Nuclear Fusion in the Cosmos and the Chemistry Curriculum

Alex Leed
George Washington Carver High School of Engineering and Science

Overview

This unit is designed to connect stellar evolution to a standard high school chemistry curriculum. Throughout the school year, the lessons contained within this unit are intended to fit within a traditional chemistry course. Much of the chemistry content covered in a standard introductory curriculum often bypasses defining and framing science as an ongoing, exploratory endeavor. The focus of this unit seeks to unite fundamental astronomical curiosities to core chemistry content through an analysis of stellar evolution, specifically, nuclear fusion.

Fusion is a driving force of the cosmos, shining light on our world by converting mass into energy. Fusion also gives birth to the study of chemistry, as all atoms heavier than hydrogen and helium are forged in stars. Taking an astronomical approach to chemistry's matter enables budding chemists to build connections between course content and our universe while gaining a humbled worldview.

For this unit, nuclear fusion and stellar evolution are taught at the outset of the year to provide a foundational introduction to science. As the year progresses, connections are made between nuclear fusion and the chemistry content when applicable, often at the culmination of a traditional unit.

Just as stardust is sprinkled throughout our world, these fusion lessons are intended to be sprinkled throughout the chemistry curriculum. While the lessons within this unit could serve as a stand-alone entity, a sporadic implementation throughout the year seeks to maintain a strong sense of balance between piquing student interest in astronomy and becoming fluent in the basic chemistry content.

This unit and the lessons and activities contained within are intended for students at a high-performing magnet high school in the School District of Philadelphia. Many of these lessons and activities could be implemented in any introductory physical science course at any level, in any school. These lessons seek to serve as hooks to engage student curiosity in the scientific process and to liven up a yearlong science class that can at times become bogged down by abstract technicalities. By exploring topics beyond the standard curriculum but vital to our basic understanding of the universe, nuclear fusion processes unite chemistry content to the cosmos and make abstract learning come alive to students.

Rationale

While the established high school curriculum is well suited to prepare students for an introductory college-level chemistry course, there are few activities that simply seek to excite students in science at the outset. This unit intends to ask students the driving questions that are at the forefront of our scientific expedition toward understanding our universe and our place in it. Too often, students are taught the applied sciences without a foundational scientific literacy. In other words, students may be taught the intricacies and elegance of chemistry without first understanding the purpose and nature of science.

No matter how fantastic the demonstrations, labs, inquiry-based and collaborative activities can be, at a certain point, some students grow tired of the particular subject at hand. Therefore, connections from specific chemistry content can be tied directly to astronomical topics to incite interest. This serves to unify what would traditionally be treated as different subjects and to frame scientific exploration more generally. Without further complicating a course that tends to be one of the more abstract classess students take in their high school careers, we examine stellar evolution in layman terms. The concepts in this unit are profound enough without developing another set of particle vocabulary and symbols for students to learn.

Science is at its core structured inquiry; however, oftentimes science is taught through content delivery. While the established chemistry curriculum can be lauded for its rigorousness in both the breadth of topics covered and the depth in which they are examined, this may turn students away from exploring a career in science by snuffing out any passion for it in their youth. Without touching upon the fundamental quest for understanding about how nature operates beyond the main chapters in a typical textbook, students can get lost in technicalities without understanding science’s underlying exploratory nature.

Students oftentimes enjoy the conceptual aspects of the physical sciences, in particular topics and theories that defy common sense. However, most introductory courses circumvent many of the topics that students find to be the most intrinsically motivating to explore and rather focus heavily on drilling and practicing the basics. While facilitating competency in these essential areas will still be the main emphasis throughout the school year, adding supplemental lessons and activities that extend beyond introductory material found in textbook pages will enhance student engagement and learning and hopefully turn students on to science rather than away from it.

Objectives

In this unit, students will learn about nuclear fusion and star processes, uniting the original science of astronomy to the specific subject of matter and its transformations on earth.

This unit breaks down into five major subtopics connecting stellar evolution to chemistry with a focus on nuclear fusion. The five subtopics are (1) How Do You Know (HDYK): A Brief History of Time, and the Evolution of our Periodic Table through Nuclear Fusion, (2) Measuring Mass to Energy Transformations through $E=mc^2$, (3) The Life Cycle of Average, Low Mass Stars and the Proton-Proton Chain Reaction, (4) The Life Cycle of Medium to High Mass Stars and the CNO-Cycle, and (5) Supernovae & Stardust Everywhere.

