.

Learning Objective (1.D.1.1):
The student is able to explain why classical mechanics cannot describe all properties of objects by articulating the reasons that classical mechanics must be refined and an alternative explanation developed when classical particles display wave properties. [See Science Practice 6.3]

Essential Knowledge 1.D.2: Certain phenomena classically thought of as waves can exhibit properties of particles.
a. The classical models of waves do not describe the nature of a photon.
b. Momentum and energy of a photon can be related to its frequency and wavelength.
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Essential Knowledge 1.D.3: Properties of space and time cannot always be treated as absolute.
a. Relativistic mass–energy equivalence is a reconceptualization of matter and energy as two manifestations of the same underlying entity, fully interconvertible, thereby rendering invalid the classically separate laws of conservation of mass and conservation of energy. Students will not be expected to know apparent mass or rest mass.
b. Measurements of length and time depend on speed. (Qualitative treatment only.)

Learning Objective (1.D.3.1):
The student is able to articulate the reasons that classical mechanics must be replaced by special relativity to describe the experimental results and theoretical predictions that show that the properties of space and time are not absolute. [Students will be expected to recognize situations in which nonrelativistic classical physics breaks down and to explain how relativity addresses that breakdown, but students will not be expected to know in which of two reference frames a given series of events corresponds to a greater or lesser time interval, or a greater or lesser spatial distance; they will just need to know that observers in the two reference frames can “disagree” about some time and distance intervals.] [See Science Practices 6.3 and 7.1]

Enduring Understanding 1.E: Materials have many macroscopic properties that result from the arrangement and interactions of the atoms and molecules that make up the material.

Essential Knowledge 1.E.1: Matter has a property called density.

Learning Objective (1.E.1.1):
The student is able to predict the densities, differences in densities, or changes in densities under different conditions for natural phenomena and design an investigation to verify the prediction. [See Science Practices 4.2 and 6.4]

Learning Objective (1.E.1.2):

The student is able to select from experimental data the information necessary to determine the density of an object and/ or compare densities of several objects. [See Science Practices 4.1 and 6.4]

Essential Knowledge 1.E.2: Matter has a property called resistivity.
a. The resistivity of a material depends on its molecular and atomic structure.
b. The resistivity depends on the temperature of the material.

Learning Objective (1.E.2.1):
The student is able to choose and justify the selection of data needed to determine resistivity for a given material. [See Science Practice 4.1]

Essential Knowledge 1.E.3: Matter has a property called thermal conductivity.
a. The thermal conductivity is the measure of a material's ability to transfer thermal energy.

Learning Objective (1.E.3.1):
The student is able to design an experiment and analyze data from it to examine thermal conductivity. [See Science Practices 4.1, 4.2, and 5.1]

Essential Knowledge 1.E.4: Matter has a property called electric permittivity.
a. Free space has a constant value of the permittivity that appears in physical relationships.
b. The permittivity of matter has a value different from that of free space.

Content Connection:
This essential knowledge does not produce a specific learning objective but serves as a foundation for other learning objectives in the course.

Essential Knowledge 1.E.5: Matter has a property called magnetic permeability.
a. Free space has a constant value of the permeability that appears in physical relationships.
b. The permeability of matter has a value different from that of free space.
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Essential Knowledge 1.E.6: Matter has a property called magnetic dipole moment.
a. Magnetic dipole moment is a fundamental source of magnetic behavior of matter and an intrinsic property of some fundamental particles such as the electron.
b. Permanent magnetism or induced magnetism of matter is a system property resulting from the alignment of magnetic dipole moments within the system.

Big Idea 2: Fields existing in space can be used to explain interactions.

Enduring Understanding 2.A: A field associates a value of some physical quantity with every point in space. Field models are useful for describing interactions that occur at a distance (long-range forces) as well as a variety of other physical phenomena.

Essential Knowledge 2.A.1: A vector field gives, as a function of position (and perhaps time), the value of a physical quantity that is described by a vector.
a. Vector fields are represented by field vectors indicating direction and magnitude.
b. When more than one source object with mass or electric charge is present, the field value can be determined by vector addition.
c. Conversely, a known vector field can be used to make inferences about the number, relative size, and location of sources.

Essential Knowledge 2.A.2: A scalar field gives, as a function of position (and perhaps time), the value of a physical quantity that is described by a scalar. In Physics 2, this should include electric potential.
a. Scalar fields are represented by field values.
b. When more than one source object with mass or charge is present, the scalar field value can be determined by scalar addition.
c. Conversely, a known scalar field can be used to make inferences about the number, relative size, and location of sources.

Enduring Understanding 2.C: An electric field is caused by an object with electric charge.

Essential Knowledge 2.C.1: The magnitude of the electric force F exerted on an object with electric charge q by an electric field E is $F = qE$. The direction of the force is determined by the direction of the field and the sign of the charge, with positively charged objects accelerating in the direction of the field and negatively charged objects accelerating in the direction opposite the field. This should include a vector field map for positive point charges, negative point charges, spherically symmetric charge distribution, and uniformly charged parallel plates.

Learning Objective (2.C.1.1):
The student is able to predict the direction and the magnitude of the force exerted on an object with an electric charge q placed in an electric field E using the mathematical model of the relation between an electric force and an electric field: $F = qE$; a vector relation. [See Science Practices 6.4 and 7.2]

Learning Objective (2.C.1.2):
The student is able to calculate any one of the variables — electric force, electric charge, and electric field — at a point given the values and sign or direction of the other two quantities. [See Science Practice 2.2]

Essential Knowledge 2.C.2: The magnitude of the electric field vector is proportional to the net electric charge of the object(s) creating that field. This includes positive point charges, negative point charges, spherically symmetric charge distributions, and uniformly charged parallel plates.

Learning Objective (2.C.2.1):
The student is able to qualitatively and semi-quantitatively apply the vector relationship between the electric field and the net electric charge creating that field. [See Science Practices 2.2 and 6.4]

Essential Knowledge 2.C.4: The electric field around dipoles and other systems of electrically charged objects (that can be modeled as point objects) is found by vector addition of the field of each individual object. Electric dipoles are treated qualitatively in this course as a teaching analogy to facilitate student understanding of magnetic dipoles.
a. When an object is small compared to the distances involved in the problem, or when a larger object is being modeled as a large number of very small constituent particles, these can be modeled as charged objects of negligible size, or "point charges."
b. The expression for the electric field due to a point charge can be used to determine the electric field, either qualitatively or quantitatively, around a simple highly symmetric distribution of point charges. **physics 2**

Learning Objective (2.C.4.1):
The student is able to distinguish the characteristics that differ between monopole fields (gravitational field of spherical mass and electrical field due to single point charge) and dipole fields (electric dipole field and magnetic field) and make claims about the spatial behavior of the fields using qualitative or semiquantitative arguments based on vector addition of fields due to each point source, including identifying the locations and signs of sources from a vector diagram of the field. [See Science Practices 2.2, 6.4, and 7.2]

Learning Objective (2.C.4.2):

The student is able to apply mathematical routines to determine the magnitude and direction of the electric field at specified oints in the vicinity of a small set (2–4) of point charges, and express the results in terms of magnitude and direction of the field in a visual representation by drawing field vectors of appropriate length and direction at the specified points. [See Science Practices 1.4 and 2.2]

Essential Knowledge 2.D.1: The magnetic field exerts a force on a moving electrically charged object. That magnetic force is perpendicular to the direction of velocity of the object and to the magnetic field and is proportional to the magnitude of the charge, the magnitude of the velocity and the magnitude of the magnetic field. It also depends on the angle between the velocity, and the magnetic field vectors. Treatment is quantitative for angles of 0°, 90°, or 180° and qualitative for other angles.

