Unit #18 Quantum, Atomic and Nuclear Physics

Big Ideas:

- At the atomic level energy is quantized and particles have wavelike properties.
- The wave properties of matter mean that the atomic-level world must be described in terms of probability.
- The nuclei of atoms can release tremendous amounts of energy when part of their mass is converted to energy.

Essential Questions:

- What does it mean to say that the energy of radiation is quantized?
- How are photons related to energy quantization?
- How does the behavior of subatomic particles compare to that of macroscopic objects?
- What happens during the process of fluorescence?
- How have the various models of the atom contributed to our present model of the atom?
- How has the increase in the knowledge of the atomic model affected society (nuclear power, weapons, medicine, etc.)?
- How are energy-level diagrams related to emission spectra?
- How does our model of the atom explain the wave and particle duality of light?
- What is the relationship between nuclear binging and the stability of the nucleus?
- What is the difference between nuclear fusion and fission?
- What happens when a nucleus decays?
- How are mass number, neutron number and atomic number related?
- What are the properties of the strong nuclear force?
- How did Einstein relate mass to energy?
- What occurs when a nuclear fission reactor is critical?
- What is the half-life of a radioactive material?
- How does carbon-14 dating work?
- Why are leptons considered elementary particles?
- What types of particles combine to make hadrons?
- How do the partial charges of quarks determine the charges of larger particles?

Vocabulary:

fission	fusion	decay
quantum	spectra	wave property
particle property	wave-particle duality	nuclear

Students who demonstrate understanding can:

HS-PS1-1. **Use the periodic table as a model to predict the relative properties of elements based on the patterns of electrons in the outermost energy level of atoms.**[Clarification Statement: Examples of properties that could be predicted from patterns could include reactivity of metals, types of bonds formed, numbers of bonds formed, and reactions with oxygen.] [*Assessment Boundary: Assessment is limited to main group elements. Assessment does not include quantitative understanding of ionization energy beyond relative trends.*]

HS-PS1-3. **Plan and conduct an investigation to gather evidence to compare the structure of substances at the bulk scale to infer the strength of electrical forces between particles.**[Clarification Statement: Emphasis is on understanding the strengths of forces between particles, not on naming specific intermolecular forces (such as dipole-dipole). Examples of particles could include ions, atoms, molecules, and networked materials (such as graphite). Examples of bulk properties of substances could include the melting point and boiling point, vapor pressure, and surface tension.] [*Assessment Boundary: Assessment does not include Raoult's law calculations of vapor pressure.*]

HS-PS1-5. **Apply scientific principles and evidence to provide an explanation about the effects of changing the temperature or concentration of the reacting particles on the rate at which a reaction occurs.**[Clarification Statement: Emphasis is on student reasoning that focuses on the number and energy of collisions between molecules.] [*Assessment Boundary: Assessment is limited to simple reactions in which there are only two reactants; evidence from temperature, concentration, and rate data; and qualitative relationships between rate and temperature.*]

HS-PS1-8. **Develop models to illustrate the changes in the composition of the nucleus of the atom and the energy released during the processes of fission, fusion, and radioactive decay.**[Clarification Statement: Emphasis is on simple qualitative models, such as pictures or diagrams, and on the scale of energy released in nuclear processes relative to other kinds of transformations.] [*Assessment Boundary: Assessment does not include quantitative calculation of energy released. Assessment is limited to alpha, beta, and gamma radioactive decays.*]

HS-PS3-3 **Design, build, and refine a device that works within given constraints to convert one form of energy into another form of energy.***[Clarification Statement: Emphasis is on both qualitative and quantitative evaluations of devices. Examples of devices could include Rube Goldberg devices, wind turbines, solar cells, solar ovens, and generators. Examples of constraints could include use of renewable energy forms and efficiency.] [*Assessment Boundary: Assessment for quantitative evaluations is limited to total output for a given input. Assessment is limited to devices constructed with materials provided to students.*]

The performance expectations above were developed using the following elements from the NRC document *A Framework for K-12 Science Education*:

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Developing and Using Models Modeling in 9–12 builds on K–8 and progresses to using, synthesizing, and developing models to predict and show relationships among variables between systems and their components in the natural and designed worlds. • Develop a model based on evidence to illustrate the relationships between systems or between	**PS1.A: Structure and Properties of Matter** • Each atom has a charged substructure consisting of a nucleus, which is made of protons and neutrons, surrounded by electrons. (HS-PS1-1) • The periodic table orders elements horizontally by the number of protons in the atom's nucleus and places those with similar chemical properties in columns. The	**Patterns** • Different patterns may be observed at each of the scales at which a system is studied and can provide evidence for causality in explanations of phenomena. (HS-PS1-1),(HS-PS1-2),(HS-PS1-3),(HS-PS1-5)

components of a system. (HS-PS1-4),(HS-PS1-8)

- Use a model to predict the relationships between systems or between components of a system. (HS-PS1-1)

Planning and Carrying Out Investigations

Planning and carrying out investigations in 9-12 builds on K-8 experiences and progresses to include investigations that provide evidence for and test conceptual, mathematical, physical, and empirical models.

