High School Science Domains Model Course 1-Chemistry-Bundle 1
Where do all the different elements come from?

This is the first bundle of the High School Domains Model Course 1-Chemistry. Each bundle has connections to the other bundles in the course, as shown in the Course Flowchart.

Bundle 1 Question: This bundle is assembled to address the question of "Where do all the different elements come from?"

Summary

The bundle organizes performance expectations around the theme of *elements are formed through nuclear processes*. Instruction developed from this bundle should always maintain the three-dimensional nature of the standards, but recognize that instruction is not limited to the practices and concepts directly linked with any of the bundle performance expectations.

Connections between bundle DCIs

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. Also, each atom has a charged substructure (PS1.A as found in HS-PS1-1). These ideas connect ideas of atomic nuclei and nuclear processes including fission, fusion and radioactive decay (PS1.C as found in HS-PS1-8).

The idea of nuclear processes also connects (PS1.C as found in HS-PS1-8) to the concepts of nuclear fusion in the center of the sun (PS3.D as in HS-ESS1-1) and the idea that the sun is changing and will eventually burn out (ESS1.A as in HS-ESS1-1). The ideas of nuclear processes and nuclear fusion (PS3.D and ESS1.A as in HS-ESS1-1) connect to the concept that other than the hydrogen and helium formed at the time of the Big Bang, nuclear fusion within stars produces all atomic nuclei lighter than and including iron, and the process releases electromagnetic energy. Heavier elements are produced when certain massive stars achieve a supernova stage and explode (ESS1.A as in HS-ESS1-3).

Bundle Science and Engineering Practices

Instruction leading to this bundle of PEs will help students build toward proficiency in elements of the practices of developing and using models, and obtaining, evaluating, and communicating information. Many other practice elements can be used in instruction.

Bundle Crosscutting Concepts

Instruction leading to this bundle of PEs will help students build toward proficiency in elements of the crosscutting concepts of Patterns, Energy and Matter, Scale, Proportion, and Quantity, and Energy and Matter. Many other CCC elements can be used in instruction.

All instruction should be three-dimensional.

Performance Expectations HS-PS1-1 is partially assessable *(it is continued in Course 2: Physics)*	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-PS1-8. **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-ESS1-1. **Develop a model based on evidence to illustrate the life span of the sun and the role of nuclear fusion in the sun's core to release energy that eventually reaches Earth in the form of radiation.** [Clarification Statement: Emphasis is on the energy transfer mechanisms that allow energy from nuclear fusion in the sun's core to reach Earth. Examples of evidence for the model include observations of the masses and lifetimes of other stars, as well as the ways that the sun's radiation varies due to sudden solar flares ("space weather"), the 11-year sunspot cycle, and non-cyclic variations over centuries.] [*Assessment Boundary: Assessment does not include details of the atomic and sub-atomic processes involved with the sun's nuclear fusion.]* HS-ESS1-3. **Communicate scientific ideas about the way stars, over their life cycle, produce elements.** [Clarification Statement: Emphasis is on the way nucleosynthesis, and therefore the different elements created, varies as a function of the mass of a star and the stage of its lifetime.] [*Assessment Boundary: Details of the many different nucleosynthesis pathways for stars of differing masses are not assessed.*]
Example Phenomena	When hydrogen gas is exposed to a lit match, it will explode. We can see the sun. When I get an x-ray, I cannot see the x-rays that are produced.
Additional Practices Building to the PEs	**Asking Questions and Defining Problems** ● Ask questions that arise from examining models or a theory, to clarify and/or seek additional information and relationships. Students could *examine the* **theories of how nuclear fusion processes in the center of the sun** *and can ask questions to seek additional information* [about the long term stability] **of the sun**. HS-ESS1-1 **Developing and Using Models** ● Develop and/or use a model (including mathematical and computational) to generate data to support explanations, predict phenomena, analyze systems, and/or solve problems. Students could *use a computational model* [of] **radioactive decays of unstable nuclei** *to generate data to support explanations [of]* **nuclear processes**. HS-PS1-8 **Planning and Carrying Out Investigations** ● Plan an investigation or test a design individually and collaboratively to produce data to serve as the basis for evidence as part of building and revising models, supporting explanations for phenomena, or testing solutions to problems. Consider possible confounding variables or effects and evaluate the investigation's design to ensure variables are controlled. Students could *plan a* [hypothetical] *investigation* [that would] *produce data to serve as the basis for evidence* [that] **the composition of the nucleus of the atom changes during the processes of fission, fusion, and radioactive decay**. HS-PS1-8 **Analyzing and Interpreting Data** ● Analyze data using tools, technologies, and/or models (e.g., computational, mathematical) in order to make valid and reliable scientific claims or determine an optimal design solution. Students could *analyze data using tools and technologies to make valid and reliable scientific claims* [about the way that] **nuclear fusion processes in the center of the sun release the energy that ultimately reaches Earth as radiation**. HS-ESS1-1

