We are Made of Star Stuff: The Cosmic Origins on the Elements on Earth

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Introduction and Rationale

Carl Sagan once wrote that "the nitrogen in our DNA, the calcium in our teeth, the iron in our blood, the carbon in our apple pies, were made in the interiors of collapsing stars. We are made of star stuff."[1] This quote has always fascinated me for its ability to connect the mundane to the phenomenal. Before I became a teacher, I was a graduate student doing research on plant and soil science. When I began writing my thesis, my advisor told me this: "your science should tell a story." At the time this felt like good solid advice that helped me frame my research in such a way that it could be easily digested by my thesis committee. It wasn't until I became a teacher that I realized the true power of good story-telling in science. With this idea of scientific storytelling, I try to frame my instruction through the lens of a story or phenomenon that students find interesting, challenging, and engaging. Fortunately, the world of chemistry is full of great scientific stories, none more so than the origin of elements that Sagan alluded to in his now famous quote. This story is so intriguing that in his recent book *Astrophysics for People in a Hurry*, Neil deGrasse Tyson refers to it as "the greatest story ever told."[2] Relying heavily on Tyson's storytelling ability, this unit on nuclear chemistry processes uses the cosmic origin of the elements to advance student understanding of nuclear fusion, fission, and the strong nuclear force and to reinforce ideas related to general atomic theory. The unit starts with the Big Bang and the origins of Hydrogen and Helium, and continues through the development of light and heavy elements later on in the history of the universe. Special emphasis is given to the origins of the elements referenced in Sagan's famous "star stuff" quote.

School Profile and Course Specifics

William Penn High School is a public high school in the Colonial School District in New Castle County, DE. It is the only high school in the district and it is the largest high school in the state of Delaware, serving approximately 2,100 students grades 9-12. The school district is mostly suburban, with small portions of the district being considered urban and some being considered rural. In total, the district serves over 10,000 students and expects to increase in size as the New Castle area experiences a revitalization of industry and job growth. African Americans students make up forty-nine percent of the student body. White students make up twenty-five percent and Hispanic students make up twenty-one percent. The remaining five percent is divided between American Indian, Asian, Hawaiian, and Multi-Racial students. The school has seen a growth in the number of English-Language Learners and Special Education students in recent years.

In order to make every student college and career ready, William Penn High School is divided in three college academies: the STEM College Academy, the Humanities College Academy, and the Business College Academy. Each college offers majors, or pathways of study. Incoming students decide on a pathway of study and must earn three consecutive credits related to that pathway as a requirement for graduation. This rebranding has helped the school retain students who would otherwise attend a vocational-technical school. However, William Penn is still committed to providing students with traditional core content in the areas of English Language Arts, Social Studies, Math, and Science. Juniors are encouraged to take Chemistry as their third science credit, especially if they are planning on attending a four-year university.
As more and more students decide to take my course, I find it necessary to provide them with the most engaging content possible. For too many students, Chemistry (and really any science course) is a "have-to-take" instead of a "want-to-take" course. They view the course as overly technical and abstract, and perhaps most upsetting, as unremarkable. I hope to change that with this research-based unit that focuses on the basic question of "where did all of the material on Earth come from?".

Learning Objectives

The overarching phenomenon for this unit is that every element here on Earth came from somewhere else (the synthetic elements notwithstanding). To that end, students learn that light elements Hydrogen (H) and Helium (He) originated some fourteen billion years ago in the Big Bang. They also learn that heavier elements such as iron and gold didn't come about until much later in cosmic evolution as stars progressed through their lifetimes and fused lighter elements into heavier and heavier ones. Students learn about how these different nuclear reactions release energy, with an emphasis on the how and why the reactions proceed the way they do. Finally, students learn that emission and absorption spectra can be used to identify the elements present in distant stars.

These objectives are met through three-dimensional Next Generation Science Standards (NGSS) instruction that includes the following Science and Engineering Practices (SEPs): asking questions, obtaining, evaluating, and communicating information, developing and using models, constructing explanations, and engaging in argument from evidence. I also use the following Cross-Cutting Concepts (XCCs) to structure information in the classroom and to set a purpose for learning: patterns, cause and effect, and energy and matter. This unit addresses several Disciplinary Core Ideas (DCIs), including *The Universe and Its Stars, Nuclear Processes*, and *Energy in Chemical Processes*. Detailed explanations of these DCIs, along with the specific aligned Performance Expectations (PEs) that students meet at the end of the unit are presented in the Appendix A. The Common Core State Standards (CCSS) addressed in the unit are also found in this section.