The specific objectives for all of the lessons vary, but the overall purpose of the unit is that the *content* of the cosmos connections to chemistry provide the *context* through which this course can be made real to students and provide them with a more profound worldview. The link to astronomy makes abstract chemistry real-world science.

While the big bang theory is explored, the emphasis is placed on the examination into the evidence supporting it. While the celestial processes of the life cycles of stars are analyzed, the emphasis is placed on how these stellar processes – their frequency, their life spans, etc. – equate to the abundance of elements in our terrestrial world. In other words, as we move forward in any lesson within an astronomy framework, we connect back to why chemistry is meaningful and relevant.

Within the first lesson, How Do You Know (HDYK): A Brief History of Time, and the Evolution of our Periodic Table, our main learning objectives beyond simply using the original science to frame its processes include students being able to: explain the evidence supporting the big bang theory, explain the premise of nuclear fusion and how our modern day periodic table of the elements was forged in stars. As the year progresses, these concepts are revisited in greater depth.

In the second lesson, Measuring Mass to Energy Transformations through $E=mc^2$, our main learning objectives include students being able to state the relationship between mass and energy and to interpret and use nuclear equations to calculate the energy produced in various nuclear processes involving transformations of matter.

In the third and fourth lessons, students are focusing more specifically on describing the life cycles of low- and higher-mass stars. The hope is to introduce students to the proton-proton chain reaction that fuels small main-sequence stars as well as the carbon-nitrogen-oxygen cycle that fuels large blue stars. Without analyzing all of the complexities, but rather simply connecting fusion's role in stellar evolution and the production of the elements in our world and bodies, the chemistry curriculum is not made more difficult but rather more relatable.

In the final unit, Supernovae and Stardust Everywhere, students learn not only about how and where elements heavier than iron are produced, but trace the abundance of elements on earth to their stellar births. This unit seeks to drive home that all of the material we have any experience dealing with was created in stars and also to unify all of the fusion concepts together to create the matter that we examine in chemistry.

Strategies

This unit will be inquiry-based, with an array of lessons and activities that use as many modalities as practically possible for student learning. From problem-based activities to teacher-led whole class discussions, we examine nuclear fusion and the life cycle of stars in a variety of ways, shining light on different perspectives of our physical world and this chemistry course. These lessons and activities are best suited for student-centered classrooms where students are free to explore, promote, and strategically defend their own ideas.

Each lesson is written to follow a seven-step lesson plan, beginning with general probing questions, or the anticipatory set. Following these brain-primers, each lesson begins with inquiry-based direct instruction. This direct instruction involves a teacher using a line of logic and questioning to lead students on their own discovery about an abstract process. The teacher poses profound, higher-level questions that promote thinking, curiosity, awe, and even confusion. The teacher provides just enough information to pique interest before asking the next question. Once students begin wondering about the topic/concept, it is time for them to begin their own exploration toward building connections between big ideas in astronomy to specific content in chemistry through the guided inquiry activities.

Classroom Activities/Lesson Plans

Lesson One: How Do You Know (HDYK): A Brief History of Time through Fusion and the Evolution of our Periodic Table

<u>Scope/Sequence</u>

This lesson serves as a fundamental core of the first unit for the year: what is science? The stellar evolution of our universe is introduced and explored very generally; however, while the specifics of the content are introductory, the evidence for these processes is emphasized. We discuss that light travels at a constant rate. Far away objects sent their light long ago. This means telescopes can *see* back in time. As the discussion proceeds, and the evidence is revealed, the scientific process is examined through the lens of the big bang theory. This lesson fits into the first unit of the year and lays the foundation for which connections between chemistry and the cosmos are made throughout the remainder of the course.

As noted above, the first lesson serves as the primary content for the first unit of the year. This unit serves as the introduction to science overall, but also provides the context to connect chemistry content to the larger scientific process and astronomy throughout the year. This unit is designed to serve as a way of looking at science as an ongoing quest for understanding how our world operates. It sets an inquiry-based tone for the year as we examine content through an exploratory lens, always focusing on the evidence for our theories rather than simply stating the findings.

Anticipatory Set

The first essential question of the year appears as a pre-class/do-now activity during one of the first days of the school year. The question is simple, yet it serves as a driving force for many of the following lessons and activities. The question is: What process is the energy source in our sun and in all stars?