Additional Practices Building to the PEs (Continued)	**Using Mathematics and Computational Thinking** ● Apply techniques of algebra and functions to represent and solve scientific and engineering problems. Students could *apply techniques of algebra and functions to represent and solve scientific problems* [related to the] **radioactive decays of unstable nuclei.** HS-PS1-8 **Constructing Explanations and Designing Solutions** ● Apply scientific ideas, principles, and/or evidence to provide an explanation of phenomena and solve design problems, taking into account possible unanticipated effects. Students could *apply scientific ideas [about the way that]* **the total number of neutrons plus protons does not change in any nuclear process** *[in order to] provide an explanation of phenomena, taking into account possible unanticipated effects.* HS-PS1-8 **Engaging in Argument from Evidence** ● Construct, use, and/or present an oral and written argument or counter-arguments based on data and evidence. Students could *present an oral argument based on data and evidence [about the claim that]* **other than the hydrogen and helium formed at the time of the Big Bang, nuclear fusion within stars produces all atomic nuclei lighter than and including iron, and the process releases electromagnetic energy**. HS-ESS1-3 **Obtaining, Evaluating, and Communicating Information** ● Critically read scientific literature adapted for classroom use to determine the central ideas or conclusions and/or to obtain scientific and/or technical information to summarize complex evidence, concepts, processes, or information presented in a text by paraphrasing them in simpler but still accurate terms. Students could *critically read scientific literature adapted for classroom use to summarize complex evidence* [for the claim that] ***the star called the sun is changing and will burn out over a lifespan of approximately 10 billion years***,. HS-ESS1-1
Additional Crosscutting Concepts Building to the PEs	**Stability and Change** ● Change and rates of change can be quantified and modeled over very short or very long periods of time. Some system changes are irreversible. Students could describe *that some changes* [that involve] **nuclear processes, including fusion, fission, and radioactive decays of unstable nuclei** *are irreversible*. HS-ESS1-8 **Energy and Matter** ● In nuclear processes, atoms are not conserved, but the total number of protons plus neutrons is conserved. Students could explain how *in nuclear processes,* **including fusion, fission, and radioactive decays of unstable nuclei**, *atoms are not conserved, but the total number of protons plus neutrons is conserved*. HS-PS1-8

Additional Crosscutting Concepts Building to the PEs (Continued)	**Scale, Proportion, and Quantity** ● The significance of a phenomenon is dependent on the scale, proportion, and quantity at which it occurs. Students could examine **radioactive decays of unstable nuclei, involving release or absorption of energy** [in order to determine] *the significance of a phenomenon* [based on its] *scale, proportion, and* [the] *quantity at which it occurs.* HS-PS1-8
Additional Connections to Nature of Science	**Scientific Knowledge is Open to Revision in Light of New Evidence** ● Most scientific knowledge is quite durable but is, in principle, subject to change based on new evidence and/or reinterpretation of existing evidence. Students could consider the history of evidence supporting the concept that **stars' light spectra and brightness** [can be] **used to identify compositional elements of stars, their movements, and their distances from Earth** [to describe that] *most scientific knowledge is quite durable but is, in principle, subject to change based on new evidence and/or reinterpretation of existing evidence*. HS-ESS1-3 **Scientific Knowledge Assumes an Order and Consistency in Natural Systems** ● Scientific knowledge is based on the assumption that natural laws operate today as they did in the past and they will continue to do so in the future. Students could gather information about how scientists have formed the idea that **other than the hydrogen and helium formed at the time of the Big Bang, nuclear fusion within stars produces all atomic nuclei lighter than and including iron** *based on the assumption that natural laws operate today as they did in the past and they will continue to do so in the future*. HS-ESS1-3

HS-PS1-1

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.*]

The performance expectation above was developed using the following elements from *A Framework for K-12 Science Education*:

Science and Engineering Practices

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 world(s).