Content Objectives

Student Prior Knowledge

Nuclear chemistry is a topic that I teach in the third marking period. At this point in the year, students have learned about the basics of atomic theory, the periodic table, conservation of mass, bonding, chemical reactions and equations, and stoichiometry. Specific to this unit, students understand that the atom is made of protons, neutrons, and electrons. They know that the protons and neutrons are located in the nucleus and that the electrons are located in probability zones known as orbitals. They know that neutrons serve as a type of sub-atomic glue that keeps the nucleus stable despite the concentration of positive charges. They know that the periodic table is organized in order of increasing atomic number and that some elements on the periodic table do not have stable nuclei and break down, but that is the limit of their knowledge of nuclear chemistry. Students also understand that the law of conservation of mass dictates that chemical reactions must be mass balanced, and that certain proportions of reactants react to produce specific proportions of products. This unit taps into this prior knowledge both to anchor the unit and to deepen their understanding of prior content.

Unit Content

As Neil deGrasse Tyson puts it, the story of how the universe came to be is the "greatest story ever told." This cosmic origin story serves as the anchoring phenomenon of this unit and is supported by an investigation into the specific origins of Sagan's "star stuff" elements, as well as an examination into differences between nuclear fusion, fission, and decay reactions. Finally, students use the phenomena of emission and absorption spectra to identify the elemental makeup of astronomical bodies.

Particles and Forces of the Early Universe

To understand where the elements on Earth come from, students must first have a general understand of how the universe we know came to be and all the "stuff" it contained then and contains now. They should also have a general understanding of the forces and processes fundamental to this story. Since the forces and processes played a critical role in the development of the subatomic particles, they are presented first. Gravity is an attractive force between objects and is responsible for binding bulk matter.[3] The strong nuclear force is an attractive force over very short distances and is responsible for binding the atomic nucleus.[4] The weak nuclear force operates at very small scales and unlike the strong nuclear force it makes things unstable (this is a good thing), controlling for radioactive decay for example.[5] Electromagnetism is what governs the interactions of charged particles and is responsible for the binding of molecules, and remarkably, the existence of life.[6,7] In fact, if electromagnetism were to suddenly cease to exist, our bodies were to collapse into a pile of goop! The following is a list and brief explanation of the elementary particles that eventually gave rise to the matter students are familiar with. Quarks are elementary particles, meaning that they cannot be further divided and are the building blocks of protons and neutrons. Quarks are the only elementary particles that experience all of the fundamental forces explained above.[8] Leptons, like quarks, are elementary particles, and examples include electrons and neutrinos. But unlike quarks, they do not experience the strong nuclear force.[9] Bosons are elementary quantum mechanical particles that enable the interaction of matter and antimatter, an example of which is the ordinary photon.[10]

Big Bang Nucleosynthesis and the Origin of Light Elements

In the very beginning of the universe all matter was condensed into a single incredibly small point. The temperature of this incredibly dense point was so hot that the point couldn't help but rapidly expand. As the early universe expanded, it cooled ever so slightly. This allowed gravity to unentangle itself from the other forces. This happened when the universe was 10^{-43} seconds old. With more expansion and cooling, the strong and weak nuclear forces and electromagnetism were detangled. This occurred while the universe was between 10^{-33} and 10^{-12} seconds old.[11]

During this time, a great showdown between subatomic particles and their energy (in the form of photons) was occurring. The quarks, leptons and their antimatter relatives, and bosons present at this time were stewing in a cosmic cauldron of subatomic particles at high heat. Because of the complex interactions that occurred during this time in the early universe, a slight asymmetry in the number of quarks and anti-quarks, electrons and anti-electrons, and neutrinos and anti-neutrinos developed. Most of these subatomic particles had an anti-matter partner to cancel each other out, but then the universe cooled below the threshold temperature necessary for these annihilations. At this time, quarks paired together as a result of the strong nuclear force to form heavier subatomic particles known has hadrons and eventually the familiar protons and neutrons. The previously mentioned asymmetry flowed through to the hadrons with cosmic consequences – those hadrons without an antimatter partner survived annihilation. These lone hadrons serve as the ultimate source to all of the matter present in the universe. At this point, the universe is a single second old.[12]

The familiar raw materials for "stuff" have now emerged from the chaos of the big bang. Just one more subatomic particle has yet to become available – the electron. Like the quarks and hadrons previously mentioned, pairs of electrons and anti-electrons annihilated one another in the early part of the universe. But just as an asymmetry emerged for quarks and the hadrons, so it did for electrons. Eventually, this asymmetry became "locked in" as the universe cooled, leaving just about one electron for every proton.[13]

Further cooling leads to the nuclear fusion of protons and neutrons, forming atomic nuclei (note that atoms are not yet formed because electrons still exist freely in the universe). These nuclei include the most common isotope of Hydrogen, ^{1}H, which consists of just a proton. Further fusion produced the other Hydrogen isotopes, deuterium, or ^{2}H (containing a proton and a neutron bound together by the strong nuclear force) and tritium, ^{3}H (containing a proton and two neutrons bound together by the strong nuclear force). Tritium is an unstable isotope and quickly decayed as the strong nuclear force was overcome by this instability. Still more fusion of protons and neutrons, as well as the now existent Hydrogen isotopes, formed the Helium nuclei, or ^{4}He, containing two protons and two neutrons bound together by the strong nuclear force Trace amounts of these nuclei collided and formed the next element on the periodic table, Lithium (Li).[14] These are considered the "light elements," and their emergence occurred when the universe was two minutes old. The long and twisting process that formed these light elements is known as "Big Bang nucleosynthesis."[15]