Learning Objective (2.D.1.1):
The student is able to apply mathematical routines to express the force exerted on a moving charged object by a magnetic field. [See Science Practice 2.2]

Essential Knowledge 2.D.2: The magnetic field vectors around a straight wire that carries electric current are tangent to concentric circles centered on that wire. The field has no component toward the current-carrying wire.
a. The magnitude of the magnetic field is proportional to the magnitude of the current in a long straight wire.
b. The magnitude of the field varies inversely with distance from the wire, and the direction of the field can be determined by a right-hand rule.

Learning Objective (2.D.2.1):
The student is able to create a verbal or visual representation of a magnetic field around a long straight wire or a pair of parallel wires. [See Science Practice 1.1]

Essential Knowledge 2.D.3: A magnetic dipole placed in a magnetic field, such as the ones created by a magnet or the Earth, will tend to align with the magnetic field vector.
a. A simple magnetic dipole can be modeled by a current in a loop. The dipole is represented by a vector pointing through the loop in the direction of the field produced by the current as given by the right-hand rule.
b. A compass needle is a permanent magnetic dipole. Iron filings in a magnetic field become induced magnetic dipoles.
c. All magnets produce a magnetic field. Examples should include magnetic field pattern of a bar magnet as detected by iron filings or small compasses.
d. The Earth has a magnetic field.

Learning Objective (2.D.3.1):
The student is able to describe the orientation of a magnetic dipole placed in a magnetic field in general and the particular cases of a compass in the magnetic field of the Earth and iron filings surrounding a bar magnet. [See Science Practice 1.2]

Essential Knowledge 2.D.4: Ferromagnetic materials contain magnetic domains that are themselves magnets.
a. Magnetic domains can be aligned by external magnetic fields or can spontaneously align.
b. Each magnetic domain has its own internal magnetic field, so there is no beginning or end to the magnetic field — it is a continuous loop.
c. If a bar magnet is broken in half, both halves are magnetic dipoles in themselves; there is no magnetic north pole found isolated from a south pole.

Learning Objective (2.D.4.1):
The student is able to use the representation of magnetic domains to qualitatively analyze the magnetic behavior of a bar magnet composed of ferromagnetic material. [See Science Practice 1.4]

Enduring Understanding 2.E: Physicists often construct a map of isolines connecting points of equal value for some quantity related to a field and use these maps to help visualize the field.

Essential Knowledge 2.E.1: Isolines on a topographic (elevation) map describe lines of approximately equal gravitational potential energy per unit mass (gravitational equipotential). As the distance between two different isolines decreases, the steepness of the surface increases. [Contour lines on topographic maps are useful teaching tools for introducing the concept of equipotential lines. Students are encouraged to use the analogy in their answers when explaining gravitational and electrical potential and potential differences.]

Learning Objective (2.E.1.1):
The student is able to construct or interpret visual representations of the isolines of equal gravitational potential energy per unit mass and refer to each line as a gravitational equipotential. [See Science Practices 1.4, 6.4, and 7.2]

Essential Knowledge 2.E.3: The average value of the electric field in a region equals the change in electric potential across that region divided by the change in position(displacement) in the relevant direction.

Learning Objective (2.E.3.1):
The student is able to apply mathematical routines to calculate the average value of the magnitude of the electric field in a region from a description of the electric potential in that region using the displacement along the line on which the difference in potential is evaluated. [See Science Practice 2.2]

Learning Objective (2.E.3.2):
The student is able to apply the concept of the isoline representation of electric potential for a given electric charge distribution to predict the average value of the electric field in the region. [See Science Practices 1.4 and 6.4]

Big Idea 3: The interactions of an object with other objects can be described by forces.

Enduring Understanding 3.A: All forces share certain common characteristics when considered by observers in inertial reference frames.

Essential Knowledge 3.A.4: If one object exerts a force on a second object, the second object always exerts a force of equal magnitude on the first object in the opposite direction.

Learning Objective (3.A.4.1):
The student is able to construct explanations of physical situations involving the interaction of bodies using Newton's third law and the representation of action-reaction pairs of forces. [See Science Practices 1.4 and 6.2]

Learning Objective (3.A.4.2):
The student is able to use Newton's third law to make claims and predictions about the action-reaction pairs of forces when two objects interact. [See Science Practices 6.4 and 7.2]

Learning Objective (3.A.4.3):

The student is able to analyze situations involving interactions among several objects by using free-body diagrams that include the application of Newton's third law to identify forces. [See Science Practice 1.4]

Enduring Understanding 3.B: Classically, the acceleration of an object interacting with other objects can be predicted by using □*m*

Essential Knowledge 3.B.1: If an object of interest interacts with several other objects, the net force is the vector sum of the individual forces. The student is able to reexpress a free-body diagram representation into a mathematical representation and solve the mathematical representation for the acceleration of the object. [See Science Practices 1.5 and 2.2]

Learning Objective (3.B.1.4):
The student is able to predict the motion of an object subject to forces exerted by several objects using an application of Newton's second law in a variety of physical situations. [See Science Practices 6.4 and 7.2]

Essential Knowledge 3.B.2: Free-body diagrams are useful tools for visualizing forces being exerted on a single object andwriting the equations that represent a physical situation.
a. An object can be drawn as if it was extracted from its environment and the interactions with the environment identified.
b. A force exerted on an object can be represented as an arrow whose length represents the magnitude of the force and whose direction shows the direction of the force.
c. A coordinate system with one axis parallel to the direction of the acceleration simplifies the translation from the free-body diagram to the algebraic representation.

Learning Objective (3.B.2.1):
The student is able to create and use free-body diagrams toanalyze physical situations to solve problems with motion qualitatively and quantitatively. [See Science Practices 1.1, 1.4, and 2.2]

Enduring Understanding 3.C: At the macroscopic level, forces can be categorized as either long-range (action-at-a-distance) forces or contact forces.

Essential Knowledge 3.C.2: Electric force results from the interaction of one object that has an electric charge with another object that has an electric charge.
a. Electric forces dominate the properties of the objects in our everyday experiences. However, the large number of particle interactions that occur make it more convenient to treat everyday forces in terms of nonfundamental forces called contact forces, such as normal force, friction, and tension.
b. Electric forces may be attractive or repulsive, depending upon the charges on the objects involved.