Direct Instruction

Of all of the cosmos connection lessons, this instruction will be much longer and more involved than any of the lessons that follow. With the aid of a colorful slideshow riddled with many graphics and just a few words, the teacher takes the class through a journey, highlighting several profound happenings in our universe. We begin by asserting that the universe had a beginning, before which our equations and theories break down. From this birth, aided by a graphical history of time, begins a process of stellar evolution that continues to this day. The formation of every element heavier than hydrogen is fused in the thermonuclear furnace of stars. Furthermore, we analyze the evidence supporting the big bang theory.

Guided Inquiry

Go Fusion! – This activity is very simple. It is hard to make nuclear fusion tangible, so the teacher creates element playing cards. Students are provided a single card to begin and a bank of cards exists in the center of the classroom. The abundance of cards should be mostly hydrogen, then some helium, a very few lithium, beryllium, and boron, then more carbon, nitrogen and oxygen, and finally just a few versions of elements leading up to iron. Samples of element playing cards are provided in the appendix, containing atomic number, element symbols, and mass number.

The activity begins after the students are introduced to stellar evolution and nuclear fusion. First, students are each handed a single element, every student except one receives hydrogen. The other student receives helium. Students slowly realize that they almost all have helium. The teacher reminds them that this is the atomic makeup of our universe shortly after the big bang.

The teacher commands, “Fuse!” Students find more hydrogen and make helium. They then take their hydrogens and put them in the element card bank and take a helium card and stand together. This part of the activity is purposefully low in excitement. The teacher announces “Isn’t this fusion game *exciting?!*” When the students give a lackluster response, the teacher explains that we are lucky that most stars are this boring. More massive stars have more matter and therefore gravity, higher temperatures and they fuse heavier elements. But these massive stars burn hotter and faster and die fast. If our sun’s fusion were any more interesting than this awful game, it would have burned out a long time ago.

The class plays again, this time mimicking a big hot blue star with more matter, gravity, heat and a different fusion process. Every student receives a helium card. Students start fusing together making heavier elements. Given the limited cards for elements 3 – 5, students begin making carbon, nitrogen, and oxygen, the elements for life. When most students are holding CNO elements, the teacher pauses the class to explain that these are the building blocks of organic chemistry. We are made of organic molecules. We are the dust of these big hot stars that fused heavy elements and died long ago. The carbon-nitrogen-oxygen cycle is discussed, but is not the focus of this lesson or activity; rather, the emphasis is exciting students with fusion basics and our universe's evolution to the elements in our bodies.

The class plays another round, fusing everything up to iron. After iron, no cards exist, and once the only cards that are in play are iron, the game ends and the room explodes in a metaphorical supernova. Students are then asked to clump the cards together like stardust in chaotically unordered sets of cards mimicking modern day entropy.

Independent Practice

Following the year's first summative assessment, students are given an assignment to write the history of our universe through the perspective of nuclear fusion as a children's book. The basic challenge is for them to put the scientific concepts into language on their own terms and to explain them as simply as they can, thus flipping the role of student and teacher, promoting mastery.

Closing

Superlative children's stories assignments are read aloud to the class.

Extensions

The topics covered within this lesson are revisited several more times throughout the school years, as laid out in the lessons and activities below.

Lesson Two: Mass and Energy Transformations in $E=mc^2$

Scope/Sequence

This lesson falls directly after the completion of unit two: an introduction to matter. Students learn about classifying matter, physical and chemical properties and changes, the concept of the mole, Avogadro's number, and the conservation laws among other introductory chemistry topics. This is an ideal moment to connect the chemistry curriculum to the nuclear fusion through mass to energy transformations.

Anticipatory Set

Students are asked about the laws of conservation and energy separately, then provided the Einstein's famous equation, $E=mc^2$, and probed to extrapolate its meaning. Without clarifying these questions, the teacher retraces the topic back to the conservation laws to begin the direct instruction.