- Plan and conduct an investigation individually and collaboratively to produce data to serve as the basis for evidence, and in the design: decide on types, how much, and accuracy of data needed to produce reliable measurements and consider limitations on the precision of the data (e.g., number of trials, cost, risk, time), and refine the design accordingly. (HS-PS1-3)

Constructing Explanations and Designing Solutions

Constructing explanations and designing solutions in 9–12 builds on K–8 experiences and progresses to explanations and designs that are supported by multiple and independent student-generated sources of evidence consistent with scientific ideas, principles, and theories.

- Apply scientific principles and evidence to provide an explanation of phenomena and solve design problems, taking into account possible unanticipated effects. (HS-PS1-5)
- Refine a solution to a complex real-world problem, based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and tradeoff considerations. (HS-PS1-6)

Constructing Explanations and Designing Solutions

Constructing explanations and designing solutions in 9–12 builds on K–8 experiences and progresses to explanations and designs that are supported by multiple and independent student-generated sources of evidence consistent with scientific ideas, principles, and theories.

- Design, evaluate, and/or refine a solution to a complex real-world problem, based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and tradeoff considerations. (HS-PS3-3)

repeating patterns of this table reflect patterns of outer electron states. (HS-PS1-1)

- The structure and interactions of matter at the bulk scale are determined by electrical forces within and between atoms. (HS-PS1-3)

PS1.B: Chemical Reactions

- Chemical processes, their rates, and whether or not energy is stored or released can be understood in terms of the collisions of molecules and the rearrangements of atoms into new molecules, with consequent changes in the sum of all bond energies in the set of molecules that are matched by changes in kinetic energy.,(HS-PS1-5)

PS1.C: Nuclear Processes

- Nuclear processes, including fusion, fission, and radioactive decays of unstable nuclei, involve release or absorption of energy. The total number of neutrons plus protons does not change in any nuclear process. (HS-PS1-8)

PS2.B: Types of Interactions

- Attraction and repulsion between electric charges at the atomic scale explain the structure, properties, and transformations of matter, as well as the contact forces between material objects. *(secondary to HS-PS1-1),(secondary to HS-PS1-3)*

ETS1.C: Optimizing the Design Solution

- Criteria may need to be broken down into simpler ones that can be approached systematically, and decisions about the priority of certain criteria over others (trade-offs) may be needed. *(secondary to HS-PS1-6)*

Energy and Matter

- In nuclear processes, atoms are not conserved, but the total number of protons plus neutrons is conserved. (HS-PS1-8)

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Connections to other DCIs in this grade-band:

HS.PS3.A (HS-PS1-5),(HS-PS1-8); **HS.PS3.B** (HS-PS1-8); **HS.PS3.C** (HS-PS1-8); **HS.PS3.D** (HS-PS1-8); **HS.LS1.C** (HS-PS1-1) **HS.ESS1.A** (HS-PS1-8); **HS.ESS1.C** (HS-PS1-8); **HS.ESS2.C** (HS-PS1-3)

Articulation of DCIs across grade-bands:

MS.PS1.A (HS-PS1-1),(HS-PS1-3),(HS-PS1-4),(HS-PS1-5), (HS-PS1-8); **MS.PS1.B** (HS-PS1-1),(HS-PS1-5),(HS-PS1-6),(HS-PS1-8); **MS.PS2.B** (HS-PS1-3),(HS-PS1-5); **MS.PS3.A** (HS-PS1-5); **MS.PS3.B** (HS-PS1-5);**MS.ESS2.A** (HS-PS1-8)

Common Core State Standards Connections:

ELA/Literacy -

RST.9-10.7	Translate quantitative or technical information expressed in words in a text into visual form (e.g., a table or chart) and translate information expressed visually or mathematically (e.g., in an equation) into words. *(HS-PS1-1)*
RST.11-12.1	Cite specific textual evidence to support analysis of science and technical texts, attending to important distinctions the author makes and to any gaps or inconsistencies in the account. (HS-PS1-3),(HS-PS1-5)
WHST.9-12.2	Write informative/explanatory texts, including the narration of historical events, scientific procedures/ experiments, or technical processes. (HS-PS1-2),*(HS-PS1-5)*
WHST.9-12.7	Conduct short as well as more sustained research projects to answer a question (including a self-generated question) or solve a problem; narrow or broaden the inquiry when appropriate; synthesize multiple sources on the subject, demonstrating understanding of the subject under investigation. (HS-PS1-3),
WHST.11-12.8	Gather relevant information from multiple authoritative print and digital sources, using advanced searches effectively; assess the strengths and limitations of each source in terms of the specific task, purpose, and audience; integrate information into the text selectively to maintain the flow of ideas, avoiding plagiarism and overreliance on any one source and following a standard format for citation. (HS-PS1-3)
WHST.9-12.9	Draw evidence from informational texts to support analysis, reflection, and research. *(HS-PS1-3)*

Mathematics -

MP.4	Model with mathematics. *(HS-PS1-4),(HS-PS1-8)*
HSN-Q.A.1	Use units as a way to understand problems and to guide the solution of multi-step problems; choose and interpret units consistently in formulas; choose and interpret the scale and the origin in graphs and data displays. *(HS-PS1-3), (HS-PS1-5)*,(HS-PS1-8)
HSN-Q.A.2	Define appropriate quantities for the purpose of descriptive modeling. (HS-PS1-8)
HSN-Q.A.3	Choose a level of accuracy appropriate to limitations on measurement when reporting quantities. *HS-PS1-3),(HS-PS1-5),(HS-PS1-8)*