Learning Objective (3.C.2.1):
The student is able to use Coulomb's law qualitatively and quantitatively to make predictions about the interaction between two electric point charges (interactions between collections of electric point charges are not covered in Physics 1 and instead are restricted to Physics 2). [See Science Practices 2.2 and 6.4]

Learning Objective (3.C.2.2):

The student is able to connect the concepts of gravitational force and electric force to compare similarities and differences between the forces. [See Science Practice 7.2]

Learning Objective (3.C.2.3):
The student is able to use mathematics to describe the electric force that results from the interaction of several separated point charges (generally 2 to 4 point charges, though more are permitted in situa tions of high symmetry). [See Science Practice 2.2]

Essential Knowledge 3.C.3: A magnetic force results from the interaction of a moving charged object or a magnet with other moving charged objects or another magnet.
a. Magnetic dipoles have “north” and “south” polarity.
b. The magnetic dipole moment of an object has the tail of the magnetic dipole moment vector at the south end of the object and the head of the vector at the north end of the object.
c. In the presence of an external magnetic field, the magnetic dipole moment vector will align with the external magnetic field.
d. The force exerted on a moving charged object is perpendicular to both the magnetic field and the velocity of the charge and is described by a right-hand rule.

Learning Objective (3.C.3.1):
The student is able to use right-hand rules to analyze a situation involving a current-carrying conductor and a moving electrically charged object to determine the direction of the magnetic force exerted on the charged object due to the magnetic field created by the current-carrying conductor. [See Science Practice 1.4]

Learning Objective (3.C.3.2):
The student is able to plan a data collection strategy appropriate to an investigation of the direction of the force on a moving electrically charged object caused by a current in a wire in the context of a specific set of equipment and instruments and analyze the resulting data to arrive at a conclusion. [See Science Practices 4.2 and 5.1]

Essential Knowledge 3.C.4: Contact forces result from the interaction of one object touching another object and they arise from interatomic electric forces. These forces include tension, friction, normal, spring (Physics 1), and buoyant (Physics 2).

Learning Objective (3.C.4.1):
The student is able to make claims about various contact forces between objects based on the microscopic cause of those forces. [See Science Practice 6.1]

Learning Objective (3.C.4.2):
The student is able to explain contact forces (tension, friction, normal, buoyant, spring) as arising from interatomic electric forces and that they therefore have certain directions. [See Science Practice 6.2]

Enduring Understanding 3.G: Certain types of forces are considered fundamental.

Essential Knowledge 3.G.1: Gravitational forces are exerted at all scales and dominate at the largest distance and mass scales.

Learning Objective (3.G.1.2):
The student is able to connect the strength of the gravitational force between two objects to the spatial scale of the situation and the masses of the objects involved and compare that strength to other types of forces. [See Science Practice 7.1]

Essential Knowledge 3.G.2: Electromagnetic forces are exerted at all scales and can dominate at the human scale.

Learning Objective (3.G.2.1):
The student is able to connect the strength of electromagnetic forces with the spatial scale of the situation, the magnitude of the electric charges, and the motion of the electrically charged objects involved. [See Science Practice 7.1]

Essential Knowledge 3.G.3: The strong force is exerted at nuclear scales and dominates the interactions of nucleons.

Learning Objective (3.G.3.1):
The student is able to identify the strong force as the force that is responsible for holding the nucleus together. [See Science Practice 7.2]

Big Idea 4: Interactions between systems can result in changes in those systems.

Enduring Understanding 4.C: Interactions with other objects or systems can change the total energy of a system.

Knowledge 4.C.3: Energy is transferred spontaneously from a higher temperature system to a lower temperature system. The process through which energy is transferred between systems at different temperatures is called heat.
a. Conduction, convection, and radiation are mechanisms for this energy transfer.
b. At a microscopic scale the mechanism of conduction is the transfer of kinetic energy between particles.
c. During average collisions between molecules, kinetic energy is transferred from faster molecules to slower molecules.

Learning Objective (4.C.3.1):
The student is able to make predictions about the direction of energy transfer due to temperature differences based on interactions at the microscopic level. [See Science Practice 6.4]

Essential Knowledge 4.C.4: Mass can be converted into energy and energy can be converted into mass.
a. Mass and energy are interrelated by $E = mc^2$.
b. Significant amounts of energy can be released in nuclear processes.

Learning Objective (4.C.4.1):
The student is able to apply mathematical routines to describe the relationship between mass and energy and apply this concept across domains of scale. [See Science Practices 2.2, 2.3, and 7.2]

Enduring Understanding 4.E: The electric and magnetic properties of a system can change in response to the presence of, or changes in, other objects or systems.

Essential Knowledge 4.E.1: The magnetic properties of some materials can be affected by magnetic fields at the system. Students should focus on the underlying concepts and not
the use of the vocabulary.
a. Ferromagnetic materials can be permanently magnetized by an external field that causes the
alignment of magnetic domains or atomic magnetic dipoles.
b. Paramagnetic materials interact weakly with an external magnetic field in that the magnetic dipole moments of the material do not remain aligned after the external field is removed.

c. All materials have the property of diamagnetism in that their electronic structure creates a (usually) weak alignment of the dipole moments of the material opposite to the external magnetic field.

Learning Objective (4.E.1.1):
The student is able to use representations and models to qualitatively describe the magnetic properties of some materials that can be affected by magnetic properties of other objects in the system. [See Science Practices 1.1, 1.4, and 2.2]

Essential Knowledge 4.E.2: Changing magnetic flux induces an electric field that can establish an induced emf in a system.
a. Changing magnetic flux induces an emf in a system, with the magnitude of the induced emf equal to the rate of change in magnetic flux.
b. When the area of the surface being considered is constant, the induced emf is the area multiplied by the rate of change in the component of the magnetic field perpendicular to the surface.
c. When the magnetic field is constant, the induced emf is the magnetic field multiplied by the rate of change in area perpendicular to the magnetic field.
d. The conservation of energy determines the direction of the induced emf relative to the change in the magnetic flux.

Learning Objective (4.E.2.1):
The student is able to construct an explanation of the function of a simple electromagnetic device in which an induced emf is produced by a changing magnetic flux through an area defined by a current loop (i.e., a simple microphone or generator) or of the effect on behavior of a device in which an induced emf is produced by a constant magnetic field through a changing area. [See Science Practice 6.4]

Essential Knowledge 4.E.3: The charge distribution in a system can be altered by the effects of electric forces produced by a charged object.
a. Charging can take place by friction or by contact.
b. An induced charge separation can cause a neutral object to become polarized.
c. Charging by induction can occur when a polarizing conducting object is touched by another.
d. In solid conductors, some electrons are mobile. When no current flows, mobile charges are in static equilibrium, excess charge resides at the surface, and the interior field is zero. In solid insulators, excess ("fixed") charge may reside in the interior as well as at the surface.

