Elements and You

Summary

Students are introduced to the periodic table and the concept of atomic elements. The group discusses how all material in the Universe is composed of elements and that the atom is the smallest particle that still has the physical and chemical properties of any given element. As an exercise in statistics, the students participate in a counting experiment in which they sample a 'Universe bead mix' (where each bead color represents a different element present in the Universe) to estimate the overall composition of the Universe. They compare their findings of the Universe's overall composition with the composition of various different objects in the Universe that are represented by mixtures of rice, beans and other dried goods in jars. Finally, students are introduced to the idea that hydrogen fusion creates heavier elements inside a star.

Objectives

- ★ To understand what an element is
- ★ To become familiar with a periodic table and common elements
- ★ To determine the most abundant elements in the Universe
- ★ To learn how heavier elements form from fusion
- ★ To gain knowledge of the processes in the interior of a star
- ★ To explore the concept of composition in the context of astronomical objects
- ★ To explore how elements link us to stars

Materials

- ★ Plain pound cake *
- ★ Knife to cut the pound cake
- ★ Gloves or wet wipes for safe food handling
- ★ Napkins or paper plates to hold the pound cake (enough to serve the group, if allowed)
- ★ Example(s) of pure elements (sheet of aluminum, copper tubing, elemental density cubes, etc.) **
- ★ Large display copy of a periodic table **
- ★ Periodic table handouts for each student (both color and black and white examples can be found following the activity)
- ★ Large bowl to mix the bead mix
- ★ Multi-colored pony beads (or other beads of the same size and weight; see preparatory procedure for colors and amounts)
- ★ Small scoops or Dixie cups
- ★ Handouts or transparency of Universe of Beads key ***
- ★ Universe of Beads worksheets
- ★ Bottle activity ingredients (see preparatory procedures for amounts): white and brown rice, split peas, black beans, white beans, pinto beans, red beans, red lentils, and brown lentils ****
- ★ 8 oz plastic bottles with lids
- ★ Funnel for pouring ingredients into bottles

- ★ Tape for sealing bottles
- ★ Handouts or transparency of Bottle Key ***
- ★ Clay (or Sculpey, for a more permanent model) of 5 or more different colors to represent different elements – enough to create the stellar core and several small balls for each element (see preparatory procedure for amounts)

** Choose one with the fewest artificial ingredients so that the students will recognize the ingredients. This activity will work best if you choose something that is as uniform looking as possible. Other food items such as brownies (brownium) or bananas (bananium) can also be substituted for the pound cake. If you are unable to have food in your classroom, or if food allergies are a concern, you can do this activity with a sponge (spongium), styrofoam (styrofoamium), Play-Doh (play-doium), or some other substance that can be easily cut or broken, and with easily recognizable properties. If you make a substitution of any kind, keep in mind that it must be dense enough to not fall apart when cut.*

*** Information about where to purchase this can be found in Appendix B.*

**** You can laminate these handouts if you want to use them with other groups. You only need to hand out one of these sheets per group of students.*

***** Food and allergy note: these items remain in a closed bottle for the entirety of the activity and thus are not handled by the students, nor are they loose in the classroom. If this is still an issue, we are working to develop a non-food alternative.*

Background

Atom: The smallest particle of an element that still has the characteristics of that element

Element: A *material* consisting of all the same atoms

Molecule: Two or more atoms of the same or different elements that are chemically bound together

Compound: A *material* consisting of atoms of two or more different elements that are chemically bound together

The copper/other pure element used here is an element, while the pound cake is a compound since it is made of many different substances (or elements).

We are made of star stuff!

The lightest elements (hydrogen, helium, and some lithium) were created in the Big Bang. Then, as the Universe cooled, matter clumped together to form stars.