Stellar Evolution and the Origin of Heavier Elements

As the universe continued to expand and cool over the next *billion* or so years, some matter concentrated into galaxies, where countless numbers of stars were still hot enough to undergo thermonuclear fusion. This fusion is where elements heavier than Lithium come from. Making sense of this process relies on an understanding of the role of gravity; as stars exhaust their supply of hydrogen, the outward push provided by the energy release of hydrogen fusion diminishes, allowing gravity to take over, leading to contraction. As contraction occurs, the temperature inside increased and can lead to fusion of heavier elements. The controlling factor in what elements get fused together is the mass of the star.[16] Low mass stars live incredibly long (and quite interesting) lives because of slow rates of fusion in their core. In fact, most of the low mass stars we know of have not been around long enough for sufficient fusion of heavier elements to have occurred. For this reason, their life cycle is omitted from this unit. In contrast, high mass stars live short lives because their rates of fusion are incredibly high. The rapid fusion of hydrogen leads to temperatures hot enough to fuse elements heavier than Helium towards the end of their lives. This temperature increase occurs as the immense weight of the outer layers bear down on the core.[17]

Of particular important is the creation of nitrogen, calcium, iron, and carbon since they tie back to Sagan's anchoring quote. Carbon is formed inside massive stars when helium nuclei fuse to form an isotope of beryllium, ^{8}Be. However, this isotope is unstable and quickly decays back into separate helium nuclei. Only if another helium nuclei fuses with ^{8}Be can carbon form. Some of this carbon is further fused into oxygen, but the unfused material is spread through the universe by ever present stellar winds when the star explodes at the end of its life cycle.[18] Nitrogen arises from a complex chain of reactions involving proton captures and beta decays between ^{12}C, ^{13}N, ^{13}C, ^{14}N, ^{15}O, ^{4}He, ^{17}Ne, and ^{17}O that ends up producing a single ^{14}N atom and an alpha particle.[19] The calcium in our teeth and the iron in our blood arise in similarly sized stars even later on their life cycle; as the stars run out of their hydrogen they start collapsing and eventually explode in an event called a supernova. This event provides sufficient temperature for fusion of such elements. Moreover, the force of the explosion overcomes the gravity that normally provides a check on this process. Because of the rarity of these events in the universe, elements heavier than iron are exceedingly rare compared to those previously discussed.[20] The gas clouds that result from these supernovae events are now free to travel the universe and interact via the laws of physics. However, just a few of these events is not enough to explain how our elements on Earth came to be.[21]

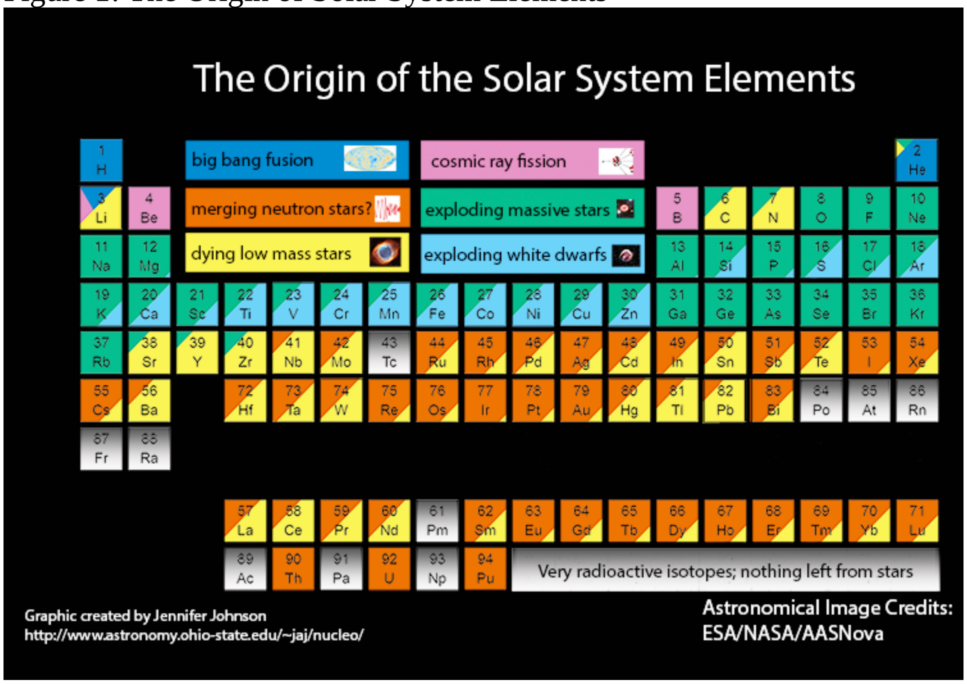
Cosmic Recycling

To accumulate the quantity of the elements our planet as takes many iterations of high mass stars living and dying (like successive generations of mosquitoes). The process by which elements have been dispersed across the universe is a combination of the stellar nucleosynthesis and the laws of conservation mass and energy. As massive stars progress through their life cycle, nuclear fusion produces heavier and heavier elements up to a point. The energy produced by these fusion reactions propped up the stars against the force of gravity. But as heavier and heavier elements form, the energy output from those reactions diminishes. Eventually, the force of gravity reigns supreme and causes the star to implode, forming a dense neutron star. This implosion eventually leads to a massive explosion where further nuclear reactions transform existing elements and spread them throughout the universe.

