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## Session 7 – Stars and Their Lives (Part II)

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### **Brief Description**

This session is an optional extension of the previous session (Session 6) on stars. It will go into more details of how stars generate energy by a process of fusion in their cores. All the elements in the Universe are made in stars. The session ends with a demonstration and an activity that show how the most massive stars collapse at the end of their lives and disperse the elements out into the Universe.

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### **Objectives**

- To expose students to the idea that stars generate energy by “cooking” elements in their cores.
- To show that supernova explosions spew out the elements stars have cooked in their interiors into the Universe.

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### **Concepts Addressed**

- Nuclear fusion
- We are all “star stuff” — we are all made of the elements stars create in their cores

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### **Materials**

- Periodic table (1 per student; black and white version included in Appendix E and color version included in Appendix F)
- 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 the “Preparation” section for procedure.
- Hotplate
- Heavy oven mitts or set of rubber-tipped tongs
- Clear bowl (at least 6” in diameter and 2” deep) filled with cold water
- Ice (to be added to the bowl of water to keep it cold during the session)
- Empty soda cans (without dents or creases)
- Tennis balls (1 per student)
- Ping pong balls (1 per student)

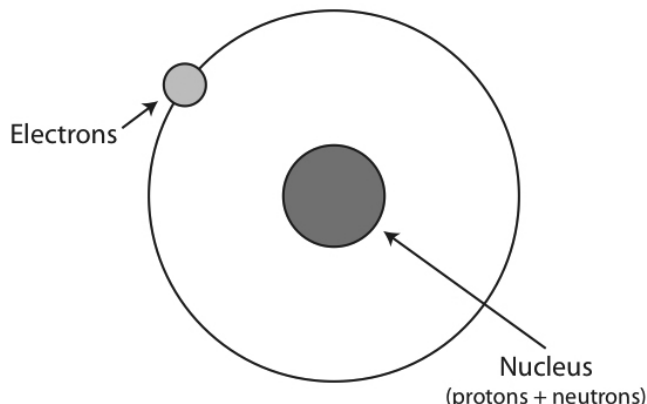
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### **Other Requirements**

- Electrical outlet for hotplate
- Large room with free space or a corridor for activity using the tennis balls and ping pong balls

## Background

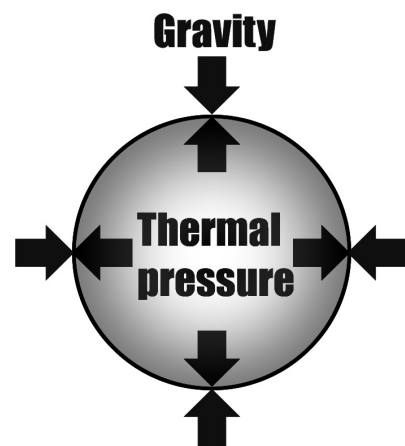
Stars are big balls of hot gas, mostly hydrogen. Stars generate energy by converting lighter elements to heavier elements by a process called “nuclear fusion” in their cores. Elements are made of atoms. Atoms are composed of a central “nugget” called the nucleus that is composed of protons and neutrons. The nucleus is surrounded by a cloud of one or more electrons. An element is characterized by the number of protons in its nucleus. 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.



*Basic elements 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 element into another. 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.

Stars go through a cycle of birth and death, but the timescales involved are much longer than we normally associate with living things. Young stars are born in clouds 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 kicks in. A star is born!



*The balance of forces within a star.*

The lifecycle of a star depends on how massive it is. Small stars live many billions of years, but the most massive stars live only a few million years. Our Sun, a medium-sized star, is 4.5 billion years old and about halfway through its life cycle.

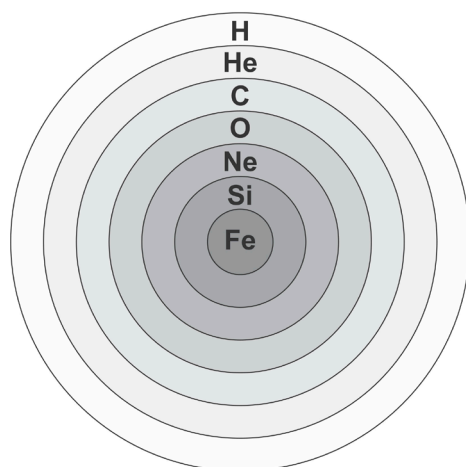
Stars that are not very massive (like our Sun) spend the majority of their lives (many billions of years) in a phase known as the “main sequence” stage in their lives. During this stage, they fuse hydrogen into helium in their cores. When this fusion ends, they expand into a “red giant” phase. Our Sun will

become a red giant 5 billion years from now. At this stage in its life, the Sun will puff up and swallow the Earth. After a brief phase in which helium is fused into carbon, red giants blow off the outermost layers. These layers form a disk of material around the star — this is called a “planetary nebula,” as it looked like a planet when seen through older telescopes. However, this has nothing to do with planets.