Learning Objective (4.E.3.1):
The student is able to make predictions about the redistribution of charge during charging by friction, conduction, and induction. [See Science Practice 6.4]

Learning Objective (4.E.3.2):
The student is able to make predictions about the redistribution of charge caused by the electric field due to other systems, resulting in charged or polarized objects. [See Science Practices 6.4 and 7.2]

Learning Objective (4.E.3.3):
The student is able to construct a representation of the distribution of fixed and mobile charge in insulators and conductors. [See Science Practices 1.1, 1.4, and 6.4]

Learning Objective (4.E.3.4):

The student is able to construct a representation of the distribution of fixed and mobile charge in insulators and conductors that predicts charge distribution in processes involving induction or conduction. [See Science Practices 1.1, 1.4, and 6.4]

Learning Objective (4.E.3.5):
The student is able to plan and/or analyze the results of experiments in which electric charge rearrangement occurs by electrostatic induction, or is able to refine a scientific question relating to such an experiment by identifying anomalies in a data set or procedure. [See Science Practices 3.2, 4.1, 4.2, 5.1, and 5.3]

Essential Knowledge 4.E.4: The resistance of a resistor, and the capacitance of a capacitor, can be understood from the basic properties of electric fields and forces, as well as the properties of materials and their geometry.
a. The resistance of a resistor is proportional to its length and inversely proportional to its cross-sectional area. The constant of proportionality is the resistivity of the material.
b. The capacitance of a parallel plate capacitor is proportional to the area of one of its plates and inversely proportional to the separation between its plates. The constant of proportionality is the product of the dielectric constant, κ, of the material between the plates and the electric permittivity, ϵ_o.
c. The current through a resistor is equal to the potential difference across the resistor divided by its resistance.
d. The magnitude of charge of one of the plates of a parallel plate capacitor is directly proportional to the product of the potential difference across the capacitor and the capacitance. The plates have equal amounts of charge of opposite sign.

Learning Objective (4.E.4.1):
The student is able to make predictions about the properties of resistors and/or capacitors when placed in a simple circuit, based on the geometry of the circuit element and supported by scientific theories and mathematical relationships. [See Science Practices 2.2 and 6.4]

Learning Objective (4.E.4.2):
The student is able to design a plan for the collection of data to determine the effect of changing the geometry and/or materials on the resistance or capacitance of a circuit element and relate results to the basic properties of resistors and capacitors. [See Science Practices 4.1 and 4.2]

Learning Objective (4.E.4.3):
The student is able to analyze data to determine the effect of changing the geometry and/or materials on the resistance or capacitance of a circuit element and relate results to the basic properties of resistors and capacitors. [See Science Practice 5.1]

Essential Knowledge 4.E.5: The values of currents and electric potential differences in an electric circuit are determined by the properties and arrangement of the individual circuit elements such as sources of emf, resistors, and capacitors.

Learning Objective (4.E.5.1):
The student is able to make and justify a quantitative prediction of the effect of a change in values or arrangements of one or two circuit elements on the currents and potential differences in a circuit containing a small number of sources of emf, resistors, capacitors, and switches in series and/or parallel. [See Science Practices 2.2 and 6.4]

Learning Objective (4.E.5.2):
The student is able to make and justify a qualitative prediction of the effect of a change in values or arrangements of one or two circuit elements on currents and potential differences in a circuit containing a small number of sources of emf, resistors, capacitors, and switches in series and/or parallel. [See Science Practices 6.1 and 6.4]

Learning Objective (4.E.5.3):
The student is able to plan data collection strategies and perform data analysis to examine the values of currents and potential differences in an electric circuit that is modified by changing or rearranging circuit elements, including sources of emf, resistors, and capacitors. [See Science Practices 2.2, 4.2, and 5.1]

Big Idea 5: Changes that occur as a result of interactions are constrained by conservation laws.

Enduring Understanding 5.A: Certain quantities are conserved, in the sense that the changes of those quantities in a given system are always equal to the transfer of that quantity to or from the system by all possible interactions with other systems.

Enduring Understanding 5.B: The energy of a system is conserved.

Essential Knowledge 5.B.2: A system with internal structure can have internal energy, and changes in a system's internal structure can result in changes in internal energy. [Physics 1: includes mass-spring oscillators and simple pendulums. Physics 2: includes charged object in electric fields and examining changes in internal energy with changes in configuration.]

Learning Objective (5.B.2.1):
The student is able to calculate the expected behavior of a system using the object model (i.e., by ignoring changes in internal structure) to analyze a situation. Then, when the model fails, the student can justify the use of conservation of energy principles to calculate the change in internal energy due to changes in internal structure because the object is actually a system. [See Science Practices 1.4 and 2.1]

Essential Knowledge 5.B.4: The internal energy of a system includes the kinetic energy of the objects that make up the system and the potential energy of the configuration of the objects that make up the system.
a. Since energy is constant in a closed system, changes in a system's potential energy can result in changes to the system's kinetic energy.
b. The changes in potential and kinetic energies in a system may be further constrained by the construction of the system.

Learning Objective (5.B.4.1):
The student is able to describe and make predictions about the internal energy of systems.
[See Science Practices 6.4 and 7.2]

Learning Objective (5.B.4.2):
The student is able to calculate changes in kinetic energy and potential energy of a system, using information from representations of that system.
[See Science Practices 1.4, 2.1, and 2.2]

Essential Knowledge 5.B.5: Energy can be transferred by an external force exerted on an object or system that moves the object or system through a distance; this energy transfer is called work. Energy transfer in mechanical or electrical systems may occur at different rates. Power is defined as the rate of energy transfer into, out of, or within a system. [A piston filled with gas getting compressed or expanded is treated in Physics 2 as a part of thermodynamics.]

Essential Knowledge 5.B.6: Energy can be transferred by thermal processes involving differences in temperature; the amount of energy transferred in this process of transfer is called heat.

Learning Objective (5.B.6.1):
The student is able to describe the models that represent processes

by which energy can be transferred between a system and its environment because of differences in temperature: conduction, convection, and radiation. [See Science Practice 1.2]

Essential Knowledge 5.B.7: The first law of thermodynamics is a specific case of the law of conservation of energy involving the internal energy of a system and the possible transfer of energy through work and/or heat. Examples should include P-V diagrams — isovolumetric process, isothermal process, isobaric process, adiabatic process. No calculations of heat or internal energy from temperature change; and in this course, examples of these relationships are qualitative and/or semi-quantitative.

Learning Objective (5.B.7.1):
The student is able to predict qualitative changes in the internal energy of a thermodynamic system involving transfer of energy due to heat or work done and justify those predictions in terms of conservation of energy principles. [See Science Practices 6.4 and 7.2]

Learning Objective (5.B.7.2):
The student is able to create a plot of pressure versus volume for a thermodynamic process from given data. [See Science Practice 1.1]

Learning Objective (5.B.7.3):
The student is able to use a plot of pressure versus volume for a thermodynamic process to make calculations of internal energy changes, heat, or work, based upon conservation of energy principles (i.e., the first law of thermodynamics). [See Science Practices 1.1, 1.4, and 2.2]

Essential Knowledge 5.B.8: Energy transfer occurs when photons are absorbed or emitted, for example, by atoms or nuclei.
a. Transitions between two given energy states of an atom correspond to the absorption or emission of a photon of a given frequency (and hence, a given wavelength).
b. An emission spectrum can be used to determine the elements in a source of light.