- Use a model to predict the relationships between systems or between components of a system.

Disciplinary Core Ideas

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.
- 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 repeating patterns of this table reflect patterns of outer electron states.

Crosscutting Concepts

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.

Observable features of the student performance by the end of the course:			
1	Components of the model		
	a	From the given model, students identify and describe* the components of the model that are relevant for their predictions, including:	
		i.	Elements and their arrangement in the periodic table;
		ii.	A positively-charged nucleus composed of both protons and neutrons, surrounded by negatively-charged electrons;
		iii.	Electrons in the outermost energy level of atoms (i.e., valence electrons); and
		iv.	The number of protons in each element.
2	Relationships		
	a	Students identify and describe* the following relationships between components in the given model, including:	
		i.	The arrangement of the main groups of the periodic table reflects the patterns of outermost electrons.
		ii.	Elements in the periodic table are arranged by the numbers of protons in atoms.
3	Connections		
	a	Students use the periodic table to predict the patterns of behavior of the elements based on the attraction and repulsion between electrically charged particles and the patterns of outermost electrons that determine the typical reactivity of an atom.	
	b	Students predict the following patterns of properties:	
		i.	The number and types of bonds formed (i.e. ionic, covalent, metallic) by an element and between elements;
		ii.	The number and charges in stable ions that form from atoms in a group of the periodic table;

		iii.	The trend in reactivity and electronegativity of atoms down a group, and across a row in the periodic table, based on attractions of outermost (valence) electrons to the nucleus; and
		iv.	The relative sizes of atoms both across a row and down a group in the periodic table.

HS-PS1-8

Students who demonstrate understanding can:

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.*]

The performance expectation above was developed using the following elements from *A Framework for K-12 Science Education*:

Science and Engineering Practices

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 components of a system.

Disciplinary Core Ideas

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.

Crosscutting Concepts

Energy and Matter

- In nuclear processes, atoms are not conserved, but the total number of protons plus neutrons is conserved.

Observable features of the student performance by the end of the course:			
1	Components of the model		
	a	Students develop models in which they identify and describe* the relevant components of the models, including:	
		i.	Identification of an element by the number of protons;
		ii.	The number of protons and neutrons in the nucleus before and after the decay;
		iii.	The identity of the emitted particles (i.e., alpha, beta — both electrons and positrons, and gamma); and
		iv.	The scale of energy changes associated with nuclear processes, relative to the scale of energy changes associated with chemical processes.
2	Relationships		
	a	Students develop five distinct models to illustrate the relationships between components underlying the nuclear processes of 1) fission, 2) fusion and 3) three distinct types of radioactive decay.	
	b	Students include the following features, based on evidence, in all five models:	
		i.	The total number of neutrons plus protons is the same both before and after the nuclear process, although the total number of protons and the total number of neutrons may be different before and after.
		ii.	The scale of energy changes in a nuclear process is much larger (hundreds of thousands or even millions of times larger) than the scale of energy changes in a chemical process.
3	Connections		
	a	Students develop a fusion model that illustrates a process in which two nuclei merge to form a single, larger nucleus with a larger number of protons than were in either of the two original nuclei.	
	b	Students develop a fission model that illustrates a process in which a nucleus splits into two or more fragments that each have a smaller number of protons than were in the original nucleus.	

	c	In both the fission and fusion models, students illustrate that these processes may release energy and may require initial energy for the reaction to take place.
	d	Students develop radioactive decay models that illustrate the differences in type of energy (e.g., kinetic energy, electromagnetic radiation) and type of particle (e.g., alpha particle, beta particle) released during alpha, beta, and gamma radioactive decay, and any change from one element to another that can occur due to the process.
	e	Students develop radioactive decay models that describe* that alpha particle emission is a type of fission reaction, and that beta and gamma emission are not.

HS-ESS1-1

Students who demonstrate understanding can:

HS-ESS1-1. **Develop a model based on evidence to illustrate the life span of the sun and the role of nuclear fusion in the sun's core to release energy in the form of radiation.** [Clarification Statement: Emphasis is on the energy transfer mechanisms that allow energy from nuclear fusion in the sun's core to reach Earth. Examples of evidence for the model include observations of the masses and lifetimes of other stars, as well as the ways that the sun's radiation varies due to sudden solar flares ("space weather"), the 11-year sunspot cycle, and non-cyclic variations over centuries.] [*Assessment Boundary: Assessment does not include details of the atomic and sub-atomic processes involved with the sun's nuclear fusion.]*

The performance expectation above was developed using the following elements from *A Framework for K-12 Science Education*:

Science and Engineering Practices

Developing and Using Models
Modeling in 9–12 builds on K–8 experiences 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 world(s).