The hot core that is left behind is approximately the size of the Earth and is called a “white dwarf.” White dwarfs are very dense — a teaspoonful of white dwarf material would weigh 15 tons on Earth! White dwarfs shine for many more billions of years as they slowly cool.

Due to the higher temperatures and pressure in their cores, the nuclear fusion in massive stars does not stop with carbon. The star goes through successive periods in which carbon is fused into oxygen, oxygen is fused into neon, neon into silicon, and silicon is fused into iron. The sequence of nuclear fusion stops with iron. This is because fusing iron into the next element requires an input of energy rather than resulting in a release of energy. At this point, the star has an “onion” structure in which an iron (Fe) core is surrounded by rings of the different elements that the star has produced, as illustrated below. The specific elements, the thickness of layers, and their order may vary from star to star.

Once nuclear fusion stops, the force of gravity finally overwhelms the core. The core collapses catastrophically, releasing enough energy to blow apart the rest of the star. These explosions, known as supernovae, are so bright that they briefly outshine entire galaxies! Supernovae also have so much



*An example of the “onion shell” structure of a star.*

energy that elements heavier than iron are formed during these explosions. With the exception of hydrogen, all of the elements that make up our body (carbon, oxygen, nitrogen, iron etc.) were formed either through nuclear fusion inside of stars or during the supernova explosions of massive stars. All the elements that were formed inside stars are spewed out when they explode, and this is how elements are dispersed throughout the Universe.

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**Session Overview**

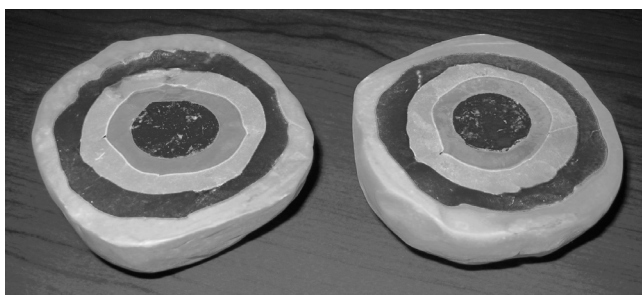
This session consists of a series of interactive demonstrations. The first demonstration shows how stars fuse elements in their cores to make new elements. The second demonstration shows how a star

collapses at the end of its life, while the final activity is intended to show how elements get dispersed into the Universe when the star explodes.

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## Preparation

- Make the stellar clay core before the session. Start by making a ball about 1 inch in diameter using the color of clay that will represent neon. Completely cover that ball with a  $\frac{1}{4}$ "– $\frac{1}{2}$ " layer of "oxygen-colored" clay. Then add a layer of "carbon," then "helium," then "hydrogen." You can choose any colors you like to represent these elements, but it will be easier to see the layers if adjacent colors contrast with each other. You may make this model out of Sculpey instead of clay if you would like a more permanent version. If you use Sculpey, you should cut this model in half before baking it. This step can wait until the demonstration if you are using soft clay.



*Onion shell model split open.*

Record the colors you used for each element and keep that handy throughout Part II.

In addition, make several small clay balls of each of the colors/elements. In order to demonstrate all the different fusion reactions you will need at least twenty balls for hydrogen, five balls for helium, one for carbon, one for oxygen, and one for neon, in order of increasing size. As they go up, they should be roughly equivalent in size to their squished counterparts.

- Plug in the hotplate so it starts heating. Set up the bowl of cold water and put aside. Allow time for the hot plate to heat thoroughly before starting. **PRACTICE** the demonstration for Activity 2 before attempting in front of students. It helps to use an underhand motion, starting with the palm of your hand pointed towards the ceiling, so you can easily flip your wrist over and dunk the can.