Stars are big balls of hot gas, mostly hydrogen. They generate energy by converting lighter elements to heavier elements by a process called "nuclear fusion" in their cores. Elements are made of atoms, and atoms are composed of a central "nugget" called the nucleus that is composed of protons and neutrons. One or more electrons surrounds this nucleus. An element is characterized by the number of protons in its nucleus, that is, different elements have different numbers of protons in their nuclei. For example, hydrogen has one proton, helium has two protons, oxygen has eight protons, and so on.

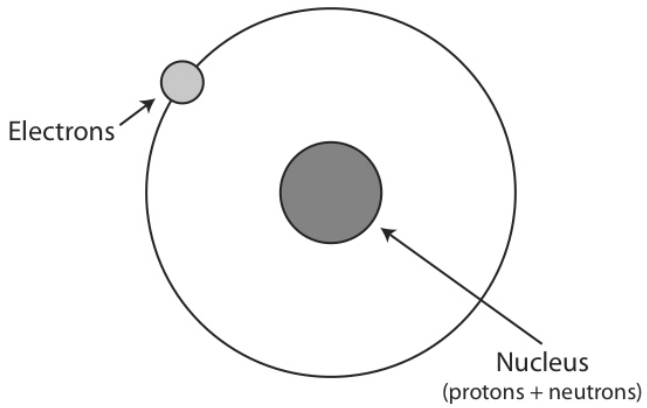
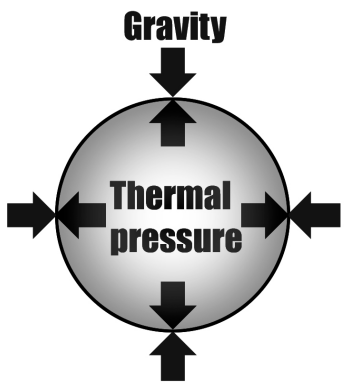


Diagram of an atom

Nuclear fusion is the process by which the nuclei of two atoms come together and merge, forming a new nucleus. Since an element is defined by the number of protons in the nucleus of each of its atoms, nuclear fusion invariably converts one or more elements into a totally different element when the protons of the two original nuclei are combined in the new nucleus. During most of a star's life, energy is generated by the fusion of hydrogen nuclei (consisting of just one proton and no neutrons) into helium nuclei (consisting of two protons and two neutrons). It takes four hydrogen nuclei to produce one helium nucleus (and, in the process, two of the protons undergo a conversion into neutrons). The energy generated by the fusion flows outward and counterbalances the inward pull of gravity on the star. Stars spend the majority of their lives with these two forces in balance.

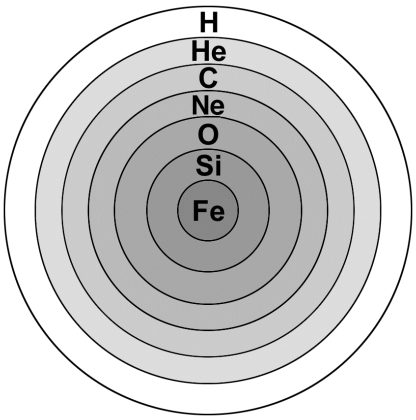


The balance of forces within a star.

Stars go through a cycle of "birth" and "death," but the timescales involved are much longer than what we associate with living things (millions or billions of years). Young stars are born in a cloud of gas and dust called a nebula. Particles inside these nebulae collide and clump together to form stars. When enough material has accumulated, the pressure and temperature in the core exceeds a critical threshold and fusion begins. A star is born!

The lifecycle of a star depends on how massive it is. All stars start by fusing hydrogen into helium in their cores, but eventually this fusion ends. If the star has sufficient mass, it goes on to the next stage of fusion, where helium is fused into carbon. More massive stars can do this because their higher temperatures and pressure in their cores allow them to fuse more and heavier elements than their less-massive counterparts. In stars like our Sun, the fusion process ends after fusing helium, but in massive stars the process continues to fuse more elements. Depending on its mass, the star may go through successive periods in which carbon is fused into neon, neon into silicon, and silicon is fused into iron. The sequence of nuclear fusion stops with iron, even in the most massive of stars, because fusing iron into the next element requires an <u>input</u> of

energy rather than resulting in a release of energy. At this point, the star has developed an "onion-shell" structure in which an iron (Fe) core is surrounded by a ring of silicon (Si), then a ring of oxygen (O), a ring of neon (Ne), a ring of carbon (C), a ring of helium (He), and finally a ring of hydrogen (H), as illustrated.