Scientists have recently used NASA's Chandra X-Ray telescope to examine the supernova remnant Cassiopeia A, which resulted from a supernovae event just 330 years ago. Data obtained from the telescope show that this event ejected silicon, sulfur, calcium, iron, oxygen, carbon, nitrogen, phosphorous, and hydrogen into interstellar space.[22] Processes like these are theorized to have occurred repeatedly throughout the universe, with some of that material ending up as the raw material for our own solar system and eventually as the sun and planets we know today. Due to the laws of conservation of mass and energy, no truly *new* matter or energy has been made in these processes – the creation of photons in stellar processes is a quirky example of this. All of the matter that gets spewed across the universe originated in the Big Bang. Figure 1 below depicts the stellar origins of the elements on the periodic table.[23] This figure is an excellent summary of the origins of our elements.

It is especially interesting to note that many elements arise from separate processes, while some originate in only one way. Oxygen, the most abundant element on Earth, was only produced by exploding massive stars. However, Lithium was produced in the aftermath of the Big Bang, through cosmic ray fission, and in dying low mass stars. It is clear from this figure that these origins are not perfectly understood, as is represented by the question mark associated with elements formed in merging neutron stars and the elements that are grayed out and not attributed to a specific process. This speaks to the nature of science as a process that relies on data to continually improve upon theories or develop new ones, a hallmark of NGSS.

Figure 1: The Origin of Solar System Elements



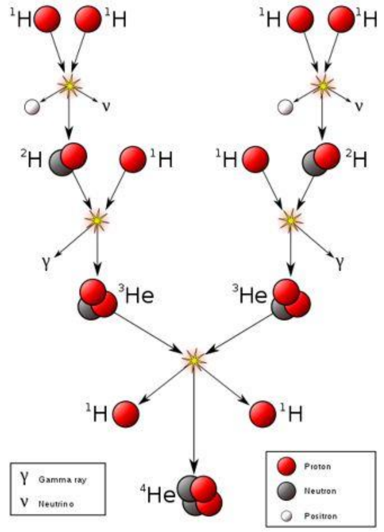
Since the majority of elements on the periodic table are heavier than iron, they must originate in processes other than those previously described. In fact, they arise from a relatively simple neutron capture process that can occur under different conditions, as is evident from the diversity of the origins of elements heavier than iron. As neutrons collide with elements some of them stick and decay into protons, thereby increasing the atomic mass and creating new, heavier elements. Successive iterations of this process create heavier and heavier elements. The conditions necessary for this occur in several stellar events, including exploding massive stars, merging neutron stars, exploding white dwarfs, and dying low mass stars.

Nuclear Reactions

Much of the material can be modeled with basic chemical equations, which are models for how atoms and/or subatomic particles react and rearrange in new ways. The synthesis of both light and heavy elements are examples of nuclear fusion reactions. These reactions model what happens when collisions between nuclei result in the formation of a new element. For example, the fusion of hydrogen nuclei into helium that occurs in stars as or massive as our sun can be modeled with a series of reactions called the proton-

proton chain, shown below in diagram[24] and equation form in Figure 2. In Step 1, two pairs of hydrogen fuse together to form deuterium and release a neutrino (v_e) and a positron (e^+). The positron emitted in this initial step quickly decays into energy. In Step 2, the resulting deuterium nuclei fuse with other hydrogen to form two unstable helium nuclei and release gamma rays. In Step 3, the unstable helium nuclei fuse to form a stable helium nucleus or alpha particle, as well as two hydrogen nuclei.

Figure 2: Fusion of Hydrogen into Helium



$$2\,x\,({}^{1}_{1}H \;+\; {}^{1}_{1}H \;\rightarrow\; {}^{2}_{1}H \;+\; \nu_e \;+\; e^{+})$$

$$2\,x\,({}^{2}_{1}H \;+\; {}^{1}_{1}H \;\rightarrow\; {}^{3}_{2}He \;\; {}^{0}_{0}\gamma)$$

$${}^{3}_{2}He \;+\; {}^{3}_{2}He \;\rightarrow\; {}^{1}_{1}H \;+\; {}^{1}_{1}H \;+\; {}^{4}_{2}He$$

Fusion is not the only nuclear reaction. Although nuclear fission is not a process tightly associated with the cosmic origins of elements, it is still nonetheless important for students to understand its relationship to nuclear processes. Fission is the breaking apart of a nucleus into two or more parts. These parts can be various combinations of nuclei and subatomic particles. Like fusion reactions, fission releases energy, thought the amount is considerably less. Fission reactions in chemistry are often discussed as they relate to nuclear energy and radioactive decay. In a nuclear reactor, fission is typically achieved by bombarding uranium pellets with an initial neutron. The uranium absorbs the neutron, but then decays into lighter elements. This decay process also involves the release of kinetic energy, gamma radiation, and free neutrons. Those free neutrons go on to be absorbed by more uranium, creating more fission in a chain reaction. The kinetic energy released by this reaction generates massive amounts of heat, which can then be used to turn water into steam. The steam passes through a turbine, which is connected to a generator that converts the mechanical energy into electricity.