*The underhand motion that helps with this demonstration*

- Make ice beforehand so that you can have a bowl of ice water for this session.
- Familiarize yourself with the periodic table.

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## Activity

### I. Demonstration of Where Elements Come From (15 minutes)



Check our online resources for a video about this clay fusion demonstration.

1. This part of the session is an interactive discussion and demonstration of how stars fuse elements inside their cores. A suggested path for this discussion is below. Allow students to reply after each of the questions before proceeding. You can have students handle the small clay balls as they come up in discussion. If you have sufficient clay, you can have the students work in pairs or small teams to make their own stellar clay models as they follow your lead.
2. Ask who in the class has heard the term “atoms.” Ask what they know about atoms. If they don’t mention protons and electrons, just leave them out. But if they do mention them, then you can say that an element is defined by the number of protons it has in its nucleus. Hand out the periodic tables.
3. 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.

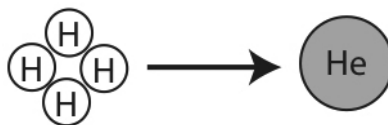


*Hydrogen and helium atoms.*

4. 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 a space that’s too small. 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.
5. 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. This is called fusion. Show four small clay balls representing hydrogen, and smash them together. You can have

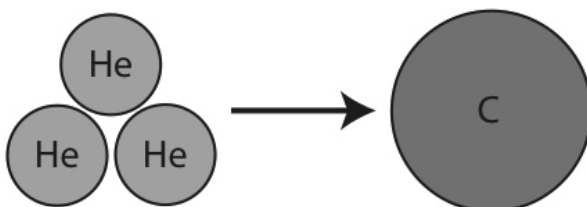
student volunteers come up and fuse the clay balls together at each step, if desired. Or the student groups can do this if they are also making clay stellar models along with you.

- When these four hydrogen atoms stick together, they form a new element called helium. Bring out a different color clay ball, and explain that it will represent helium. 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 for about another 5 billion years.



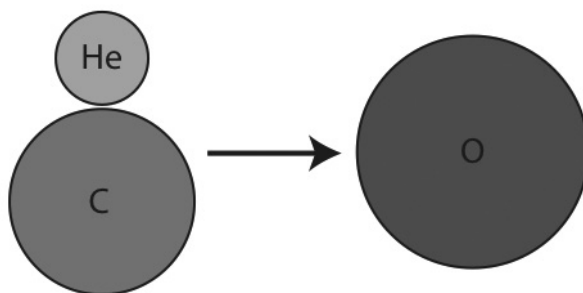
*Four hydrogen atoms becoming a helium atom.*

- Although there is a lot of hydrogen in the star, at some point the hydrogen in the center runs out. Ask what do you think happens at this stage. Remind them of the dance in Session 6 and ask what they did at this point. The correct answer is that the core of the star shrinks.
- This increases the temperature. Since it is now hotter, helium will start fusing. Helium is heavier than hydrogen so it takes more energy — a higher temperature — to fuse. Explain that when helium fuses, carbon (C) is formed. Smash three balls representing helium, and bring up the clay ball for carbon.



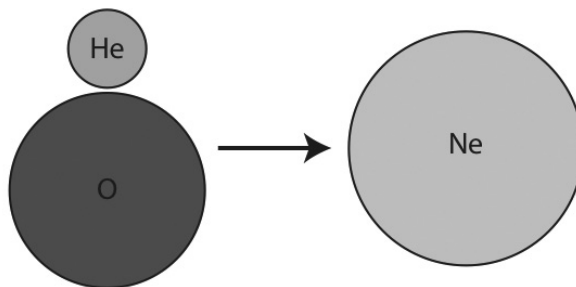
*Three helium atoms becoming a carbon atom.*

- Point out that helium fusion continues until the the core is predominantly carbon, and the helium is not bumping into much other helium. In the Sun, things actually stop there! Again, remind them of what happened in Session 6 during the dance. But if the star is much bigger than the Sun, the core shrinks again and it gets even hotter at the center. A carbon and a helium atom can then fuse together to make an oxygen (O) atom.