- Develop a model based on evidence to illustrate the relationships between systems or between components of a system.

Disciplinary Core Ideas

ESS1.A: The Universe and Its Stars

- The star called the sun is changing and will burn out over a lifespan of approximately 10 billion years.

PS3.D: Energy in Chemical Processes and Everyday Life

- Nuclear fusion processes in the center of the sun release the energy that ultimately reaches Earth as radiation. *(secondary)*

Crosscutting Concepts

Scale, Proportion, and Quantity

- The significance of a phenomenon is dependent on the scale, proportion, and quantity at which it occurs.

Observable features of the student performance by the end of the course:			
1	Components of the model		
	a	Students use evidence to develop a model in which they identify and describe* the relevant components, including:	
		i.	Hydrogen as the sun's fuel;
		ii.	Helium and energy as the products of fusion processes in the sun; and
		iii.	That the sun, like all stars, has a life span based primarily on its initial mass, and that the sun's lifespan is about 10 billion years.
2	Relationships		
	a	In the model, students describe* relationships between the components, including a description* of the process of radiation, and how energy released by the sun reaches Earth's system.	
3	Connections		
	a	Students use the model to predict how the relative proportions of hydrogen to helium change as the sun ages.	
	b	Students use the model to qualitatively describe* the scale of the energy released by the fusion process as being much larger than the scale of the energy released by chemical processes.	
	c	Students use the model to explicitly identify that chemical processes are unable to produce the amount of energy flowing out of the sun over long periods of time, thus requiring fusion processes as the mechanism for energy release in the sun.	

HS-ESS1-3

Students who demonstrate understanding can:

HS-ESS1-3. **Communicate scientific ideas about the way stars, over their life cycle, produce elements.** [Clarification Statement: Emphasis is on the way nucleosynthesis, and therefore the different elements created, varies as a function of the mass of a star and the stage of its lifetime.] [*Assessment Boundary: Details of the many different nucleosynthesis pathways for stars of differing masses are not assessed.*]

The performance expectation above was developed using the following elements from *A Framework for K-12 Science Education*:

Science and Engineering Practices

Obtaining, Evaluating, and Communicating Information
Obtaining, evaluating, and communicating information in 9–12 builds on K–8 experiences and progresses to evaluating the validity and reliability of the claims, methods, and designs.

- Communicate scientific ideas (e.g., about phenomena and/or the process of development and the design and performance of a proposed process or system) in multiple formats (including orally, graphically, textually, and mathematically).

Disciplinary Core Ideas

ESS1.A: The Universe and Its Stars

- The study of stars' light spectra and brightness is used to identify compositional elements of stars, their movements, and their distances from Earth.
- Other than the hydrogen and helium formed at the time of the Big Bang, nuclear fusion within stars produces all atomic nuclei lighter than and including iron, and the process releases electromagnetic energy. Heavier elements are produced when certain massive stars achieve a supernova stage and explode.

Crosscutting Concepts

Energy and Matter

- In nuclear processes, atoms are not conserved, but the total number of protons plus neutrons is conserved.

Observable features of the student performance by the end of the course:			
1	Communication style and format		
	a	Students use at least two different formats (e.g., oral, graphical, textual, and mathematical) to communicate scientific information, and cite the origin of the information as appropriate.	
2	Connecting the DCIs and the CCCs		
	a	Students identify and communicate the relationships between the life cycle of the stars, the production of elements, and the conservation of the number of protons plus neutrons in stars. Students identify that atoms are not conserved in nuclear fusion, but the total number of protons plus neutrons is conserved.	
	b	Students describe* that:	
		i.	Helium and a small amount of other light nuclei (i.e., up to lithium) were formed from high-energy collisions starting from protons and neutrons in the early universe before any stars existed.
		ii.	More massive elements, up to iron, are produced in the cores of stars by a chain of processes of nuclear fusion, which also releases energy.
		iii.	Supernova explosions of massive stars are the mechanism by which elements more massive than iron are produced.
		iv.	There is a correlation between a star's mass and stage of development and the types of elements it can create during its lifetime.
		v.	Electromagnetic emission and absorption spectra are used to determine a star's composition, motion and distance to Earth.