Curricular Requirements	Page(s)
CR 1 Students and teachers have access to college-level resources including college-level textbooks and reference materials in print or electronic format.	2
CR 2a The course design provides opportunities for students to develop understanding of the foundational principles of thermodynamics in the context of the big ideas that organize the curriculum framework.	5
CR2b The course design provides opportunities for students to develop understanding of the foundational principles of fluids in the context of the big ideas that organize the curriculum framework.	4
CR2c The course design provides opportunities for students to develop understanding of the foundational principles of electrostatics in the context of the big ideas that organize the curriculum framework.	6
CR2d The course design provides opportunities for students to develop understanding of the foundational principles of electric circuits in the context of the big ideas that organize the curriculum framework.	6, 7
CR2e The course design provides opportunities for students to develop understanding of the foundational principles of magnetism and electromagnetic induction in the context of the big ideas that organize the curriculum framework.	7
CR2f The course design provides opportunities for students to develop understanding of the foundational principles of optics in the context of the big ideas that organize the curriculum framework.	8
CR2g The course design provides opportunities for students to develop understanding of the foundational principles of modern physics in the context of the big ideas that organize the curriculum framework.	8-10
CR3 The students have opportunities to apply AP Physics 2 learning objectives connecting across enduring understandings as described in the curriculum framework. These opportunities must occur in addition to those within the laboratory investigations.	4-7, 9
CR4 The course provides students with opportunities to apply their knowledge of physics principles to real world questions or scenarios (including societal issues or technological innovations) to help them become scientifically literate citizens.	5-8, 10
CR5 Students are provided with the opportunity to spend a minimum of 25 percent of instructional time engaging in hands-on laboratory work with an emphasis on inquiry-based investigations.	2, 3
CR6a The laboratory work used throughout the course includes investigations that support the foundational AP Physics 2 principles.	2
CR6b The laboratory work used throughout the course includes guided-inquiry laboratory investigations allowing students to apply all seven science practices.	2
CR7 The course provides opportunities for students to develop their communication skills by recording evidence of their research of literature or scientific investigations through verbal, written, and graphic presentations.	2
CR8 The course provides opportunities for students to develop written and oral scientific argumentation skills.	3, 5-8

Course Overview

This course introduces the concepts of modern physics, aligned to seven fundamental themes of the nature of matter and energy called the Big Ideas, as shown in parentheses below **[CR2**]:

- Big Idea 1: Objects and systems have properties such as mass and charge. Systems may have internal structure.
- Big Idea 2: Fields existing in space can be used to explain interactions.
- Big Idea 3: The interactions of an object with other objects can be described by forces.
- Big Idea 4: Interactions between systems can result in changes in those systems.
- Big Idea 5: changes that occur as a result of interactions are constrained by conservation laws.
- 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.
- 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 system.

Topics include

Instructional Resources

Students are required to obtain the following texts **[CR1]**:

- *Physics: Principles with Applications,* 7th edition (2013), Douglas Giancoli. Students may purchase hardcover or electronic versions of the text.

Instructional Context

Class meets two times a week in online live chat sessions of 90 minutes each. Two sessions are used to discuss assigned text readings and web-hosted lecture materials. Sessions make extensive use of internet resources including simulations, pictures, diagrams and animations, short videos, and current events, as well as the textbook publisher's companion site. Chat logs are available as soon as chat ends for students who missed class or need to review discussions.

A third weekly hour-long session is used to analyze posted lab results, improve student lab techniques, data analysis and presentation skills. These quasi-tutorial sessions provide materials that bridge the high school-to-college gaps in student backgrounds and cover selected topics in greater depth than the text, and include review of representative questions from previous AP courses.

**Students who have previously demonstrated mastery of scientific practices in honors or AP level courses and who are have taken or are concurrently taking pre-calculus may, with the instructor's permission, opt to complete AP Physics 1 and AP Physics 2 in a single academic year plus one summer.*

Investigative Laboratory Component

Students are required to obtain lab equipment to perform a minimum of 16 labs, spending 3-5 hours for each on lab setup, execution, and reporting, for a total commitment of 25% of their course time **[CR5]**.