A diagram illustrating the "onion" structure of a star.

Though the formation of elements heavier than iron requires more energy than a star has, the explosion of a star at the end of its life (a supernova) provides the energy necessary to make the much heavier elements. A supernova explosion also throws all of the elements created in that star out into space where new star systems can use them in their own formation processes. These explosions will be discussed in more detail in the activity called Supernova Explosions.

We know the Sun is a later-generation star because it has those heavier elements (we know that from spectroscopy, among other ways). So the elements in our bodies - like carbon, hydrogen, nitrogen, oxygen, and trace amounts of many others - came from the explosion of earlier stars!

Preparation

1. Universe of Beads: ~15 minutes

   In this activity, each element is represented by a different color of bead. Mix the ingredients ahead of the planned activity in a large bowl. Using the same, or larger, size "measuring cup" for preparation as the students will each have during the activity. Mix the following:

   - 50 scoops of clear beads (to represent 90% abundance of hydrogen in Universe)
   - 5 scoops of light blue beads (to represent 9% abundance of helium)
   - 3 scoops of dark blue beads (to represent 0.08% abundance of oxygen)
   - 2 scoops of black beads (to represent 0.03% abundance of carbon)
   - 1 scoop of green beads (to represent 0.01% abundance of nitrogen)
   - 1 scoop of orange beads (to represent 0.01% abundance of neon)
   - 1 scoop of pink, purple, red, and yellow beads in roughly equal amounts (to represent 0.01% abundance of magnesium, silicon, iron, and sulfur together)

2. Bottle Activity: ~4 hours

In this activity, each element is represented by a different food. Prepare mixtures of these items according to the recipes below for the sources we are modeling. Note that these abundances are *by volume*, not weight. Because these items are approximately the same size, using dry measurements (volume) is very roughly equivalent to measuring numbers of atoms.

The number of bottle sets that you make is somewhat discretionary. The more sets you have, the smaller the group students can work in. 3-4 students working together is ideal. For a group of 25 students, that would be 6-8 bottle sets.

Place each mixture into a separate jar or bottle (these recipes are scaled for 8 oz. plastic bottles, available from many online suppliers). In each set, label each bottle with a number correlating to a specific source, and then record the key for later identification (ex. #1 = supernova). Cap all the jars/bottles. Taping shut the bottles when you are done can help to ensure that no food items escape into the classroom if this is a concern, as well as discourage students from opening the bottles, which may disrupt the activity and ruin the bottles for use at future events.

For each source, the recipes give the abundance (in %) and the volume of each element required in dry-measured cups (C), tablespoons (tbsp), and teaspoons (tsp). Note that the percentages may not add to 100% due to rounding amounts and excluding less significant elements.

Carbonaceous Chondrite (a type of meteorite)

O	44.3%	5 tbsp + 2 tsp	Brown Rice
H	30.8%	4 tbsp	White Rice
Mg	6.2%	1 tbsp	Red Beans
Si	5.5%	1 tbsp	Pinto Beans
Fe	4.9%	2 tsp	Red Lentils
C	4.2%	2 tsp	Black Beans

Supernova Remnant

O	42.2%	5 tbsp	Brown Rice
Fe	36.7%	4 tbsp + 3 tsp	Red Lentils
C	11.1%	1 tbsp + 1 tsp	Black Beans
Si	3.7%	2 tsp	Pinto Beans
Mg	2.8%	2 tsp	Red Beans