Direct Instruction

During this inquiry-driven instruction, the teacher begins by asking students about the conservation laws that are covered in the second unit of the traditional chemistry curriculum. Once these laws are revisited, the teacher introduces the topics of electricity and magnetism. (This moment could serve as an opportunity to perform elementary electric or magnetic demos in a chemistry classroom, although that will not be discussed here.) Investigations into electricity and magnetism are explored, as is the ultimate triumph of their marriage, producing our understanding of electromagnetism. Likewise, the interplay between mass and energy are famously described through Einstein's most famous equation. The students are provided the equation's units and tasked with solving several problem sets with varying levels of difficulty in the section below, as they calculate amounts of energy produced by first determining mass lost in a series of nuclear equations.

Guided Inquiry

The calculations included in this lesson involve math and nuclear processes at the simplest and introductory senses regarding mass and energy transformations in stars. These problems are easily tweaked to be made more complicated and to revisit these concepts later in the year. Every equation provided includes each substance's molar mass. Students are provided with the nuclear equations for (1) the synthesis of a helium nucleus from 4 hydrogen atoms, (2) the synthesis of a carbon nucleus from 3 helium atoms, (3), the synthesis of an oxygen nucleus from 4 helium atoms. Again, these equations are simplistic and the calculations are easy. The purpose is to simply provide the students with some sense of understanding $E=mc^2$ that is not explored by the traditional curriculum.

Independent Practice

Students work independently to calculate the exact energy that their bodies could produce if they were to in some hypothetical laws-of-nature-breaking way spontaneously fuse the atoms in their body to from mass to pure energy. This task is silly and unrealistic, but every student begins with a different weight in pounds and will obtain a slightly different answer.

Closing

Two more examples of fusion reactions are briefly covered by the teacher in the form of nuclear equations at the front of the class. The concepts and the math are explicitly reinforced.

Extensions

(1) Measuring the mass that is converted to energy in the sun in a day: Students explore the mass of hydrogen fused into helium in a day and project those numbers onto the molar masses in the nuclear equation to determine the energy produced by our sun.

(2) Using the daily output of energy for the sun, we can calculate how much mass it loses per day, and estimate when it will run out of hydrogen to fuse.

(3) In lessons three and four, $E=mc^2$ can be used to calculate the energy produced from the proton-proton chain reaction and the carbon-nitrogen-oxygen cycle, respectively.

Lesson Three: The Life Cycle of Average, Low-Mass Stars & the Proton-Proton Chain Reaction

Anticipatory Set

Revisiting the original stellar evolution unit from the beginning of the year, this lesson delves slightly deeper. Essential questions include: What elements make up our sun? What element is the most abundant on earth, in our solar system, in the universe?

Direct Instruction

The teacher reintroduces the overall life cycle of a star, and the two general pathways. The focus of this lesson is on the life cycle of the main sequence stars like our sun, through the proton-proton chain reaction, again, in simple terms that seek to unite core chemistry concepts to the cosmos without making the material unnecessarily more demanding or abstract.

Guided Inquiry

The elemental playing cards from the Go Fusion! card activity outlined above are redistributed. This time, the teacher does not give students commands to perform. Rather, this activity challenges students to collaborate in small groupings to create the rules of a game that could teach younger students about hydrogen to helium fusion in main-sequence stars. For this learning activity, the process that the students go through to begin to create rules is more important than the anticipated product. By discussing possible ways to create rules to teach about the fusion processes in main sequence stars, the students are tricked into explaining star processes to one another.

Independent Practice

Individual students write a justification for each rule that their group created to teach hydrogen to helium fusion and the life cycle of main sequence stars.

Closing

Student groups share out their rules for their activities and the class votes on the best game. The teacher provides the winning team a reward.

Extensions

(1) When discussing isotopes, connections can be made of the various hydrogen isotopes involved in the p-p chain. Students use algebra to determine missing numbers of protons and neutrons from various nuclear equations.

(2) During the next lesson, the CNO-cycle and the life of massive stars is explored, students can use any down-time or the teacher can implement class-time to allow the students to create the rules of a similar game to teach CNO-cycle concepts.

Lesson Four: The Life Cycle of Medium to High Mass Stars & the CNO-Cycle

Anticipatory Set

The following questions serve as the introduction to this lesson. These questions may either appear on the screen of a projector to begin a class period, on a small piece of paper to hand to students when they turn in an exam, or through a combination of the two as guided notes. The questions are: What color of flame is hottest on a Bunsen burner? What color of star is the hottest? Would you expect a hot star to live longer or shorter than a less hot star?