Radioactive decay is a less dramatic but still fascinating process whereby unstable nuclei break down into more stable products and release comparatively smaller quantities of energy than the fusion and fission reactions previously discussed. Alpha, beta, and gamma decay are examples of types of radioactive decay reactions and are represented in Figure 3 a, b, and c, respectively.

Figure 3: Radioactive Decay Reactions

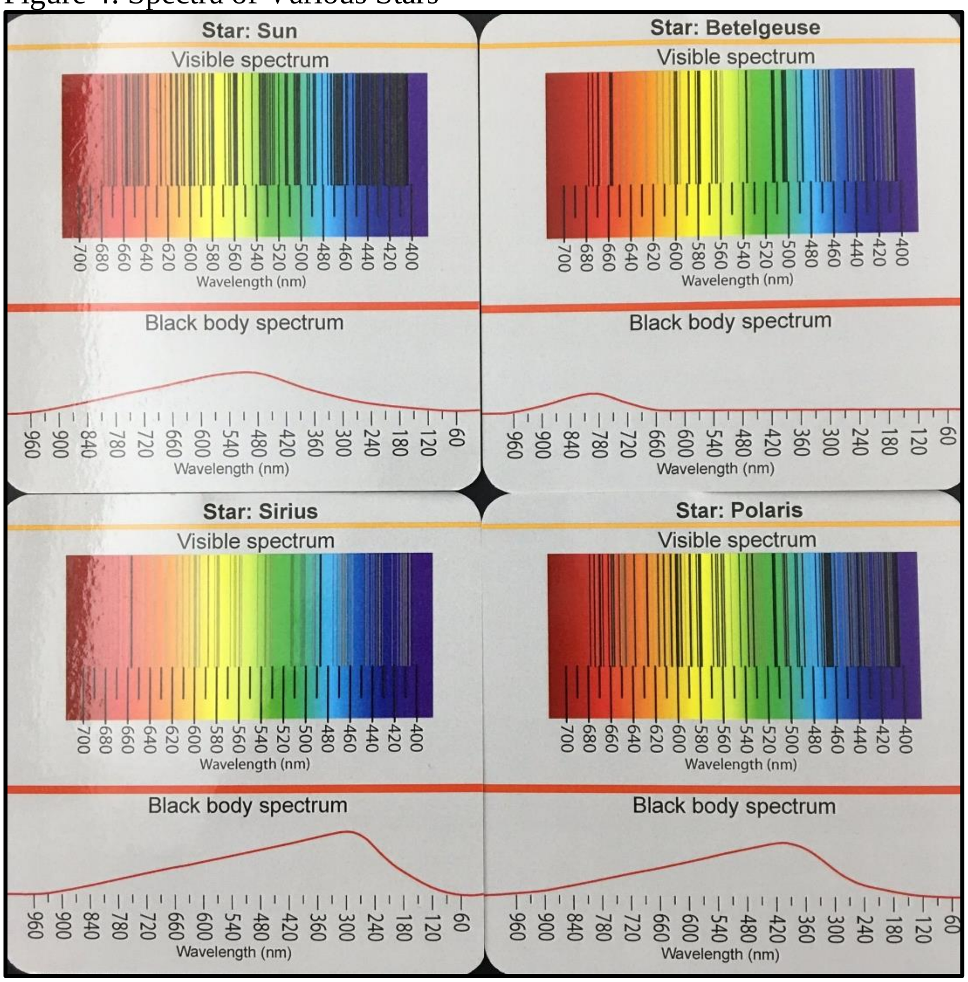
a) Alpha Decay:	${}^{A}_{Z}X$	$\rightarrow$	${}^{A-4}_{Z-2}Y$	$+$	${}^{4}_{2}He$
	Parent Material		Daughter Material		Alpha Particle
b) Beta Decay:	${}^{A}_{Z}X$	$\rightarrow$	${}^{A}_{Z+1}Y$	$+$	${}^{0}_{-1}\beta$
	Parent Material		Daughter Material		Beta Particle
c) Gamma Decay:	${}^{A}_{Z}X^{*}$	$\rightarrow$	${}^{A}_{Z}X'$	$+$	${}^{0}_{0}\gamma$
	Parent Material		Daughter Material		Gamma Particle