Labs are selected from a bank of lab exercises that have been designed by the teacher to demonstrate foundational AP Physics 2 principles for individual students working outside a school laboratory **[CR6a]**. Labs early in the sequence require students to build their own equipment, helping them develop an understanding of the relationship between the measuring device and the quantity measured, as well as challenging their creative skills. Subsequent labs provide skill-building in all seven scientific practices. Each student must maintain a laboratory notebook as evidence of his or her work. **[CR6b]**.

Students review the lab purpose and techniques in chat, and also identify specific learning objectives for each lab before attempting the lab. After completing the lab activities, students upload formal laboratory reports to a common bulletin board for teacher and peer review. Each report includes the title, an abstract (under 200 words), a list of materials and equipment used, and a description of the procedure followed. These must be in sufficient detail that another student can repeat the experiment. The rest of the report includes data tables, sample calculations demonstrating the data reduction methods used, including statistical error analysis, all derived or calculated organized appropriately in list or tabular format, and clearly identified conclusions. Students may also be required to answer specific questions and upload further evidence (photos or videos) to prove they conducted the lab as stipulated **[CR7]**.

Live-chat and asynchronous bulletin-board discussions of lab exercise processes, individual adaptations required by local conditions, and data analysis techniques allow students to develop skill in precisely communicating lab experiences, and to work together to identify successful strategies for current and subsequent laboratory work.

Teaching Strategies

All our school courses are designed to take advantage of our asynchronous environment and based on a "flipped classroom" approach. This course uses a Physics content site developed by the teacher and a Moodle course content delivery system, along with standard email, to support asynchronous access to course materials, including web-based lecture notes, course calendars and lecture schedule, quizzes, forums, and wikis. The latter two techniques allow students to enter materials at their own convenience and share their homework assignments and study notes with each other, supporting a cooperative learning environment. In the content site, along with general study aids, there is a homework assignment page for each chat session, with study notes for the day's reading assignment, a teacher-written web-based lecture that provides additional material and explains many concepts in more detail, and instructions for the lab associated with that unit.

Students are expected to demonstrate a high level of self-discipline and self-motivation in preparing for our limited discussion time. All preparation work (reading text, completing exercises in the study guide, posting assigned essays must be completed prior to chat sessions. In particular, materials normally presented by a teacher standing in front of a class and lecturing are presented instead as teacher-written web lectures, read at the student's own convenience. These may employ teacher-designed animations, or refer to animation and simulations on the web to better explain processes.

Sstudents are assigned individual problems to solve for each their homework, and required to present solutions that include the rational for formula choice, variable identification and substitution, mathematical calculations, and justification for final units for each problem. These solutions, as well as lab data and lab reports, must be posted to the Moodle forum for peer review and comment [CR8]. Students are also encouraged to contribute definitions of terms and concepts or historical notes to the Moodle wiki pages. Chat logs, solved homework problems, lab reports, and wiki entries become part of the course content, accessible to all class participants, supporting a student-centered, cooperative learning environment.

The flexibility of the Moodle environment, real-time online chat, ten years of previous chat records, and access to the Internet allow the teacher to respond quickly to specific interests or learning needs of the student, tailoring the presentation of material to compensate for differences in background and to challenge gifted students with additional material by creating alternate presentations on the fly, or (where a traditional classroom teacher might use a blackboard or slides), leading students on "Web tours" to sites that contain descriptions of research, animations, and simulations of the topic raised by the student.

Students are encouraged to view science as a complex human endeavor, and examine the benefits and limitations of current scientific methodologies. Supplemental historical, philosophical, and religious materials from books, articles, and current events are used to help students understand the interaction of scientific theories with human societies, especially where theories involve ethical and religious issues, such as appropriate use of natural resources and possibilities of environmental damage.