Learning Objective (5.B.8.1):
The student is able to describe emission or absorption spectra associated with electronic or nuclear transitions as transitions between allowed energy states of the atom in terms of the principle of energy conservation, including characterization of the frequency of radiation emitted or absorbed. [See Science Practices 1.2 and 7.2]

Essential Knowledge 5.B.9: Kirchhoff's loop rule describes conservation of energy in electrical circuits. The application of Kirchhoff's laws to circuits is introduced in Physics 1 and further developed in Physics 2 in the context of more complex circuits, including those with capacitors.
a. Energy changes in simple electrical circuits are conveniently represented in terms of energy change per charge moving through a battery and a resistor.
b. Since electric potential difference times charge is energy, and energy is conserved, the sum of the potential differences about any closed loop must add to zero.
c. The electric potential difference across a resistor is given by the product of the current and the resistance.
d. The rate at which energy is transferred from a resistor is equal to the product of the electric potential difference across the resistor and the current through the resistor.
e. Energy conservation can be applied to combinations of resistors and capacitors in series and parallel circuits.

Learning Objective (5.B.9.4):
The student is able to analyze experimental data including an analysis of experimental uncertainty that will demonstrate the validity of Kirchhoff's loop rule ($\sum \Delta V = 0$). [See Science Practice 5.1]

Learning Objective (5.B.9.5):
The student is able to use conservation of energy principles (Kirchhoff's loop rule) to describe and make predictions regarding electrical potential difference, charge, and current in steady-state circuits composed of various combinations of resistors and capacitors. [See Science Practice 6.4]

Learning Objective (5.B.9.6):
The student is able to mathematically express the changes in electric potential energy of a loop in a multiloop electrical circuit and justify this expression using the principle of the conservation
of energy. [See Science Practices 2.1 and 2.2]

Learning Objective (5.B.9.7)?
The student is able to refine and analyze a scientific question for an experiment using Kirchhoff's Loop rule for circuits that includes determination of internal resistance of the battery and analysis of a non-ohmic resistor. [See Science Practices 4.1, 4.2, 5.1, and 5.3]

Learning Objective (5.B.9.8):
The student is able to translate between graphical and symbolic representations of experimental data describing relationships among power, current, and potential difference across a resistor. [See Science Practice 1.5]

Essential Knowledge 5.B.10: Bernoulli's equation describes the conservation of energy in fluid flow. **physics 2**

Learning Objective (5.B.10.1):
The student is able to use Bernoulli's equation to make calculations related to a moving fluid. [See Science Practice 2.2]

Learning Objective (5.B.10.2):
The student is able to use Bernoulli's equation and/or the relationship between force and pressure to make calculations related to a moving fluid. [See Science Practice 2.2]

Learning Objective (5.B.10.3):
The student is able to use Bernoulli's equation and the continuity equation to make calculations related to a moving fluid. [See Science Practice 2.2]

Learning Objective (5.B.10.4):
The student is able to construct an explanation of Bernoulli's equation in terms of the conservation of energy. [See Science Practice 6.2]

Essential Knowledge 5.B.11: Beyond the classical approximation, mass is actually part of the internal energy of an object or system with E $mc2$.
a. $E = mc^2$ can be used to calculate the mass equivalent for a given amount of energy transfer or an energy equivalent for a given amount of mass change (e.g., fission and fusion reactions).

Learning Objective (5.B.11.1):
The student is able to apply conservation of mass and conservation of energy concepts to a natural phenomenon and use the equation E $mc2$ to make a related calculation. [See Science Practices 2.2 and 7.2]

Enduring Understanding 5.C: The electric charge of a system is conserved.

Essential Knowledge 5.C.1: Electric charge is conserved in nuclear and elementary particle reactions, even when elementary particles are produced or destroyed. Examples should include equations representing nuclear decay.

Learning Objective (5.C.1.1):
The student is able to analyze electric charge conservation for nuclear and elementary particle reactions and make predictions related to such reactions based upon conservation of charge. [See Science Practices 6.4 and 7.2]

Essential Knowledge 5.C.2: The exchange of electric charges among a set of objects in a system conserves electric charge.
a. Charging by conduction between objects in a system conserves the electric charge of the entire system.
b. Charge separation in a neutral system can be induced by an external charged object placed close to the neutral system.
c. Grounding involves the transfer of excess charge to another larger system (e.g., the earth).

Learning Objective (5.C.2.1):
The student is able to predict electric charges on objects within a system by application of the principle of charge conservation within a system. [See Science Practice 6.4]

Learning Objective (5.C.2.2):
The student is able to design a plan to collect data on the electrical charging of objects and electric charge induction on neutral objects and qualitatively analyze that data. [See Science Practices 4.2 and 5.1]

Learning Objective (5.C.2.3):
The student is able to justify the selection of data relevant to an investigation of the electrical charging of objects and electric charge induction on neutral objects. [See Science Practice 4.1]

Essential Knowledge 5.C.3: Kirchhoff's junction rule describes the conservation of electric charge in electrical circuits. Since charge is conserved, current must be conserved at each junction in the circuit. Examples should include circuits that combine resistors in series and parallel. [Physics 1: covers circuits with resistors in series, with at most one parallel branch, one battery only. Physics 2: includes capacitors in steady-state situations. For circuits with capacitors, situations should be limited to open circuit, just after circuit is closed, and a long time after the circuit is closed.]

Learning Objective (5.C.3.4):
The student is able to predict or explain current values in series and parallel arrangements of resistors and other branching circuits using Kirchhoff's junction rule

The student is able to determine missing values and direction of electric current in branches of a circuit with resistors and NO capacitors from values and directions of current in other branches of the circuit through appropriate selection of nodes and application of the junction rule. [See Science Practices 1.4 and 2.2]

Learning Objective (5.C.3.6):
The student is able to determine missing values and direction of electric current in branches of a circuit with both resistors and capacitors from values and directions of current in other branches of the circuit through appropriate selection of nodes and application of the junction rule. [See Science Practices 1.4 and 2.2]

Learning Objective (5.C.3.7):
The student is able to determine missing values, direction of electric current, charge of capacitors at steady state, and potential differences within a circuit with resistors and capacitors from values and directions of current in other branches of the circuit. [See Science Practices 1.4 and 2.2]

Enduring Understanding 5.D: The linear momentum of a system is conserved.

Essential Knowledge 5.D.1: In a collision between objects, linear momentum is conserved. In an elastic collision, kinetic energy is the same before and after.
a. In a closed system, the linear momentum is constant throughout the collision.
b. In a closed system, the kinetic energy after an elastic collision is

Learning Objective (5.D.1.6):
The student is able to make predictions of the dynamical properties of a system undergoing a collision by application of the principle of linear momentum conservation and the principle of the conservation of energy in situations in which an elastic collision may also be assumed. [See Science Practice 6.4]

Learning Objective (5.D.1.7):
The student is able to classify a given collision situation as elastic or inelastic, justify the selection of conservation of linear momentum and restoration of kinetic energy as the appropriate principles for analyzing an elastic collision, solve for missing variables, and calculate their values. [See Science Practices 2.1 and 2.2]

Essential Knowledge 5.D.2: In a collision between objects, linear momentum is conserved. In an inelastic collision, kinetic energy is not the same before and after the collision.
a. In a closed system, the linear momentum is constant throughout the collision.
b. In a closed system, the kinetic energy after an inelastic collision is different from the kinetic energy before the collision.