Alpha decay occurs when an unstable isotope, known as the parent material breaks down into a lighter element, referred to as the daughter material and helium nucleus, known as an alpha particle. The daughter material is necessarily four atomic mass units lighter than the original element because of this. Beta decay occurs when a neutron inside the parent material nucleus converts to a proton and ejects a beta particle. For this reason, the atomic mass of the atom does not change significantly (there is a slight change due to the difference in the mass of the proton and neutron, but not enough to change the mass number), but the atomic number increases by one. Beta decay is the process by which two protons decay into a proton and a neutron in the proton-proton chain described above and presented in Figure 2 in the discussion of fusion reactions. Gamma decay occurs when the unstable nucleus of the parent material ejects excess energy in the form of a gamma ray, leaving the existing nucleus intact but in a more stable form.[25]

Spectra

One of the most interesting stellar phenomenon having to do with chemistry are light spectra. These spectra are categorized as continuous, emission, or absorption. Continuous spectra appear like rainbows covering a broad range of wavelengths without interruption and are produced from hot and dense objects that emit their own light such as stars. Emission spectra arise from cooler, less dense objects such as gas clouds that emit their own light but at specific wavelengths depending on conditions. These appear as bright colored lines against a black background. Absorption spectra arise when a cool and less dense object lies between a hot denser one, and appear as generally continuous with dark interrupting lines where light has been absorbed.[26] What is so powerful about spectra is that they can be used to determine the conditions and composition of stellar bodies. Elements emit and absorb light at specific wavelengths and in specific patterns. With the right technology, determining the elemental makeup of stellar objects is essentially a giant matching game. This phenomenon is depicted in Figure 4 below. In this figure, four different stars' spectra are presented: our sun, Betelgeuse, Sirius, and Polaris. The different spectra tell vastly different stories about each star. Our sun has a temperature around 5900 K and appears yellowish to the naked eye. Betelgeuse is a distinctly reddish star in the Orion constellation and has a temperature of 3,500 K. Sirius is actually a binary star system is located in the Canis Majoris constellation. This system appears as the brightest in our night sky and has a temperature of almost 10,000 K. It appears bluish to the naked eye. Polaris, otherwise known as the "north star" is located in the Ursa Minor constellation and has a temperature of 7200 K. It appears white to the naked eye.

Figure 4: Spectra of Various Stars



The temperatures and colors have a fundamental connection to the elemental composition of the star, which as described above can be determined by looking at spectra. It is no coincidence that the cooler stars (our sun and Betelgeuse) have emission spectra with peaks closer to the longer wavelength (less energetic) side of the light spectrum as compared to the warmer Polaris and Sirius. At this point in its stellar life cycle, Betelgeuse has consumed all of its hydrogen and begun fusing heavier elements according to processes described above. These include carbon, oxygen, neon, magnesium, sodium, and iron.[27] Our sun has yet to enter into this phase of its life and still is primarily composed of hydrogen and helium. The presence of other elements' signatures in the spectrum is due to a skewing based on mass. Our sun is roughly 75% hydrogen, 23% helium, and only 2% "other." However, the higher mass of the "other" elements translates to more electrons being available to move between quantum states, causing them to over-appear in terms of their true abundance. Polaris demonstrates significantly abundant carbon, nitrogen, and oxygen,[28] indicating that its temperature is sufficient for fusion of heavier elements via the processes described above. Finally, the Sirius system shows the high levels of hydrogen indicating plenty of material available for fusion. It is also shows the presence of carbon, oxygen, and other metallic elements whose existence pre-dates the stars and was already present in the gas cloud from which the star system formed.[29]

There are two difficulties with observing spectra. The first is that the overlapping of absorption lines from different elements muddle the spectra, but the fixed distances between those spectra are strictly related to certain elements, thus solving the problem. Knowing the elemental makeup of stellar objects can help discern the conditions present in that particular part of the universe because as discussed earlier, certain elements only arise under certain conditions. The second is that spectra get distorted as they travel through space because of the Doppler effect, which compresses or elongates wave depending on whether the source is moving towards or away from the viewer. [30] But again, the distances between the absorption lines respond to the Doppler effect in specific patterns, allowing the problem to be overcome.

Strategies

In order to instill in students as understanding that science is not merely a body of isolated facts but a systematic process for acquiring new knowledge, we as teachers must incorporate real aspects of the scientific process into the classroom. The National Research Council (NRC) lays out a framework for how to ensure that under NGSS students have authentic scientific experiences in their classrooms even as they learn the bodies of knowledge of the specific sciences. When implemented properly, this framework of SEPs "supports a better understanding of how scientific knowledge is produced and how engineering solutions are produced…help[ing] students become more critical consumers of scientific information."[31] This focus on process, according to the NRC, improves upon previous practices that reduced scientific procedures to isolated aims of instruction, rather than a vehicle for developing a meaningful understanding of the true scientific concept. Additionally, the process of discovering scientific truths allows students to engage in the types of critical thinking necessary to understand why the right is answer is right, and perhaps more importantly, why the wrong answer is wrong.