Syllabus

Text Unit/ Chapters	Text/Lecture/Discussion Topic	Opportunities to achieve specific Learning Objectives using textbook readings (TB), teacher written web lectures (WL), class discussion CD), homework assignments (HW), or selected AP Free Exercise questions (AP). NOTE: Students post individually assigned homework solutions to a common forum, where they must critique their peers' answers. [CR8]	Coordinated Lab Exercises may be Confirmation (C), Structured Inquiry (SI), Guided Inquiry (GI), or Open Inquiry (OI), or a combination. Key (but not all) scientific practices emphasized in each lab are indicated as (SP#). Note: Students post all lab reports and data to a common forum where they compare lab results and critique each other's reports for clarity and completeness. [CR8]. A few examples are listed below.	Big Idea, Enduring Understanding
None	**Introduction to Course** • Course methods and expectations • Online course delivery processes (Moodle, forum use, posting homework, quizzes, email) • Textbook (hardcopy and/or eCopy), publisher website helps, teacher's web lecture content, lab resources • Overview of Big Ideas		NO LAB	Review of all Big Ideas for the course.
10: 1-5	**Fluid Dynamics** • Specific gravity • Fluid statics: Pascal's Principle	CD/HW: Students use Pascal's law to identify the force, pressure, and surface area parameters necessary to design a hydraulic lift capable of raising average car. LO: 1E12, 2A1, 3A21	**Buoyancy (C, SI):** Students measure density of unknown objects by water displacement; estimate percent error in calculations. SP 2.1, 2.2, 2.3, 4.1, 4.2, 4.3, 4.4, 5.1	**Big Ideas 1, 3, 5 [CR2b]** **Fluids** **EU 1E, 2A, 3A** **EU 3A, 3B, 5B** **[CR3]**
10: 6-14	**Buoyancy** • Fluid statics: Archimedes' Principle • Fluid dynamics: Bernoulli's Principle	CD/HW: Students apply Archimedes' principle to determine specific gravity of unknown substance by determining displacement and buoyant force. Students also apply Bernoulli's principle and the continuity equation to calculate lift of plane wing and fluid velocity through pipes with changing diameters. LO: 3A41,3A42, 3A43, 3B11, 3B12, 3B13, 3B14, 5B10.1-5B10.4 In the above assigned problem sets, students connect and apply concepts from EU 3A (Forces), 3B (Acceleration), and 5B (Conservation of energy) to analyze fluid dynamics. **[CR3]**	**Bernoulli's Principle (OI)** Students calculate, then measure buoyant forces required to keep mass (paper streamer, ping pong ball) afloat in air stream, and use results to determine stream velocity. SP 2.1, 2.2, 3.1, 3.2, 4.1, 4.2, 4.3, 4.4, 5.1, 5.2	