Human Body

H	61.6%	1/2 C	White Rice
O	26.3%	3 tbsp + 1 tsp	Brown Rice
C	10.0%	1 tbsp	Black Beans
N	1.5%	1 tsp	Brown Lentils

The Sun

H	92.1%	1/2 C + 3 tbsp + 1 tsp	White Rice
He	7.8%	4 tsp	Green Split Peas

Earth's Atmosphere

N	78.0%	1/2 C + 1 tbsp	Brown Lentils
O	21.0%	2 tbsp + 2 tsp	Brown Rice
Ar	1.0%	1/2 tsp	White Beans

3. Clay star: ~2 hours to assemble

For this demonstration, we use the following color correlations as an example, but the colors can be changed. Regardless of the colors you use, it is easier to see the layers if adjacent colors contrast with each other.

Clay Color	Element
Red	Hydrogen
Yellow	Helium
Orange	Carbon
Green	Oxygen
Blue	Neon

Make the clay star in 5 color-coded layers.

- Start by making a ball about 2 inches in diameter using the blue clay
- Completely cover that ball with a layer of green clay about an inch thick
- The next layer will be orange in color with a shell thickness of ~ 1 inch
- The next layer will be yellow in color with a shell thickness of ~ 2 inches
- The next layer will be red in color with a shell thickness of ~ 2-3 inches

Example clay core model using our example colors

You may make this model out of Sculpey instead of clay if you would like a more permanent version. If you pursue this course, you should cut this model in half before baking it. This step can wait until the demonstration if you are using clay, but we found that pre-cutting the ball as the layers were added can be helpful for the demonstration because clay can be very hard to cut through.

This Sculpey model uses different colors for the same effect.

Make extra fusion demonstration small clay balls

- 4 red ~ 1 inch in diameter for hydrogen
- 5 yellow ~ 1.5 inches in diameter for helium
- 1 orange ~ 2 inches in diameter for carbon
- 1 green ~ 2.5 inches in diameter for oxygen
- 1 blue ~ 3 inches in diameter for neon

Clay core with extra element balls

Some portions of this preparation can be very time-intensive. It goes faster with friends, so have a party to make bottles and clay balls!

Activity

Demonstration: Poundcakium (approximately 15 minutes)

Ask the students if they know what elements are. We are going to do a demonstration to explore this concept.

We'll start this activity with a pound cake. Show it to the students and tell them that we are going to pretend we have just discovered this new element. We'll call it "Poundcakium." Ask the students what some of its characteristics are. Let the students answer. They will hopefully come up with answers about it being all one flavor, texture, and color (at least on the inside).

Next, cut the loaf of poundcakium in half. Ask the students what we have now? We still have poundcakium, albeit two pieces of it. Does it still have the same flavor, texture and color as poundcakium? Yes, because it is still poundcakium.

Sliced poundcake.

Now cut it in half again, and once again ask the student what we now have. Once again, it's still poundcakium, with all the same characteristics. Continue this process for one or two more cuts. The students should get the idea that no matter how many times the poundcakium gets cut in half, it remains the same.

If you were to continue to cut it in half, you would eventually get to single crumbs. Ask the students if you would have destroyed or created any poundcakium as you did this? Does it become something else other than poundcakium by cutting it? The answer is no.

This is the very basis of the idea of elements. An element is a material made of atoms of a single type, like carbon or hydrogen. Elements are the building blocks for matter - everything that we can see and touch.

You can now have volunteers hand out pieces of the pound cake to the students as a snack while you continue the discussion.

Discuss with the students how many things are made of more than one ingredient. Ask them what they think the ingredients are in pound cake (which you used to represent poundcakium). Let them answer, then read through the pronounceable ingredients on the pound cake label. Tell the students that flour, sugar, milk, and eggs (or whatever the recognizable ingredients are) are made of elements such as carbon and hydrogen.