This emphasis on developing a strong evidence foundation supports student understanding of fundamentals of scientific truths instead of the traditional model of asking for rote memorization of facts that didn't serve students well in their post-secondary education or in the workforce. In fact, the NRC designed the NGSS model with this specifically in mind, citing that in the past "rather than learning how to think scientifically, students [were] generally being told about science and asked to remember facts," whereas the new standards focus on student understanding by "linking concepts and practices that build coherently over time throughout K–12, thereby helping to ensure that students who meet the NGSS will be prepared to succeed in science courses in both 2- and 4-year institutions."[32] The presentation of content in this unit is phenomena-based, another hallmark of NGSS that helps students deepen their content understanding. In this unit, I employ several traditional teaching strategies, NGSS SEPs and XCCs, and some novel strategies to help my students understand the nuclear processes behind the cosmic origins of the elements. The teaching strategies used in this unit include, but are not limited to: Close Reading, Blended Learning, Use of SEPs and XCCs, and Partnered Summaries.

Close Reading

Students are presented with an abridged version of Tyson's "greatest story every told" as a way to introduce the topic. This account of the origins of the universe, which was written for an audience without an advanced knowledge of physics and astronomy, provides a low-stakes entry point into the content for students. They engage in a "close read" of this text. This strategy requires students to engage with a text several times, resulting in a thoughtful critical analysis focused on specific details or patterns in the text. Depending on student needs, close reading may best be accomplished when paired with a graphic organizer. More advanced students may be able to create their own notes when provided with prompting and structure, and the most advanced students may be able to use this strategy in isolation. Specific to this text, students focus on the details of subatomic particles and the patterns in asymmetry that led to the development of matter instead of a universe full of nothing but photons.

Blended Learning

Students use our online learning management system Schoology throughout this unit. Schoology allows me to house resources students may find helpful as they progress through the unit and it helps me differentiate by providing students with different resources depending on their academic needs. In addition, it allows students to complete assignments ranging from readings to discussions to quizzes online, reducing the need for paper copies. Rubrics can be embedded into assignments on Schoology making it easier for me to provide students with constructive feedback in a timely manner. I think it is important for students to experience the blended learning approach since learning management systems like Schoology are almost ubiquitous on college campuses across the country.

Engaging Students using SEPs and XCCs.

Students use the following SEPs in this unit: “obtaining, evaluating, and communicating information,” “developing and using models,” “constructing explanations,” and “engaging in argument from evidence.” The XCCs that students make use of in this unit include “patterns,” “cause and effect,” and “energy and matter.” Specific DCIs and PEs are presented in the Appendix entitled “Implementing District Standards.” Students obtain, evaluate, and communicate information as they investigate the origins of the elements on Earth. This requires the use of the cause and effect XCC. They develop and use models to help trace the origins of light elements to the beginning of the universe and heavy elements to stellar processes. They also use models as they demonstrate the differences in energy release from various nuclear reactions. Students use these models as they construct explanations and argue from evidence for the origins of various elements. Additionally, students identify patterns in the spectra of different stars to construct explanations for their elemental composition. In addition to establishing and identifying patterns, the use of such models requires that students focus on the relationship between energy and matter, both of which are key XCCs. Three-dimensional assessment tools are used in order to accurately assess student mastery of content at strategic points during the unit and at the end of the unit.

Partnered Summaries

Students use the partnered summarization strategy to complete formative assessments throughout this unit. This strategy is designed to help students better translate their conceptual understanding of content into written explanations. Student A dictates their initial answer to student B, who writes it down or records it. Student B then dictates their answer to student A, who writes it down or records it. The students then reevaluate the questions and work together to refine their answers in a more accelerated version of peer review. After revision, students work together to turn their summaries into a creative story for submission as a summative assessment.

Classroom Activities

Snowball Questions

Students are introduced to the unit by reading Sagan’s “star stuff” quote and generating a question based on the text. Once they write their question, students crumple the paper and throw it across the room. Students then have to pick up someone else’s piece of paper and share out the question on it. From this master list of questions, students identify similarities between questions, group them together, and refine and revise them (with my guidance) until they develop a set of questions that set a purpose for learning throughout the unit. This is a variation of a questioning technique designed to engage low-participation students that has been adapted to have students generate instead of answer the question. This technique is an excellent low-stakes way of having students engage in the "Ask Question" NGSS SEP. The refined and revised questions are used to guide student learning for the rest of the unit.

From "The Greatest Story Ever Told" to the Origins Periodic Table

Students engage in a close read of an abridged version of Tyson's "greatest story ever told" to begin answering the guiding questions from the snowball activity. As they read the first time, they focus on the complex technical vocabulary. On the second time through, students apply that vocabulary to they develop initial models for how the vast array of subatomic particles came together to start forming the familiar universe. Once their models are complete, they read a final time to create a timeline of the critical stellar events that lead to the formation of our solar system. Students are given a very basic graphic organizer to keep track of the information as they read. This activity satisfies the obtain, evaluate, and communicate information SEP. At this point, they are introduced to the periodic table presented in Figure 1 and tasked with identifying the origins of each of the elements in the "star stuff" quote. More specifically, students are asked to identify any patterns they observe in the model and to connect those patterns back to the text they read.