13: 1-5	**Thermal Equilibrium** • Zeroth law of thermodynamics • Thermal expansion and stress	CD/HW: Students defend solutions for thermal expansion required to fit rings together to form seal. LO: 1E31, 4C31	**Thermal expansion (OI)** Students estimate temperature change required to loosen metal screw-cap lid from sealed glass jar that has been cooled at least 20°C, then test predictions to evaluate metal expansion and partial pressure change. SP 2.1, 2.2, 3.1, 3.2, 4.1, 4.2, 4.3, 4.4	**Big Ideas 1, 4, 5, 7** **[CR2a]**
13: 7-14	**Ideal Gas Law** • Ideal Gas Law • Kinetic molecular theory of gases	CD: Presentation of Ideal Gas law, discussion of determination of absolute zero for Kelvin scale from pressure and/or volume data. Students use online simulators to manipulate P, V, n, and T values and observe effects. LO: 5D16, 5D17, 5D25, 5D26, 7A11, 7A12, 7A21, 7A22; 7A31, 7A32, 7A33 Students use EU 5D (Conservation of momentum in elastic and inelastic collisions) and 7A (Properties of Ideal gas) to explain the deviation of real gases from the ideal gas law. **[CR3]**	**Gas volumes** (SI) Using balloons and water baths, students predict, then measure change in volume as a function of temperature. SP 2.1, 2.2, 4.1, 4.2, 4.3, 4.4, 5.1, 5.2	**Thermodynamics** **EU 1E, 4C** **EU 5D, 7A** **[CR3]**
14: 1-4	**Specific Heat** • Energy transfer • Calorimetry	CD/HW: Students use conservation of energy to determine density, heat capacity and identity of unknown metal sample in calorimetry experiment. LO: 5B41, 5B42, 5B6	**Calorimetry (OI)** Students propose and execute methods of measuring volume and mass (without using a scale) to confirm density, then build a simple calorimeter and use heat transfer to determine specific heat and identify a metal sample of irregular shape. SP 2.1, 2.2, 2.3, 3.1, 3.2, 4.1-4.4	
14: 5-8	**Heat Transfer** • Conduction, convection, and radiation	CD/HW: Students determine energy required for temperature and phase changes using heat conduction and radiation sources (Stefan-Boltzmann equation). LO: 4C31, 4C32	**Specific Heat** (GI) Using calorimeter setup from previous experiment, measure specific heats of various substances. SP 2.1, 2.2, 2.3	**Big Ideas 1, 4, 5, 7** **[CR2a]**
15: 1-4	**Laws of Thermodynamics** • Conservation of energy (first law) • Increasing entropy	CD: Students use graphical representations to explain and identify adiabatic, isobaric, and isovolumetric processes. WL: History of derivation of first law as conservation of energy. LO: 1A1, 1A52, 5B71-5B73	**Adiabatic changes (OI)** Students devise a way to measure change in pressure when heating a gas in a confined volume, then graph pressure as temperature increases over a minimum 40°C range. SP 3.1, 3.2, 4.1, 4.2, 4.3, 4.4	**Thermodynamics (cont'd)** **EU 5B** **EU 4C** **EU 1A, 5B** **EU 7B**
15: 5-6	**Heat Engines** • Efficiency • Practical applications	CD/HW: Students calculate engine efficiency for Carnot ideal (reversible) engines and real heat engines (refrigerators, heat pumps) to evaluate manufacturer's claims for efficiency. **[CR4, CR8].** LO: 1A1, 1A52, 5B71, 5B72, 5B73	**Joule's experiment (GI):** Students repeat Joule's experiment to determine heat energy produced by mechanical energy, then compare experimental results with accepted conversion factor to estimate error. SP 2.1, 2.2, 2.3, 4.1, 4.2, 4.3, 4.4	**[CR3]**
15: 7-12	**Entropy** • Increasing disorder • Time's arrow, heat death • Statistical interpretations of entropy	CD: Students use statistical analysis to count micro-states of 2-variable coin toss system). HW: Students analyze phase changes for entropy changes. LO: 7B11, 7B12	**Statistical implications (GI)** Students use spreadsheets to determine increase in entropy as systems become more complicated. SP 1.1-1.4, 5.1-5.3, 6.1,-6.5, 7.1, 7.2	