Ask them to come up with examples of elements that they know from everyday life – things around your house or room? What about in Earth's atmosphere? Allow them to answer. If they need prodding, suggest categories, such as 'things around us in the room,' 'things in your home,' 'metals used for money or jewelry,' etc. Guide the conversation, but let it go where they take it. (examples: aluminum in soda cans, silver/gold in jewelry, diamonds (carbon), iron in steel, hydrogen and oxygen in water - "lead in pencils" should be corrected to "carbon (in the form of graphite) in pencils")

Pass out the individual copies of the periodic table, and put up the poster of the periodic table. Point out carbon and hydrogen. See what else the students recognize. Are there things on the periodic table that surprise them? Ask them what their favorite element is.

Hold up one of the pure element examples from your density cube set (or an alternate example of a pure element such as a copper tube).

An example of a copper pipe.

Tell them that copper (or aluminum or iron, etc.) is an element that occurs naturally on Earth.

Say that copper is very hard to cut, but in theory we could do the same thing we did with poundcakium. If we could cut the copper in half, would it be a different substance? No, it's still the same thing, with all of the same properties. Since copper is an element, no matter how many times it's cut it in half, we will always be copper.

We could cut the copper in half and in half again until all we were left with was a single atom of copper. An atom is the smallest piece of copper, or any element, that we can have that still has the same properties as the original piece.

An element is a chemically pure substance composed of atoms of a single type. Elements are the building blocks for all matter, everything that we can see and touch. Copper is an element that we can find naturally occurring on Earth. All copper atoms are the same.

Refer back to the periodic table. The elements known to scientists are cataloged in this table. The elements in the rows and columns of the tables have common traits or characteristics. Each element is different from the next in many measurable ways. Some are solid, some are gas, and some are liquid. They each have a unique mass. They can all be described with qualities like hardness or softness.

Some elements are common to us in their pure form, like silver or gold. Some are common to us in compounds like salt (NaCl) or water (H_2O).

Ask if poundcakium is an element or a compound. Wait for responses with explanations. They should answer that we were pretending that it was an element for our purposes.

Now ask if the pound cake is an element or compound. Again, wait for responses with explanations. The answer is that it is a compound, because it's made of more than one element.

Activity: Universe of Beads (approximately 15 minutes)

Ask the students what they think is the most common element in the Universe? Let the students give some guesses.

Ask what they think we would have if we were able to go out and grab a handful of space particles. Let the students give some guesses. Tell them that we will explore these questions through an activity.

Tell the students that you have a Universe of Beads, which is a model of the percentages of all the elements in the Universe. Each student will take a random scoop of the Universe of Beads, and will count or estimate how many of each bead color (element) they have. A white napkin or piece of paper provides a good surface for the student to sort and count their sample, and allows for easier re-collection of the beads after the activity.


Two girls sort their element beads.

Give the students 5-10 minutes to get a scoop and to inventory their ingredients.

Make a tally on a white board, easel pad, or overhead projector of the counts from each student. Observe which color they had the most of. See how many of them had hydrogen? Helium? Carbon? How about Oxygen? Nitrogen? Iron?

Most, if not all, students should have more beads representing hydrogen than any other element. They should also mostly have helium represented in their sample. After that, everything is probably quite variable. Find out if anybody had all of the elements represented. Did anybody have the exact same distribution as one of their neighbors? This is very symbolic of the Universe as a whole. Different corners of the Universe are made of different things, but hydrogen is very prevalent everywhere.

Hydrogen is the most abundant element in the Universe and the first element on the periodic table. Almost 90% of the Universe is hydrogen. The second most abundant element is helium. Nearly 10% of the Universe is helium. All of the other elements exist in much lower abundances, much less than 1%. Carbon, nitrogen, oxygen, magnesium, silicon, and iron are some of the common and more abundant heavier elements in the Universe.

Activity: Element Bottles (approximately 15 minutes)

We are now going to look at the elemental distributions of some specific objects in the Universe.