Learning Objective (5.D.2.5):
The student is able to classify a given collision situation as elastic or inelastic, justify the selection of conservation of linear momentum as the appropriate solution method for an inelastic collision, recognize that there is a common final velocity for the colliding objects in the totally inelastic case, solve for missing variables, and calculate their values. [See Science Practices 2.1 and 2.2]

Learning Objective (5.D.2.6):
The student is able to apply the conservation of linear momentum to a closed system of objects involved in an inelastic collision to predict the change in kinetic energy. [See Science Practices 6.4 and 7.2]

Essential Knowledge 5.D.3: The velocity of the center of mass of the system cannot be changed by an interaction within the system. [Physics 1: includes no calculations of centers of mass; the equation is not provided until Physics 2. However, without doing calculations, Physics 1 students are expected to be able to locate the center of mass of highly symmetric mass distributions, such as a uniform rod or cube of uniform density, or two spheres of equal mass.]
a. The center of mass of a system depends upon the masses and positions of the objects in the system. In an isolated system (a system with no external forces), the velocity of the center of mass does not change.
b. When objects in a system collide, the velocity of the center of mass of the system will not change unless an external force is exerted on the system.

Learning Objective (5.D.3.2):
The student is able to make predictions about the velocity of the center of mass for interactions within a defined one-dimensional system. [See Science Practice 6.4]

Learning Objective (5.D.3.3):
The student is able to make predictions about the velocity of the center of mass for interactions within a defined two-dimensional system. [See Science Practice 6.4]

Enduring Understanding 5.G: Nucleon number is conserved.

Essential Knowledge 5.G.1: The possible nuclear reactions are constrained by the law of conservation of nucleon number.

Learning Objective (5.G.1.1):
The student is able to apply conservation of nucleon number and conservation of electric charge to make predictions about nuclear reactions and decays such as fission, fusion, alpha decay, beta decay, or gamma decay. [See Science Practice 6.4]

Big Idea 6: Waves can transfer energy and momentum from one location to another without the permanent transfer of mass and serve as a mathematical model for the description of other phenomena.

Enduring Understanding 6.A: A wave is a traveling disturbance that transfers energy and momentum.

Essential Knowledge 6.A.1: Waves can propagate via different oscillation modes such as transverse and longitudinal.
b. Electromagnetic waves are transverse waves.
c. Transverse waves may be polarized.

Learning Objective (6.A.1.2):
The student is able to describe representations of transverse and longitudinal waves. [See Science Practice 1.2]

Learning Objective (6.A.1.3):
The student is able to analyze data (or a visual representation) to identify patterns that indicate that a particular mechanical wave is polarized and construct an explanation of the fact that the wave must have a vibration perpendicular to the direction of energy propagation. [See Science Practices 5.1 and 6.2]

Essential Knowledge 6.A.2: For propagation, mechanical waves require a medium, while electromagnetic waves do not require a physical medium. Examples should include light traveling through a vacuum and sound not traveling through a vacuum.

Learning Objective (6.A.2.2):
The student is able to contrast mechanical and electromagnetic waves in terms of the need for a medium in wave propagation. See Science Practices 6.4 and 7.2]

Enduring Understanding 6.B: A periodic wave is one that repeats as a function of both time and position and can be described by its amplitude, frequency, wavelength, speed, and energy.

Essential Knowledge 6.B.3: A simple wave can be described by an equation involving one sine or cosine function involving the wavelength, amplitude, and frequency of the wave.

Learning Objective (6.B.3.1):
The student is able to construct an equation relating the wavelength and amplitude of a wave from a graphical representation of the electric or magnetic field value as a function of position at a given time instant and vice versa, or construct an equation relating the frequency or period and amplitude of a wave from a graphical representation of the electric or magnetic field value at a given position as a function of time and vice versa. [See Science Practice 1.5]

Enduring Understanding 6.C: Only waves exhibit interference and diffraction.

Essential Knowledge 6.C.1: When two waves cross, they travel through each other; they do not bounce off each other. Where the waves overlap, the resulting displacement can be determined by adding the displacements of the two waves. This is called superposition.

Learning Objective (6.C.1.1):
The student is able to make claims and predictions about the net disturbance that occurs when two waves overlap. Examples should include standing waves. [See Science Practices 6.4 and 7.2]

Learning Objective (6.C.1.2):
The student is able to construct representations to graphically analyze situations in which two waves overlap over time using the principle of superposition. [See Science Practice 1.4]

Essential Knowledge 6.C.2: When waves pass through an opening whose dimensions are comparable to the wavelength, a diffraction pattern can be observed.

Learning Objective (6.C.2.1):
The student is able to make claims about the diffraction pattern produced when a wave passes through a small opening, and toqualitatively apply the wave model to quantities that describe the generation of a diffraction pattern when a wave passes through an opening whose dimensions are comparable to the wavelength of the wave. [See Science Practices 1.4, 6.4, and 7.2]

Essential Knowledge 6.C.3: When waves pass through a set of openings whose spacing is comparable to the wavelength, an interference pattern can be observed. Examples should include monochromatic double-slit interference.

Learning Objective (6.C.3.1):
The student is able to qualitatively apply the wave model to quantities that describe the generation of interference patterns to make predictions about interference patterns that form when waves pass through a set of openings whose spacing and widths are small compared to the wavelength of the waves. [See Science Practices 1.4 and 6.4]

Essential Knowledge 6.C.4: When waves pass by an edge, they can diffract into the “shadow region” behind the edge. Examples should include hearing around corners, but not seeing around them, and water waves bending around obstacles.

Learning Objective (6.C.4.1):
The student is able to predict and explain, using representations and models, the ability or inability of waves to transfer energy around corners and behind obstacles in terms of the diffraction property of waves in situations involving various kinds of wave phenomena, including sound and light. [See Science Practices 6.4 and 7.2]

Enduring Understanding 6.E: The direction of propagation of a wave such as light may be changed when the wave encounters an interface between two media.

Essential Knowledge 6.E.1: When light travels from one medium to another, some of the light is transmitted, some is reflected, and some is absorbed. (Qualitative understanding only.)

Learning Objective (6.E.1.1):
The student is able to make claims using connections across concepts about the behavior of light as the wave travels from one medium into another, as some is transmitted, some is reflected, and some is absorbed. [See Science Practices 6.4 and 7.2]

Essential Knowledge 6.E.2: When light hits a smooth reflecting surface at an angle, it reflects at the same angle onthe other side of the line perpendicular to the surface (specular reflection); and this law of reflection accounts for the size and location of images seen in plane mirrors.

Learning Objective (6.E.2.1):
The student is able to make predictions about the locations of object and image relative to the location of a reflecting surface. The prediction should be based on the model of specular reflection with all angles measured relative to the normal to the surface. [See Science Practices 6.4 and 7.2]

Essential Knowledge 6.E.3: When light travels across a boundary from one transparent material to another, the speed ofpropagation changes. At a non-normal incident angle, the path of the light ray bends closer to the perpendicular in the optically slower substance. This is called refraction.
a. Snell's law relates the angles of incidence and refraction to the indices of refraction, with the ratio of the indices of refraction inversely proportional to the ratio of the speeds of propagation in the two media.
b. When light travels from an optically slower substance into an optically faster substance, it bends away from the perpendicular.
c. At the critical angle, the light bends far enough away from the perpendicular that it skims the surface of the material.
d. Beyond the critical angle, all of the light is internally reflected.