16: 1-6	**Electrical Charge** • Electrical charge • Charge conservation • Insulation and conduction • Coulomb's law	CD: Students use Coulomb's law to predict charge required to counter gravitational pull on object with static charge and compare magnitudes of gravitational and electrical forces. LO: 1B21, 1B22, 1B23, 1B31; 2C31, 3C21-3C23; 4E31-4E35	**Floating Balloon (GI)** Students build a simple electrometer and practice charging balloons with static electricity to different measurable levels. Then using weighted balloons, they predict the charge amount required to allow a balloon to float for several seconds against a vertical wall. SP 4.1, 4.2, 4.3, 4.4, 5.1, 5.2, 5.3	**Big Ideas 1, 2, 3, 4, 5** **[CR2c]** **Electrostatics** **EU 1B, 2C, 3C, 4E** **EU 2C, 2E, 3A, 3B, 3C** **EU 1E, 2A, 2C, 2E, 5B** **EU 2C 4E** **[CR3]**
16: 7-12	**The Electric Field** • Electric force • Electric field lines and conduction • Electric permittivity • Gauss's law	CD/HW: Students use vector analysis to calculate electrical force and direction in 2, 3, and 4 point charge arrangements, and qualitatively describe electric flux through a surface. LO: 2C11, 2C12,, 2E11, 3A21, 3A34, 3B11-3B14; 3B21, 3C22, 3C41, 3C42	**Determination of ε_0 (C)** Students study, discuss, and use dry lab data to "perform" an MIT experiment to determine the electric permittivity constant. *Note: the HVPS required is not easily available for home students.* SP 2.1, 2.2, 2.3	
17: 1-6	**Electric Potential** • Potential difference and the electric field • The Electron Volt • Point charge potentials	CD/HW: Students represent electric fields with equipotential line diagrams (2D) and surfaces (3D) for both single point charge and dipole situations. LO: 1E41, 2A1, 2A2, 2C41, 2C42, 2E21-2E23, 2E31, 2E32, 5B21 Students connect concepts from EU 1E (Matter has charge), 2A (Field models), 2C (Electric fields), 2E (Isoline representations), and 5B (Conservation of energy) to explain motion of test charges in electric fields. **[CR3]**	**Equipotential lines (GI)** Students use conductive paper to measure electric potential and map the electric field around several 2D shapes. SP 1.1, 1.2, 1.3, 1.4, 5.1, 6.1, 6.2, 6.3	
17: 7-11	**Storing Electric Energy** • Capacitance • Dielectrics	CD: Comparison of analog and digital methods of data storage and signal transference, and implications for computer screen technologies **[CR4]**. HW: Students design circuits by specifying capacitors of appropriate size and dielectric characteristics. LO: 2C51, 2C52, 2C53, 4E41, 4E42, 4E43	**Electric circuit 1 (GI)** Students design and construct series and/or parallel circuits with four known and one unknown capacitor to determine capacitance of the fifth capacitor. SP 2.1, 2.2, 4.1, 4.2, 4.3, 4.4	
18: 1-6	**Current and Power** • Microscopic explanation of current • Potential difference and batteries • Ohm's Law • Resistivity	CD: Students must defend or refute a claim that aluminum is preferable to copper in transmission lines, while copper is preferable in household situations. **[CR8]** HW: Students use Ohm's law to explain current flow through simple circuits with known loads (lamps, internal resistance). LO: 1B11, 1B12, 1E21, 4C41, 4E41, 4E42, 4E51	**Internal resistance (GI)** Students construct a circuit to determine the internal resistance in multiple batteries. SP 2.1, 2.2, 2.3, 4.1, 4.2, 4.3, 4.4	**Big Ideas 1, 4, 5** **[CR2d]** **Electric Circuits** **EU 1B, 1E, 4C, 4E** **EU 4E, 5B** **[CR3]**
18: 7-10	**Alternating Current** • Electrical power • Alternating current	CD/HW: Students analyze power transfer in natural phenomena (lightning) and alternating current. LO: 4E51, 4E45, 4E53, 5B51		