Give one set of bottles (minus the Human Body bottle) and a key to each group of students. Have students estimate the composition of the bottles by giving the percentage of hydrogen, percentage of helium, etc. See if they can match the element bottles with the different types of objects listed on the key.

Once a group has matched all four of their bottles, give them the last bottle. Let them try to work out the mystery of what it might represent. Encourage students to identify the elements they see in this bottle, and then to ponder what those elements could form. Once all of the groups have this bottle, discuss it as a group. The mystery bottle is made of hydrogen, oxygen, carbon, and nitrogen – the elements used in living creatures. Students might guess this bottle represents plants, animals, sea water, soil, etc. This bottle actually represents the *human body*!

Two girls work to figure out which bottles correspond to which objects.

A key point of this activity is comparing and contrasting the composition of these objects on Earth and in space. Ask follow-up questions: *What do all of the bottles have in common? What makes each one stand out? Does this surprise you? Did you know that you are made of "star stuff"?*

Discuss the composition of the human body. What are they are made of? Let the students answer. Water (which has a lot of oxygen!), carbon, nitrogen, etc. How does that compare to the other bottles in the activity? How did we come to have this rich selection of elements on Earth? How do we go from mainly hydrogen and helium to all of these elements we need to build people and plants?

Discussion: Where do elements come from? (approximately 15 minutes)

Ask the students what they know about atoms (if anything), and see what their answers are. If they don't mention protons and electrons, just leave them out, but if they do mention them, you can say that an element is defined by the number of protons it has in its nucleus.

Ask where the elements come from. In the Big Bang, hydrogen (H) - the lightest element, and helium (He) - the second lightest, were created. This is partly why there is so much of these elements in the Universe. The Universe today is about 90% hydrogen and almost 10% helium. All the rest of the elements make up much less than 1% of the Universe. (A very small amount of lithium - the third lightest element – was also created in the Big Bang, but mention this only if it comes up in discussion.) But where does everything else come from? See if anybody has any ideas.

Diagram of hydrogen and helium atoms.

All of the other elements come from stars, but how? The center of a star is very hot (millions of degrees) and very dense. This means that there's a lot of stuff in too small of a space. Draw an analogy to cooking. Ask them what happens when you cook. They probably know that you mix and heat ingredients, and get something new. This is a good analogy to what happens in a star. The process of fusion releases energy. And it is this energy that makes the Sun and all other stars shine. This keeps the balance in the star – the energy generated by the fusion flows outward and balances the pressure inwards from the force of gravity so the star doesn't collapse.

In the early life of a star, there is a lot of hydrogen in the center, and all those hydrogen atoms bump into each other. Often, some of them will stick together, and this is called fusion.

Demonstration: Fusion (approximately 15 minutes)

Have student volunteers come up. Show the small clay balls representing hydrogen, and let the volunteer stick four of them together. The process of fusion releases energy. It is this energy that makes the Sun and all other stars shine. When H fuses, it forms a new element. It forms He.

Diagram of hydrogen atoms becoming a helium atom.

Ask for another volunteer to come up. Now bring up a different color clay ball that represents helium. Let the student hold the helium clay ball. If you could change the color of the H clay balls as they join, you'd get this second color. Explain that this is what our Sun is doing now – fusing hydrogen to helium. It has been doing this for 4.5 billion years and will continue to do so for about another 5 billion years.

Although there is a lot of H in the star, at some point the H in the center runs out. When this happens the core of the star shrinks, causing the temperature to increases. Since it is now hotter, there is enough energy for the He to start fusing. When He fuses, C (carbon) forms. Let the second volunteer stick three helium clay balls together. Then, bring up the clay ball representing carbon.