Learning Objective (6.E.3.1):
The student is able to describe models of light traveling across a boundary from one transparent material to another when the speed of propagation changes, causing a change in the path of the light ray at the boundary of the two media. [See Science Practices 1.1 and 1.4]

Learning Objective (6.E.3.2):
The student is able to plan data collection strategies as well as perform data analysis and evaluation of the evidence for finding the relationship between the angle of incidence and the angle of refraction for light crossing boundaries from one transparent material to another (Snell's law).
[See Science Practices 4.1, 5.1, 5.2, and 5.3]

Learning Objective (6.E.3.3):
The student is able to make claims and predictions about path changes for light traveling across a boundary from one transparent material to another at non-normal angles resulting from changes in the speed of propagation. **[See Science Practices 6.4 and 7.2]**

Essential Knowledge 6.E.5: The refraction of light as it travels from one transparent medium to another can be used to form images.
a. Ray diagrams are used to determine the relative size of object and image, the location of object and image relative to the lens, the focal length, and the real or virtual nature of the image. Converging and diverging lenses should be included as examples.

Learning Objective (6.E.5.1):
The student is able to use quantitative and qualitative representations and models to analyze situations and solve problems about image formation occurring due to the refraction of light through thin lenses. [See Science Practices 1.4 and 2.2]

Learning Objective (6.E.5.2):
The student is able to plan data collection strategies, perform dataanalysis and evaluation of evidence, and refine scientific questions about the formation of images due to refraction for thin lenses. [See Science Practices 3.2, 4.1, 5.1, 5.2, and 5.3]

Enduring Understanding 6.F: Electromagnetic radiation can be modeled as waves or as fundamental particles.

Essential Knowledge 6.F.1: Types of electromagnetic radiation are characterized by their wavelengths, and certain ranges of wavelength have been given specific names. These include (in order of increasing wavelength spanning a range from picometers to kilometers) gamma rays, x-rays, ultraviolet, visible light, infrared, microwaves, and radio waves.

Learning Objective (6.F.1.1):
The student is able to make qualitative comparisons of the wavelengths of types of electromagnetic radiation. [See Science Practices 6.4 and 7.2]

Essential Knowledge 6.F.2: Electromagnetic waves can transmit energy through a medium and through a vacuum.
a. Electromagnetic waves are transverse waves composed of mutually perpendicular electric and magnetic fields that can propagate through a vacuum.
b. The planes of these transverse waves are both perpendicular to the direction of propagation.

Learning Objective (6.F.2.1):
The student is able to describe representations and models of electromagnetic waves that explain the transmission of energy when no medium is present. **[See Science Practices 1.1]**

Essential Knowledge 6.F.3: Photons are individual energy packets of electromagnetic waves, with $E_{photon} = hf$, where h is Planck's constant and f is the frequency of the associated light wave.
a. In the quantum model of electromagnetic radiation, the energy is emitted or absorbed in discrete energy packets called photons. Discrete spectral lines should be included as an example.
b. For the short-wavelength portion of the electromagnetic spectrum, the energy per photon can be observed by direct measurement when electron emissions from matter result from the absorption of radiant energy.
c. Evidence for discrete energy packets is provided by a frequency threshold for electron emission. Above the threshold, emission increases with the frequency and not the intensity of absorbed radiation. The photoelectric effect should be included as an example.

Learning Objective (6.F.3.1)

The student is able to support the photon model of radiant energy with evidence provided by the photoelectric effect. [See Science Practice 6.4]

Essential Knowledge 6.F.4: The nature of light requires that different models of light are most appropriate at different scales.
a. The particle-like properties of electromagnetic radiation are more readily observed when the energy transported during the time of the measurement is comparable to E_{photon}.
b. The wavelike properties of electromagnetic radiation are more readily observed when the scale of the objects it interacts with is comparable to or larger than the wavelength of the radiation.

Learning Objective (6.F.4.1)
The student is able to select a model of radiant energy that is appropriate to the spatial or temporal scale of an interaction with matter. **[See Science Practices 6.4 and 7.1]**

Enduring Understanding 6.G: All matter can be modeled as waves or as particles.

Essential Knowledge 6.G.1: Under certain regimes of energy or distance, matter can be modeled as a classical particle.

Learning Objective (6.G.1.1)
The student is able to make predictions about using the scale of the problem to determine at what regimes a particle or wave model is more appropriate. [See Science Practices 6.4 and 7.1]

Essential Knowledge 6.G.2: Under certain regimes of energy or distance, matter can be modeled as a wave. The behavior in these regimes is described by quantum mechanics.
a. A wave model of matter is quantified by the de Broglie wavelength that increases as the momentum of the particle decreases.
b. The wave property of matter was experimentally confirmed by the diffraction of electrons in the experiments of Clinton Joseph Davisson, Lester Germer, and George Paget Thomson.

Learning Objective (6.G.2.1)
The student is able to articulate the evidence supporting the claim that a wave model of matter is appropriate to explain the diffraction of matter interacting with a crystal, given conditions where a particle of matter has momentum corresponding to a de Broglie wavelength smaller than the separation between adjacent atoms in the crystal. [See Science Practice 6.1]

Learning Objective (6.G.2.2)
The student is able to predict the dependence of major features of a diffraction pattern (e.g., spacing between interference maxima), based upon the particle speed and de Broglie wavelength of electrons in an electron beam interacting with a crystal. (de Broglie wavelength need not be given, so students may need to obtain it.) [See Science Practice 6.4]

Big Idea 7: The mathematics of probability can be used to describe the behavior of complex systems and to interpret the behavior of quantum mechanical systems.

Essential Knowledge 7.A.1: The pressure of a system determines the force that the system exerts on the walls of its container and is a measure of the average change in the momentum or impulse of the molecules colliding with the walls of the container. The pressure also exists inside the system itself, not just at the walls of the container.

Learning Objective (7.A.1.1):

The student is able to make claims about how the pressure of an ideal gas is connected to the force exerted by molecules on the walls of the container, and how changes in pressure affect the thermal equilibrium of the system. [See Science Practices 6.4 and 7.2]

Learning Objective (7.A.1.2):
Treating a gas molecule as an object (i.e., ignoring its internal structure), the student is able to analyze qualitatively the collisions with a container wall and determine the cause of pressure, and at thermal equilibrium, to quantitatively calculate the pressure, force, or area for a thermodynamic problem given two of the variables. [See Science Practices 1.4 and 2.2]

Essential Knowledge 7.A.2: The temperature of a system characterizes the average kinetic energy of its molecules.
a. The average kinetic energy of the system is an average over the many different speeds of the molecules in the system that can be described by a distribution curve.
b. The root mean square speed corresponding to the average kinetic energy for a specific gas at a given emperature can be obtained from this distribution.

Learning Objective (7.A.2.1):
The student is able to qualitatively connect the average of all kinetic energies of molecules in a system to the temperature of the system. [See Science Practice 7.1]

Learning Objective (7.A.2.2):
The student is able to connect the statistical distribution of microscopic kinetic energies of molecules to the macroscopic temperature of the system and to relate this to thermodynamic
processes. [See Science Practice 7.1]

Essential Knowledge 7.A.3: In an ideal gas, the macroscopic (average) pressure (P), temperature (T), and volume (V), are related by the equation $PV = nRT$.