19: 1-4	**DC Circuits and EMFs** • EMF • Resistors in circuits • Kirchhoff's rules in simple DC circuits	CD/HW: Students diagram and analyze series and parallel circuits with resistors including a Wheatstone bridge using Kirchhoff's rules. 4E51, 4E52, 4E53, 5B91, 5B94-5B98	**Electric circuit 2 (OI)** Students construct an RC circuit including switches, an ammeter, and a voltmeter, then predict, measure and confirm current and voltage behavior when charging and discharging capacitors. SP 3.1, 3.2	**Big Ideas 1, 4, 5** **[CR2d]** **Electric Circuits** *(con't)* **EU 4E, 5B** **EU 5C** **[CR3]**
19: 5-8	**RC Circuits** • Kirchhoff's rules in complex DC circuits • Steady-state RC circuits	CD/HW: Students diagram and analyze series and parallel circuits with capacitors and with both resistors and capacitors using Kirchhoff's rules. LO: 5C34-5C37		
20: 1-4	**Magnetic Fields** • Electric current and magnetic fields • Wire configurations and field production	CD/WL: Students use right hand rules to determine magnetic field and force directions for fields around current wires and moving magnetics. LO: 1E5, 1E6, 2C41, 2D11, 2D21, 2D31 3C31, 3C3 Students combine principles from EU 1E (Macroscopic properties), 2C (Electric fields), 2D (Origins of magnetic fields), and 3C (Force acting at a distance) to predict the behavior of magnetic fields arising from moving charged particles.**[CR3]**	**Map a magnetic field 1 (GI)** Using a compass, students map the field around a magnet; determine where the earth's magnetic field exceeds the magnet's own field, and calculate the magnet's strength SP 1.1, 1.2, 1.3, 1.4, 5.1	**Big Ideas 1-4** **[CR2e]** **Magnetism and Electromagnetic Induction** **EU 1E, 2C, 2D, 3C** **EU 2D** **EU 4E** **EU 6F** **[CR3]**
20: 5-12	**Ampere's Law** • Torque on current loops • Practical applications: motors, galvanometers	HW: Students calculate field strength and magnetic force from current amount and distance from wire, and practical applications in electric motors, comparing energy efficiency claims for gas and electric motors to determine which is "greener". **[CR4]** **[CR8]** LO: 2D41	**Map a magnetic field 2 (OI)** Using a compass and test magnets, students map the field a current-carrying wire, varying current amounts by adding resistors to circuit, OR **Magnetic field of Slinky (OI)** Determine an experimental value for the permeability of free space using a Slinky solenoid and a magnetic field sensor (iPhone app) SP 4.1, 4.2, 4.3, 4.4, 5.1, 5.2	
21: 1-5	**Induction** • Induced EMF • Lenz's law • Faraday's law • Generators	CD/HW: Students apply Lenz's law and Faraday's law to predict magnetic fields generated by current flow in loops and current flow generated in loops moving in magnetic fields. LO: 4E11, 4E12	**Electric motor** (GI) Students build a simple electric motor and determine mechanical work from current. SP 4.1, 4.2, 4.3, 4.4	
21: 6-14	**Transformers and LRC Circuits** • Transformers • Practical applications of induction	CD/HW: Students calculate power loss over transmission lines from power plant through step-up and step-down transformers to home delivery. LO: 4E51		
22: 1-7	**Electromagnetic Waves** • Maxwell's equations • Speed of light	CD/WL: Discussion of Maxwell's equation as example of scientific "elegance" in formulating natural laws. HW: Students use wave relationships c = vf to explore range of EM radiation. LO: 6F11, 6F12	**Speed of light (OI)** Students determine the speed of light using a suitable medium (e.g. chocolate) and a microwave oven of known frequency and wattage. SP 2.1, 2.2, 2.3, 3.1, 3.2, 7.1, 7.2	