*Helium and carbon atoms becoming an oxygen atom.*

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



*Helium and oxygen atoms becoming a neon atom.*

11. Explain to them that in the largest stars, this process can continue up to the point where iron (Fe) is formed. In order to fuse iron, energy is required. That is, the process requires an input of energy rather than producing energy. Now the balance in the star is broken — the gravity pressing inward isn't balanced by the outward energy created by fusion.
12. Hold up the clay stellar core and then slice into it. Explain that at the end of its life, the center of a massive star looks like this, with all the elements that a star has created in its lifetime in layers inside. It should be similar to a color version of the image in the background, with concentric rings of the different elements.
13. Have them look at their copies of the periodic table. Mention that nearly all elements in the periodic table are made in stars.

## II. Demonstration of stellar core implosion (20 minutes)

*(Adapted from the Chandra X-ray Observatory's activity on supernovae)*



Check our online resources for a video about the can crunch procedure and explanation.

### **Warning: Make sure students don't get too close to this one!** **The hot plate remains hot for most of this session!**

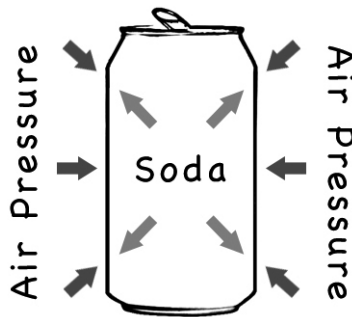
1. Start by telling the students that we will now explore what happens inside the star when the fusion stops. We will do a demonstration that models this process. But as we learned in Session 1, models do not necessarily depict the situation exactly. This demonstration only shows the principle of how the collapse of a stellar core occurs.
2. Place a small amount of water in an empty aluminum soda can (one or two tablespoons). Too much or too little water will affect how well this demonstration works. Set the can on the hot plate. Heat the can until the water starts to boil. When you can hear the rapid boil of the water, and plenty of steam starts to come out of the opening in the top of the can, quickly pick up the can with an oven mitt or tongs and flip it over (open side down) into a bowl of cold water. The can will instantly implode with a crunching sound.



*An example of a can that has been imploded.*

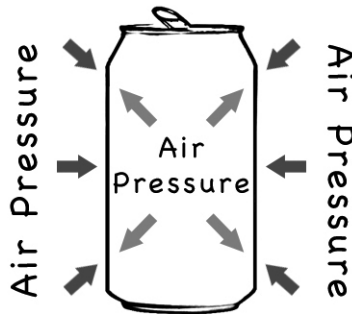
3. Explanation:

When you buy the aluminum can from the store and it still has liquid in it, the can holds its shape due to the equilibrium between the pressure from the soda inside directed outward and the pressure of the air outside of the can directed inward.



*The balance of forces in a can full of soda.*

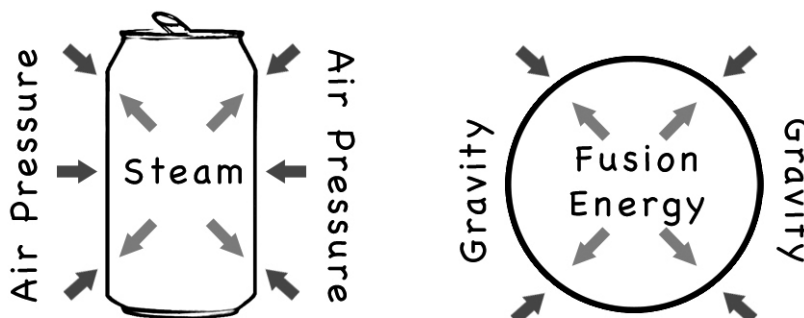
After the can has been emptied of liquid, the shape is held in equilibrium by the pressure of the air inside the can directed outward and the pressure of the air outside of the can directed inward.



*The balance of forces in a can after the soda has been emptied.*

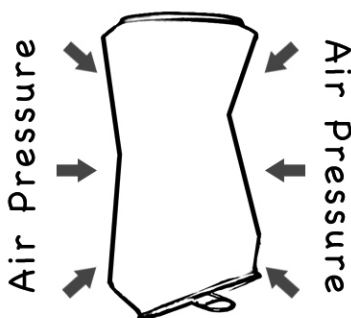


Heating the water in the can causes it to turn into steam, which drives the air out of the can because the steam has higher pressure. Now the can is held in equilibrium by the pressure of the steam pushing outwards (like fusion energy in a star) and the pressure of the outside air directed inwards (like the gravity of the star, but not quite the same).