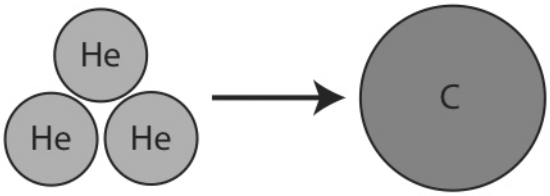


Diagram of helium atoms becoming a carbon atom.

This continues until the He runs out. For stars like our Sun, this is where the process stops. But in more massive stars, there is enough energy to continue the process. The more massive the star, the further the process can continue. To compare the mass/size of the Sun to that of Earth, the Sun's mass is 330,000 times that of the Earth; the Sun's volume is 1.3 million times that of the Earth. What's more, a large star can be 15 times more massive than the Sun and have a volume 4000 times that of the Sun.

If the star is massive enough to continue on to the next stage, a carbon and a helium atom will then fuse together to make an oxygen (O) atom.

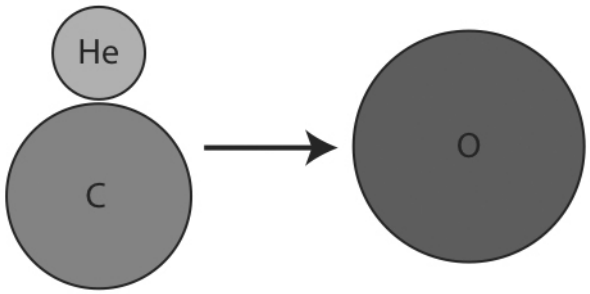


Diagram of helium and carbon atoms becoming an oxygen atom.

Then a helium atom and an oxygen atom can also fuse to form a neon (Ne) atom. Use clay balls of other colors to demonstrate these steps.

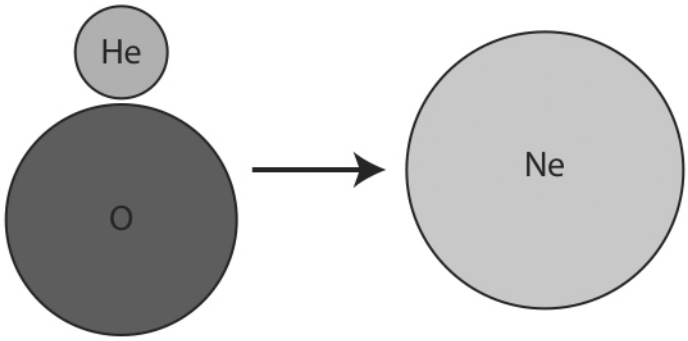


Diagram of helium and oxygen atoms becoming a neon atom.

This process continues in the most massive stars until iron (Fe) is created. Unlike the fusion processes up to this point, which release energy as part of the process, fusing iron requires an extra input of energy. This means that the creation of new elements in the cores of stars halts with iron, no matter how big the star is. (If they ask what is special about iron, it's because iron is the most stable of the nuclei, and the process of fusion puts together less stable nuclei to form more stable nuclei.)

Now is the time to cut open the clay star model. At the end of its life, the center of a star will look like this. Have a volunteer student carry one half around the room so that each of the students can see it up close while you hold the other half for all to see. All the elements that the star has created in its lifetime are inside the star in concentric shells. Because the area of the most intense fusion is always at the core of the star, the outermost shell is made of hydrogen, the first element to be fused, and the innermost shell will be of the last element to be fused, which depends on the star's mass. In the case of the largest stars, this will be iron. In this case, we have only gone up to neon.

The number of element layers at the end of a star's life will depend on the mass of the star. For a star like the Sun, there will only be two layers – hydrogen on the outside with helium on the inside. For the most massive of stars, the center will be iron with layers of all the other elements out to hydrogen on the outside. Our clay model is somewhere in between.

The colors of clay used in this model are not necessarily the color of the elements or the star. They are just bright colors used for the demonstration. The accompanying Supernova activity will illustrate what happens next in very massive stars. In particular, you will see how the elements get out of the center of this star and into space (where they eventually can become part of the earth and you and me).