23: 1-5	**Light and Refraction** • Reflection of light • Refraction and Snell's law	CD/HW: Students use ray diagrams and Snell's law to demonstrate and calculate reflection and refraction by plane surfaces. LO: 6E11, 6E21, 6E41, 6E42	**Reflection (GI)** Using a laser, students map reflections from a curved surface such as a metal water pitcher. SP 1.1, 1.2, 1.3, 1.4	
23: 6-10	**Lenses** • Applications of refraction: fiber optics • Applications of refraction: thin lenses	CD/HW: Students use ray diagrams, reflection and refraction rules, and the thin lens equation to demonstrate and calculate focal length, object and image locations, real vs. virtual image formation, and magnification for curved reflective surfaces and transparent lenses. LO: 6E31, 6E32, 6E33, 6E51, 6E52	**Refraction (C, SI)** Students determine focal lengths for lenses supplied by the teacher, some of which are identical. Students first meet to discuss methods of measurement, then compare data and results, and finally create peer reviews of reports as though they were judging results for academic publishing. **[CR8]** SP 2.1, 2.2, 2.3	**Big Idea 6** **[CR2f]**
24: 1-5	**Light and Waves** • Huygens's principle • Young's experiment	CD/HW: Students use Huygen's principle to calculate change in wave front velocity. LO: 6A11-6A13, 6A22	**Young's experiment (GI)** Students use single slits and double slits of known width or separation separation, to observe interference maxima and minima and determine the wavelength of a source laser. SP 2.1, 2.2, 2.3, 6.1, 6.2, 6.3, 6.4, 6.5	
24: 6-12	**Diffraction** • Diffraction Grating • Thin Films • Polarization	CD: Demonstration of LCD technology design using LCD Simulator website (www.dinceraydin.com) **[CR4]** HW: Students demonstrate application of diffraction and polarization technologies. LO: 6B31, 6C11, 6C12, 6C21, 6C31, 6C41	**Thin Film Interference (OI)** Students devise experiments to use glass plates, small separation device such as a hair, and a laser to determine the thickness of the separator. SP 2.1, 2.2, 2.3, 3.1, 3.2, 7.1, 7.2	**Optics** **EU 6E** **EU 6A** **EU 6B, 6C** **EU 6E**
25: 1-6	**Optical Instruments 1** • Vision correction • Telescopes • Aberration	CD/HW: Students discuss their own vision correction, and calculate telescope magnification and resolution limitations as a function of aperture, with additional application to photographic equipment. **[CR4]** LO: 6E31, 6E32, 6E33, 6E51, 6E52	**Telescope:** Build a simple telescope from two lenses with known focal lengths, and determine magnification. Position in both Keplerian and Galilean modes. SP 4.1, 4.2, 4.3, 4.4	**[CR3]**
25: 7-12	**Optical Instruments 2** • Limits of resolution • Microscopes • X-ray diffraction	CD/HW: Students discuss and calculate limits of resolution for light, SEM, and TEM microscopes, and justify claims of the suitability of each for particular observations, e.g., that light microscopes are better for observing living cell processes than SEM or TEM microscopes. **[CR8]** LO: 6E31, 6E32, 6E33, 6E51, 6E52	**Resolution:** Measure resolution of telescope and compare with predicted value. SP 2.1, 2.2, 2.3	
26: 1-5	**Special Relativity** • Classical relativity • Postulates of special relativity • Simultaneity • Time dilation	CD/HW: Students explore differences between classical and relativistic frames of reference, the concept of simultaneity, and calculate time dilation for objects at relativistic speeds, including overview of the muon experiment. LO: 1C4, 1D31	**GPS Relativity (C):** Students review and defend or refute evidence for relativity based on the synchronization requirements of GPS satellite clocks (http://www.ipgp.fr/~tarantola/Files/Professional/GPS/Neil_Ashby_Relativity_GPS.pdf)	

26: 6-11	**Mass and Energy** • Relativistic momentum • Mass-energy equivalence	CD/HW: Students use E = mc² to determine mass-energy equivalence for common objects, then apply relativistic moment to analyze hadron accelerations. LO: 4C41, 5B11	**[CR8]** SP 1.5, 3.1, 3.2, 3.3, 5.3, 6.1, 6.2, 6.3, 7.1, 7.2	
27: 1-6	**Early Quantum Mechanics** • Blackbody radiation • Photons • Compton Effect • Pair production	CD/HW: Students discuss blackbody radiation and the ultraviolet catastrophe as background for quantum explanations of energy transfer, and use Planck's theories to calculate photon energy from frequency and wavelength. LO: 1A4, 5B81, 6F31 Students connect EU concepts 1A (Properties due to system structure), 5B (Conservation of Energy), and 6F (Wave models of EM radiation) to explain Planck's resolution to the ultraviolet catastrophe in blackbody radiation. **[CR3]**	**CHALLENGE LAB (OI): Blackbody radiation** Use a Crooke's radiometer and Leslie's cube to qualitatively evaluate emissivity of radiation from different surfaces illuminated by a tungsten light. SP 3.1, 3.2, 3.3	**Big Ideas 1-8 [CR2g]** **Optics** **EU 1C, 1D** **EU 4C, 5B** **EU 1A, 5B, 6F** **EU 1A, 6G** **EU 6F, 7C** **EU 1A, 1E, 4E**
27: 7-13	**Wave-Particle Duality** • Wave nature of matter • De Broglie waves • Bohr atom	CD/HW: Students use online simulator (U of CO BEC site) to map wave pattern to electron orbitals and verify Bohr electron transition models, then calculate wavelengths and energy absorbed/transmitted by electron transitions. LO: 1A41, 6G11, 6G21, 6G22	**Spectrometry (GI)** Using a diffraction grating spectroscope, observe and classify spectra from hydrogen and helium sources; estimate wavelength and determine energy separation of electron orbitals. SP 2.1, 2.2, 2.3, 6.1, 6.2, 6.3	**EU 3G, 7C** **[CR3]**
28: 1-6	**Quantum Mechanics** • Wave Function and the double-slit • Heisenberg's uncertainty principle • Uncertainty and determinism	CD/HW: Students explore implications of uncertainty principle to analysis of physical systems, and calculate limitations in determining positions of quantum particles for Bohr hydrogen atom. LO: 6F41, 7C11, 7C21, 7C41	**DEMONSTRATION LAB (C): VIDEO** Students watch a video demonstration of the photoelectric effect (http://www.nationalstemcentre.org.uk/elibrary/resource/4102/oscilloscope) based on the Nuffield foundation experiment. SP 3.1, 3.2, 3.3, 6.1, 6.2, 6.3, 6.4, 6.5	
28: 7-12	**Quantum Numbers** • Quantum numbers • Exclusion principle • Practical implications: Lasers	CD/HW: Students use online resources to determine graphical representations of wave equation for electron orbitals for a given quantum state.		
29: All	**Molecules and Solids** • Molecular bonding • Band theory in metals • Practical implications for diodes and transistors	CD/HW: Students distinguish between covalent, ionic, and continuous metal bonding to explain electrical phenomena. LO: 1A3, 1E11, 1E12, 4E31	NO LAB	
30: 1-7	**Radioactivity** • Binding energy in the nucleus • Types of decay: alpha, beta, gamma • Conservation laws for nuclear reactions	CD/HW: Students calculate binding energy for different atomic nuclei using mass-energy equivalence and conservation of energy in nuclear reactions. LO: 3G31, 7C31	**CHALLENGE LAB (OI): Geiger Counter** Build a simple Geiger counter and detect sources of radioactivity (e.g., computer screens).	