*During our demonstration we heat water in our soda can, which means the can fills with steam, which balances the air pressure from outside. We compare this to the balance of forces in a star during the majority of its life.*

When the can is inverted over the cold water, the steam instantly condenses into water. The water occupies a much smaller volume than the steam did, resulting in much less pressure inside the can. With nothing on the inside to balance the outside pressure the can will implode (like the core of a star collapsing).

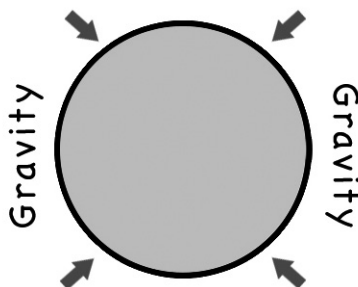


*The can collapses because there is no longer a balance of forces.*

This is sort of like what happens in a supernova, the end of the line for large stars. The star explodes when the two forces that were balancing each other — pressure outwards from the energy generated at the center countering the force of gravity inwards — are no longer in equilibrium.

The central core of the star collapses (similar to the implosion of the can) and the material in the rest of the star starts to fall onto this core. It rebounds and sends the material in the star flying out. This is what is called a supernova explosion and the power of this rebound

effect can be seen in the next demonstration. Supernovae do a very important job in the Universe — the explosion sends all those elements out into space and makes new elements with its energy.



*The lack of fusion energy inside the star to balance the gravity causes the final collapse of the star.*

Tie this activity into the kinesthetic activity that students did in Session 6. How does this experiment parallel the motions that they made at the end of the life cycle of a large star?

### III. Ejection of Outer Layers of a Star (20 minutes)

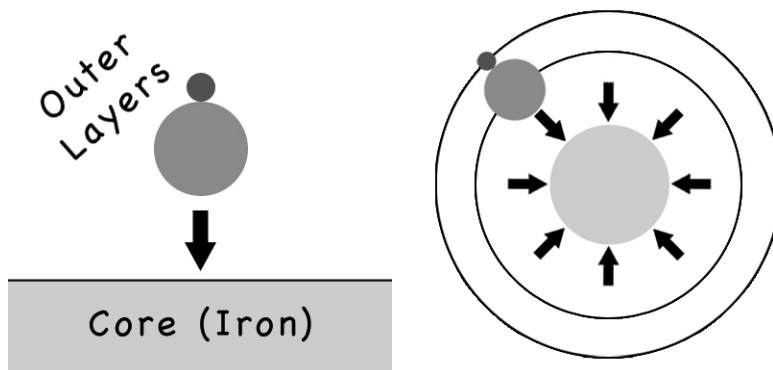
*(Adapted from the Chandra X-ray Observatory’s activity on supernovae.)*



Check our online resources for a video about the ball bounce procedure and explanation.

This activity is intended to show how elements created inside a star get flung out into space during a supernova explosion. Again, this activity only shows the principle behind how this happens and does not reflect the exact process. This activity is best done in a large room with some open space or in a corridor (or it can be done outdoors).

1. Have participants stand in a group, each holding a ping pong ball and a tennis ball. Bring the focus back to the end of the large star kinesthetic life cycle in Session 6. Explain that the ground (Earth) represents the dense inner core of a star. The tennis ball represents the outer part of the core that is falling inward as the star collapses. The ping pong ball represents the outer layers of the star. This idea is illustrated in the following images. Tell them that



*The tennis and ping pong balls represent the outer layers of a star falling towards the iron core as it goes supernova.*

they are now going to model a supernova explosion and see what happens to the stuff in a star when it explodes.

2. Have everyone drop the tennis ball alone, then the ping pong ball alone. Ask them to notice how high the ping pong ball bounces when dropped in this fashion. Have them hold the balls in a stack (ping pong ball on top of tennis ball, as shown in the photo below), and think about what's happening — these layers are falling inward toward the Earth. Have them predict what might happen when the balls fall.



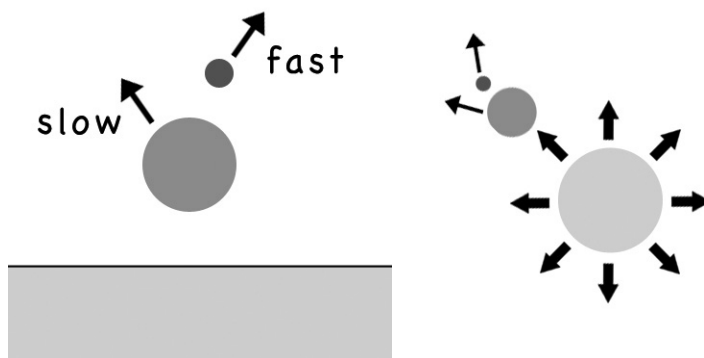
*Participants waiting to drop their balls on cue.*

3. Have everyone drop their stacked balls and yell, “3-2-1-SUPERNOVA!” What happened? Let everyone do it again once or twice.