Examining Nuclear Processes

Now that students have a basic understanding of the cosmic origins of elements, they can dive into specific nuclear processes, including the proton-proton chain and the various nuclear decay reactions. Students are first given models of nuclear fusion, fission, and radioactive decay in the form of a card sort. Using only the cards and any prior knowledge, students are asked to match the model to the correct term. Once students have a handle on the basic processes, they are given the different nuclear decay reactions – alpha, beta, and gamma. They are then tasked with examining the proton-proton chain model and writing mass-balanced reactions for each step in the chain. They do this by using chalk markers and writing their equations right on their lab benches. This allows students to work in collaborative pairs and easily check their work with me before moving on.

Once students have complete and correct equation sets they record them in their notebooks. This process requires that students first develop and then use models. Students complete the activity by constructing an explanation for how nuclear reactions release energy that references the equations they generated, their base definitions of different nuclear processes, and the role of the strong and weak nuclear forces. Students submit their answer in Schoology where I grade it with using a rubric. Students are encouraged to view their feedback and resubmit up to three total submissions if they receive a grade they are unhappy with.

Using Spectral Line Cards

As discussed above, spectra can be used to analyze the elemental composition of stellar objects. Specific to this unit, students are given a set of spectral cards for twenty common elements and then the spectra for the four stars discussed above – our sun, Betelgeuse, Polaris, and Sirius. This activity is essentially a detailed matching game, as students are looking for signatures in the element cards that match up with the stars. In all cases there are multiple elements that students are looking for. In addition to determining what elements are present in each of the stars, students are asked to put the stars in order from youngest to oldest by considering the information presented in the abridged Tyson text that they started the unit with.

These activities require students to engage in argument from evidence. Collaboration between student groups is encouraged during the matching phase of the assignment. Ultimately students submit their answers in Schoology as part of a quiz. As in the previous assignment, students have multiple attempts to achieve a perfect score. This encourages them to go back and analyze the cards in greater detail if they don't get it right the first time.

Scientific Storytelling

As a summative assessment, students first engage in a partnered summary of the stellar processes that produced most of the common elements. Students are presented with the prompt and first asked to generate a response independently. Then they dictate their response to a partner, who records it *as they understand it*. Students reverse roles and then begin revising and refining their answers collaboratively by referring to texts, notes and online content. Once students have agreed to a revised answer, they are tasked with transforming what is likely a rather technical, dry and un-engaging response into a scientific story in the vein of the story told by Tyson.

Students can choose from a variety of formats to convey their story, including but not limited to a creative writing piece, a children's book, comic strip, podcast, or short video. Students submit their work to Schoology where it is graded using a built-in rubric. This summative assessment satisfies the "engage in argument from evidence," "construct explanations" and "communicate information" SEPs while also requiring that students identify patterns, understand the cause and effect of stellar processes, and the fundamental relationship between matter and energy, all of which are critical XCCs.

Appendix A

Next Generation Science Standards

Disciplinary Core Ideas

ESS1.A: *The Universe and Its Stars* – other than the hydrogen and helium formed at the time of the Big Bang, nuclear fusion within stars produces all the atomic nuclei lighter than and including iron. Heaver elements are produced when certain massive stars achieve a supernova stage and explode. Stars' light spectra can be used to identify compositional elements of stars.

PS1.C: *Nuclear Processes* – fusion, fission, and radioactive decays unstable nuclei involve the release or absorption of energy. The total number of neutrons and protons does not change in any nuclear process.

PS3.D: *Energy in Chemical Processes* – nuclear fusion processes in the sun release the energy that ultimately reaches Earth as radiation

Performance Expectations

HS-ESS1-3: *Communicate ideas about the way stars, over their life cycle, produce elements*. Students learn that the mass of the star dictates its life cycle and that different life cycles are responsible for the production and/or recycling of elements. Students use spectral lines as evidence for the existence of different elements in different stars.

HS-ESS1-1: *Develop a model based on evidence to illustrate the role of nuclear fission in the core to release energy*. Students learn how the energy released by nuclear fission is related to changes in the nuclei of atoms involved in the reaction.

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*. Students are challenged with writing the various nuclear reactions after being given textual explanations of the process. Students also demonstrate the quantitative differences in the energy released by each type of reaction.

Common Core State Standards

CCSS.ELA-LITERACY.RST.11-12.2: students determine the central ideas of a text and summarize complex concepts presented in the text

CCSS.ELA-LITERACY.RST.11-12.9: students synthesize information from a range of sources into a coherent understanding of a phenomenon

CCSS:ELA-LITERACY.WHST.11-12.1A: students present precise and knowledgeable claims, establish significance for their claims, distinguish their claim from alternative or opposing ones, and use logical sequencing to their argument in support of their claim.

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