Learning Objective (7.A.3.1):
The student is able to extrapolate from pressure and temperature or volume and temperature data to make the prediction that there is a temperature at which the pressure or volume extrapolates to zero. [See Science Practices 6.4 and 7.2]

Learning Objective (7.A.3.2):
The student is able to design a plan for collecting data to determine the relationships between pressure, volume, and temperature, and amount of an ideal gas, and to refine a scientific question concerning a proposed incorrect relationship between the variables. [See Science Practices 3.2 and 4.2]

Learning Objective (7.A.3.3):
The student is able to analyze graphical representations of macroscopic variables for an ideal gas to determine the relationships between these variables and to ultimately determine the ideal gas law $PV = nRT$. [See Science Practice 5.1]

Enduring Understanding 7.B: The tendency of isolated systems to move toward states with higher disorder is described by probability.

Essential Knowledge 7.B.1: The approach to thermal equilibrium is a probability process.
a. The amount of thermal energy needed to change the temperature of a system of particles depends both on the mass of the system and on the temperature change of the system.

b. The details of the energy transfer depend upon interactions at the molecular level.
c. Since higher momentum particles will be involved in more collisions, energy is most likely to be transferred from higher to lower energy particles. The most likely state after many collisions is that both systems of particles have the same temperature.

Learning Objective (7.B.1.1):
The student is able to construct an explanation, based on atomic scale interactions and probability, of how a system approaches thermal equilibrium when energy is transferred to it or from it in a thermal process. [See Science Practice 6.2]

Essential Knowledge 7.B.2: The second law of thermodynamics describes the change in entropy for reversible and irreversible processes. Only a qualitative treatment is considered in this course.
a. Entropy, like temperature, pressure, and internal energy, is a state function, whose value depends only on the configuration of the system at a particular instant and not on how the system arrived at that configuration.
b. Entropy can be described as a measure of the disorder of a system, or of the unavailability of some system energy to do work.
c. The entropy of a closed system never decreases, i.e., it can stay the same or increase.
d. The total entropy of the universe is always increasing.

Learning Objective (7.B.2.1):
The student is able to connect qualitatively the second law of thermodynamics in terms of the state function called entropy and how it (entropy) behaves in reversible and irreversible processes. [See Science Practice 7.1]

Enduring Understanding 7.C: At the quantum scale, matter is described by a wave function, which leads to a probabilistic description of the microscopic world.

Essential Knowledge 7.C.1: The probabilistic description of matter is modeled by a wave function, which can be assigned to an object and used to describe its motion and interactions. The absolute value of the wave function is related to the probability of finding a particle in some spatial region. (Qualitative treatment only, using graphical analysis.)

Learning Objective (7.C.1.1):
The student is able to use a graphical wave function representation of a particle to predict qualitatively the probability of finding a particle in a specific spatial region. [See Science Practice 1.4]

Essential Knowledge 7.C.2: The allowed states for an electron in an atom can be calculated from the wave model of an electron.
a. The allowed electron energy states of an atom are modeled as standing waves. Transitions between these levels, due to emission or absorption of photons, are observable as discrete spectral lines.
b. The de Broglie wavelength of an electron can be calculated from its momentum, and a wave representation can be used to model discrete transitions between energy states as transitions between standing waves.

Learning Objective (7.C.2.1):
The student is able to use a standing wave model in which an electron orbit circumference is an integer multiple of the de Broglie wavelength to give a qualitative explanation that accounts for the existence of specific allowed energy states of an electron in an atom. [See Science Practice 1.4]

Essential Knowledge 7.C.3: The spontaneous radioactive decay of an individual nucleus is described by probability.

a. In radioactive decay processes, we cannot predict when any one nucleus will undergo a change; we can only predict what happens on the average to a large number of identical nuclei.
b. In radioactive decay, mass and energy are interrelated, and energy is released in nuclear processes as kinetic energy of the products or as electromagnetic energy.
c. The time for half of a given number of radioactive nuclei to decay is called the half-life.
d. Different unstable elements and isotopes have vastly different half-lives, ranging from small fractions of a second to billions of years. **physics 2**

Learning Objective (7.C.3.1):
The student is able to predict the number of radioactive nuclei remaining in a sample after a certain period of time, and also predict the missing species (alpha, beta, gamma) in a radioactive decay. [See Science Practice 6.4]

Essential Knowledge 7.C.4: Photon emission and absorption processes are described by probability.
a. An atom in a given energy state may absorb a photon of the right energy and move to a higher energy state (stimulated absorption).
b. An atom in an excited energy state may jump spontaneously to a lower energy state with the emission of a photon (spontaneous emission).
c. Spontaneous transitions to higher energy states have a very low probability but can be stimulated to occur. Spontaneous transitions to lower energy states are highly probable.
d. When a photon of the right energy interacts with an atom in an excited energy state, it may stimulate the atom to make a transition to a lower energy state with the emission of a photon (stimulated emission). In this case, both photons have the same energy and are in phase and moving in the same direction.

Learning Objective (7.C.4.1):
The student is able to construct or interpret representations of transitions between atomic energy states involving the emission and absorption of photons. [For questions addressing stimulated emission, students will not be expected to recall the details of the process, such as the fact that the emitted photons have the same frequency and phase as the incident photon; but given a representation of the process, students are expected to make inferences such as figuring out from energy conservation that since the atom loses energy in the process, the emitted photons taken together must carry more energy than the incident photon.] [See Science Practices 1.1 and 1.2]

ASSESSMENTS

Suggested Formative Assessments: The teacher will develop and use standards-based assessments throughout the course.

- Pre-Assessments of prior knowledge (e.g. entrance cards or KWL chart)
- Labs/lab reports
- Bell ringers/Problems of the Day(PODs)
- Discussions
- Teacher observation/Questioning
- Graphic organizers (e.g. Venn diagrams, word mapping, webbing, KWL chart, etc.)

- Summarizing
- Retelling
- Notetaking
- Problem-based learning modules
- Authentic assessment
- Oral presentations
- Outlining
- Journaling
- Student presentations/projects
- Open-ended response
- Classroom Performance System (CPS)

Suggested Summative Assessments:
- Essays
- Open-Ended Responses
- Projects
- Quizzes/tests
- Student presentations
- Portfolios

District Approved Assessment Instruments
- Any district approved assessment instrument

Portfolio Assessment: ______ Yes __x__ No

District-wide Final Examination Required: ______ Yes __x__ No

WRITING TEAM: J.Blum

WCSD STUDENT DATA SYSTEM INFORMATION

1. Is there a required final examination? __x__ Yes ______ No
2. Does this course issue a mark/grade for the report card?

   __x__Yes ______ No
3. Does this course issue a Pass/Fail mark? ______Yes __x__ No

4. Is the course mark/grade part of the GPA calculation?

   __x__Yes   ______ No

5. Is the course eligible for Honor Roll calculation?   __x__ Yes   ______ No

6. What is the academic weight of the course?

   ______ No weight/Non credit   ______ Standard weight

   __x__ Enhanced weight (Describe) as per current school board policy