*Participants observe what happens to the balls once they are dropped.*

4. Discuss what happened with the students. What did each ball represent? Did the experiment match their predictions? (When the two balls hit the floor, the ping pong ball will suddenly rebound with a lot of energy. It will bounce higher than it did when it was dropped by itself.) What will happen in space when a spherical star explodes? (The material will go shooting out in all directions.) This idea is again illustrated in the following images.



*The tennis and ping pong balls as the outer layers of a star shooting off into space after they have rebounded off of the iron core during a supernova explosion.*

5. Have the students imagine what it would be like if everyone on Earth did this at the same time. With the idea of 6 billion ping pong balls shooting off in all directions from the Earth at the exact same time, we get a more accurate mental image of a supernova.
6. Explanation:

Once the core of a star has been turned to iron, no more energy can be generated through nuclear fusion. The balance between gravity and the outward flow of energy is broken, and gravity causes the core of the star to catastrophically collapse. This collapse takes just a few seconds. At the end of this collapse, the material in the core comes together with such a large force that some part of it “rebounds.” This rebounding material slams into the outer layers of the star, blowing them into space at great speed. This is the supernova. This activity illustrates how a gravitational bounce can eject material at great speed. The tennis ball represents rebounding core material. As it bounces, it slams into the ping-pong ball representing matter in the outer parts of the star, causing the ping-pong ball to be ejected upwards at great speed.

So the supernova explosion sends all of the elements the star created out into space. They become a part of other stars, planets, galaxies, and even you and me. We are all made of “star stuff!”

Discuss the difference between an *implosion* (falling inward) and *explosion* (going outward). Tie this activity into the kinesthetic activity that students did in Session 6.

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## ***Suggestions for Running this Session***

- If you are having trouble with the can crunch demonstration, consider whether you have too much water, whether you are too slow in turning the can over, or whether you haven't let it heat long enough and there isn't enough steam. Practice is very important for getting this right.
- We recommend that you always handle the aluminum cans with some sort of protection, even if the can seems cool enough to touch. While you could use oven mitts for this, we've found that tongs work better for two reasons - it's easier to see the can as you handle it, and it reduces the potential for being accused, "Hey, I think you crunched that with your hand!" All in all, it makes the demonstration much clearer when you use tongs. Silicon-tipped cooking tongs work especially well for grabbing the can gently and securely.
- As mentioned earlier, you'll want to flip the can over into the ice water as quickly as possible. To facilitate this, use an underhanded motion with your tongs. Start by holding the tongs with your palm and wrist facing upward, grab the can, and then flip your hand (and the can) over so that your palm and wrist are now facing downward. It's a little unnatural at first, but it makes flipping the can much quicker and easier! Practice really does make perfect, too.
- If you are considering running this program more than once, consider buying non-pressurized tennis balls. Pressurized ones will lose pressure with time, and will no longer bounce. Non-pressurized ones do not have this problem, and you will save money in the long run.

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## ***Misconceptions***

- Whether it's squishing clay, crunching a can, or bouncing a tennis ball and ping pong ball, none of these examples are literal parallels to the behavior of a star. We certainly don't want to give the idea that atoms squish together, or that a star collapses when water condenses inside! Be sure to give equal explanation to what's going on in the activity... and the similar behavior in the life cycle of a star.

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## ***Useful websites for background or activity extension***

- ***Imagine the Universe!***  
Check out this site for more information and activity books on the life cycles of stars. Designed for educators at the high school level.  
<http://imagine.gsfc.nasa.gov/docs/teachers/lifecycles/stars.html>
- **Chandra X-Ray Observatory**  
This page from the Chandra X-Ray Observatory discusses the supernova demonstrations  
<http://chandra.harvard.edu/edu/formal/demos/snr.html>  
[http://chandra.harvard.edu/edu/formal/stellar\\_ev/](http://chandra.harvard.edu/edu/formal/stellar_ev/)