Direct Instruction

The teacher calls back to the fact that blue flames are the hottest and that blue stars are hotter and fuse heavier elements than main-sequence stars. Students are then asked what elements are at the center of organic life. (*CHNOPS*) The teacher leads the students through the progression of a blue stars life through the viewpoint of the atoms fusing within it.

Guided Inquiry

Students analyze their bodies' own chemical composition and investigate where and how those organic atoms are fused. Students are implored with connecting the abundance and significance of the organic elements on earth to their production in the carbon-nitrogen-oxygen cycle that fuels medium to high mass stars. An expected learning outcome is that the complex carbon-based molecules responsible for life on earth owe their creation and abundance to the CNO-cycle in medium to high mass stars.

Independent Practice

Students write the history of the atoms in their bodies. They begin as hydrogen, but quickly find themselves in a blue star. From there, the student writings vary. Creativity is encouraged and rewarded. The students relate the stellar evolution of organic elements to the atoms inside them.

Closing

A few exemplary student atomic histories are read aloud to the class.

Extensions

As noted above, the Go Fusion! cards can be used to facilitate student mastery of the CNO-cycle. Additionally, Einstein's equation relating mass to energy transformations can be used to quantitatively describe the CNO-cycle.

Lesson Five: Supernovae and Stardust Everywhere

Anticipatory Set

Students are asked to recall the violent deaths of the biggest hottest stars. Students are then asked to answer the following: What is the heaviest element that is fused under normal nuclear fusion processes? In what event are the elements heavier than this "fusion threshold" element produced?

Direct Instruction

Students are reminded that all elements heavier than hydrogen and helium were fused in stars in the time since the big bang. The overall life cycle of main-sequence stars is reviewed through the proton-proton chain reaction. The life cycle of medium- to high-mass stars is reviewed through the carbon-nitrogen-oxygen cycle. Finally, the brilliant death of high-mass stars is reviewed through supernovae. Students are reminded that all elements heavier than iron are produced during this explosion. Following this brief review, the teacher leads the students through a class-wide inquiry into several higher-level probes: (1) The frequency of low- vs. high-mass stars in the universe. (2) The mass comparisons of low- vs. high-mass stars. Finally, (3) the life expectancy of low- vs. high-mass stars. From these three comparisons, students will connect the abundance of heavy elements on earth given the low occurrence of high-mass stars to their comparatively enormous masses and shorter life cycles. This Q&A discussion transitions nicely into the guided inquiry activity.

Guided Inquiry

In this activity, students are encouraged to work collaboratively to explore the abundance of elements on earth and relate their terrestrial quantities to the celestial processes that form them. These eight elements are: (1) helium, (2) carbon, (3) aluminum, (4) iron, (5) copper, (6) molybdenum, (7) gold, and (8) uranium. The specific data that students must collect are the (A) estimated abundance of each element of earth, (B) estimated abundance of each element in the universe, and (C) the stellar process that forges these atoms.

Independent Practice

Following the above elemental abundance activity, the students submit their group's findings and are charged with writing a reflective paragraph summarizing the content that they learned. They are then specifically and individually tasked with repeating the procedure with three different elements: (1) hydrogen, (2) oxygen, and (3) silver, to determine their abundance on earth, the universe, and the star process that creates them.

Closing

The teacher showcases exceptional student work asking students to explain, promote, and justify their strategic reasoning.

Extension

Students are challenged to create digital media projects to teach the fusion relevant material covered in the chemistry course as a culminating project.

Annotated Bibliography/Resources

Bellini, G. (2014). Neutrinos from the primary proton-proton fusion process in the sun. *Nature*, 512, 383-86.

This very brief article gives a detailed overview of the proton-proton chain reaction. It provides nuclear equations for simple to complex interactions between subatomic particles involved in p-p chain reactions.

Hawking, Stephen. *The Illustrated Brief History of Time*. Bantam, 1996.

This classic staple provides any secondary science teacher with a united perspective of our understanding of the universe, how we know what we do and how we came to verify that. It also contains hundreds of beautiful and detailed illustrations so a student could pick up the book, examine one illustration, and need to explore further.

Hawking, Stephen. *The Universe in a Nutshell.* Bantam, 2001.

This book explains much of the same content as A Brief History of Time, but follows a non-linearly complicated trajectory from chapter to chapter, thus providing an easier read. This book can also be sought out for exceptionally advanced students bitten with the astronomy bug.