30: 8-13	**Decay and Half-lives** • Measuring half-lives • Decay series	CD/HW: Students apply half-life rule to determine age of sample from radioactivity levels. LO: 3G31, 7C31	SP 4.1, 4.2, 4.3, 4.4	
31: 1-4	**Nuclear Fission and Fusion** • Fission a and nuclear reactors • Fusion and stellar energy generation	CD/HW: Students estimate energy generation in cores of stars from fission and fusion energy relationships, estimating mass of materials involved. LO: 5C11, 5F11, 5G11	**CHALLENGE LAB (OI): Hadron Collider data** Students participate in the LHC data analysis project (www.higgshunters.org) SP 4.1, 4.4, 6.1, 6.2, 6.3, 6.34	**Big Ideas 1-8 [CR2g]** ***(con't)*** **EU 3G, 7C** **EU 5C, 5F, 5G** **EU 1A** **EU 3G** **[CR3]**
31: 5-9	**Practical uses for Radiation** • Radiation damage • Practical uses of radiation in medicine	CD/HW: Students discuss safety hazards and radiation level detection when working with radioactive materials, including practical applications for medical procedures. **[CR4]** LO: 5C11, 5F11, 5G11		
32: 1-7	**Elementary Particles** • Particles and antiparticles • Neutrinos • Particle classification	CD/HW: Students create identify classes of particles and become familiar with notation for elementary particles. LO: 5C11, 5G11	**CHALLENGE LAB (OI): Cloud Chamber** Build a simple cloud chamber to detect elementary particles and even observe events. SP 6.1, 6.2, 6.3, 6.4	
32: 8-12	**Strange Particles and Quarks** • Quarks • Chromodynamics • Grand Unified Theory	CD/HW: Students use Feynman diagrams to explain and predict outcomes of elementary particle interactions. Students identify and calculate relative strengths of the four fundamental forces. LO: 1A21		
33: 1-10	**Astrophysics and Cosmology** • Stellar evolution • Red shifts and Hubble's Law • The first three minutes of the big bang • Dark matter and dark energy	CD/HW: Students evaluate current cosmological theories using observations and laws from relativity, conservation of mass and energy, and the four fundamental forces. LO: 3G12, 3G21	NO LAB	