Scilla, Degl'Innocenti. (2016). Introduction to stellar evolution. *Journal of Physics: Conference series*, 703.

This article provides a succinct yet thorough overview of the life cycle of stars and how we interpret the information they send us. The articles discusses various types of stars and the processes that drive their luminosity, specifically the different fusion processes involved their required temperatures.

Wiescher, M., J. Gorres, and H. Schatz. (1999). Break-out reactions from the CNO cycles. *Journal of Physics: Nuclear and Particle Physics*, 25.

This article provides an in-depth analysis of fusion, from the proton-proton chain reaction to the triple-alpha process. The reading is dense, but provides a rich overview of the entire fusion cycle in higher mass stars as well as great diagrams, figures and explanations.

Student Resources

PhET: Free Online Physics Simulations. < https://phet.colorado.edu/ >

These interactive tutorials can provide students with the most realistic immersion into nuclear processes. From alpha and beta decay to nuclear fission to simply building an atom, these tutorials supply students with as close to real-world nuclear reaction laboratory experiences as practically possible. Register as a teacher for free, and gain access to lesson materials.

Appendix: Go Fusion Playing Card Templates

1 H 1.00794	1 H 1.00794	1 H 1.00794	1 H 1.00794	1 H 1.00794
2 He 4.002602	2 He 4.002602	2 He 4.002602	2 He 4.002602	2 He 4.002602
3 Li 6.941	4 Be 9.012182	5 B 10.811	6 C 12.0107	6 C 12.0107
6 C 12.0107	7 N 14.00674	7 N 14.00674	7 N 14.00674	8 O 15.9994
8 O 15.9994	8 O 15.9994	9 F 18.9984032	10 Ne 20.1797	11 Na 22.989770
12 Mg 24.3050	13 Al 26.981538	14 Si 28.0855	15 P 30.973761	16 S 32.066
17 Cl 35.4527	18 Ar 39.948	19 K 39.0983	20 Ca 40.078	21 Sc 44.955910
22 Ti 47.867	23 V 50.9415	24 Cr 51.9961	25 Mn 54.938049	26 Fe 55.845

Standards

The School District of Philadelphia is making the shift to the PA Common Core set of standards. The college and career ready standards in Language and Mathematics that are supported by this unit are as follows:

Writing:

- Write informative/explanatory texts to examine and convey complex ideas and information clearly and accurately through the effective selection, organization, and analysis of content.

- Use technology, including the Internet, to produce and publish writing and to interact and collaborate with others.

- Conduct short as well as more sustained research projects based on focused questions, demonstrating understanding of the subject under investigation.

- Gather relevant information from multiple print and digital sources, assess the credibility and accuracy of each source, and integrate the information while avoiding plagiarism.

- Draw evidence from literary or informational texts to support analysis, reflection, and research.

Speaking and Listening:

- Present information, findings, and supporting evidence such that listeners can follow the line of reasoning and the organization, development, and style are appropriate to task, purpose, and audience.

- Make strategic use of digital media and visual displays of data to express information and enhance understanding of presentations.

Language:

- Acquire and use accurately a range of general academic and domain-specific words and phrases sufficient for reading, writing, speaking, and listening at the college and career readiness level; demonstrate independence in gathering vocabulary knowledge when encountering an unknown term important to comprehension or expression.

Standards of Mathematical Practice:

- Make sense of problems and persevere in solving them.
- Reason abstractly and quantitatively.
- Construct viable arguments and critique the reasoning of others.
- Use appropriate tools strategically.

PA Core Standards Aligned System (SAS):

CC.3.5:
- Reading Informational Text: Students read, understand and respond to informational text – with emphasis on comprehension, making connections among ideas and between texts with focus on textual evidence.

PA Science and Technology Standards:

3.2.C.A6:
- Compare and contrast scientific theories and laws.
- Know that both direct and indirect observations are used by scientists to study the natural world and universe.
- Identify questions and concepts that guide scientific investigations.
- Formulate and revise explanations and models using logic and evidence.
- Recognize and analyze alternative explanations and models.
- Examine the status of existing theories.
- Interpret results of experimental research to predict new information, propose additional investigable questions, or advance a solution.
- Communicate and defend a scientific argument.

3.2.C.A3:
- Describe the three normal states of matter in terms of energy, particle motion, and phase transitions.
- Compare and contrast nuclear fission and nuclear fusion.