Activity 11: Life and Death of Stars

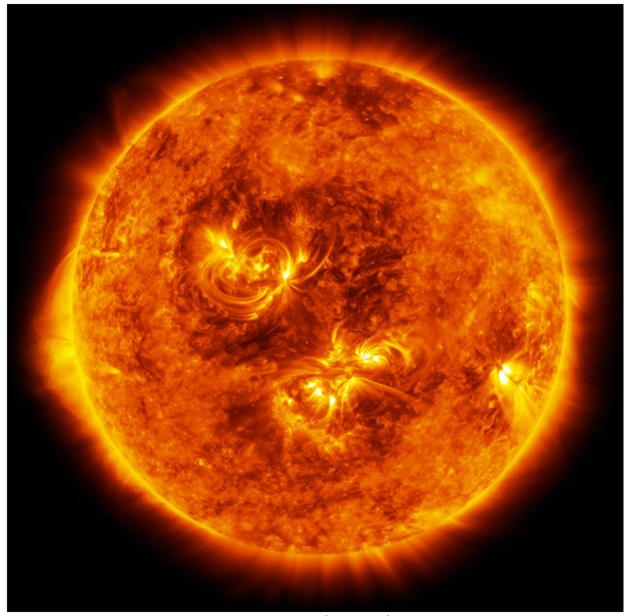


Image credit: NASA / SDO / Seán Duran

Materials:

- Periodic table handout, or use the interactive one at www.ptable.com
- One basketball and one tennis ball

In today's activity we're going to "look inside a star" and learn about what a star actually *is*. From there we can study the stages of a star's life, including its sometimes dramatic ending. First, we need to develop some basic relationships regarding gas pressure and temperature, discuss how gravity fits in, and talk about the basics of nuclear fusion.

Part 1: Gas Laws

STEP 1: Review the following principles and definitions from the Pre-Lab, filling in blanks where needed:

Principle #1: The average speed of the particles that make up a gas is

______________________ proportional to the temperature of the gas.

Temperature defined

The above principle is really the *definition* of temperature. **Temperature** is nothing more than a *macroscopic* measure of the *average speed* of an object's *microscopic* particles.

Principle #2: The volume of a gas is ____________________________

proportional to the pressure of the gas.

The **pressure** of a gas can be thought of as the tendency of a gas's particles to spread out.

Principle #3: If something pushes (or pulls) on a gas to make its volume smaller, its temperature ________________________.

STEP 2: In this Activity we will hereafter refer to these three principles as "**gas laws**". Now let's use gas laws #1, #2, and #3 in relation to stars.

A star is born from a cloud of interstellar gas and dust that starts to contract under its own weight (i.e., it contracts because of the force of gravity).

Gravity is pulling the cloud of gas down towards its center as a result of the mutual gravitational attraction of every atom of gas on every other atom of gas. Without any barriers, the atoms would all meet at a mutual center of gravity. However, as the particles contract together in reality, they will get in each other's way and start to bounce around randomly.

Is something pushing or pulling on the particles in the cloud of gas to make the cloud's volume smaller? If so, what's doing the pushing or pulling?

What is happening to the temperature of the gas as it contracts? Which gas law (1, 2, or 3) supports your answer?

Based on your previous conclusion, what is happening to the average speed of the gas atoms as the cloud of gas contracts? Which gas law (1, 2, or 3) supports your answer?

Lastly, what is happening to the pressure of the cloud of gas as it contracts? Which gas law (1, 2, or 3) supports your answer?

SQ1: Complete the summary below.

A cloud of interstellar gas begins to contract under the force of

____________________. As this happens, the temperature of the gas (increases / decreases). Therefore, the average speed of the gas's atoms (increases / decreases). And, the pressure of the gas (increases / decreases).

Part 2: Nuclear Fusion

In this part we will be discussing nuclear fusion. In order to understand this, we will need another principle from physics:

Electric Attraction and Repulsion

Two charged objects can attract or repel via the **electric force**. If both objects are positive, or if both are negative, they repel. If one is positive and one is negative, they attract. Remember: *Opposites attract and likes repel.*

STEP 1: Go to https://phet.colorado.edu and hover over "Simulations", then click on "Chemistry", and then scroll down and click on the "Build an Atom" simulation. Click Play. Or go to the following URL:

https://phet.colorado.edu/sims/html/build-an-atom/latest/build-an-atom_en.html

When it opens, click on the "Atom" applet.

STEP 2: Click and drag to add a proton to the atom. What element have you made? Notice where you are on the periodic table.

Add a neutron too. Now what element is it?

Also add an electron. Now what element is it?

STEP 3: Add a second proton to the atom. What element is it now? Notice where you are on the periodic table.

Experiment with adding protons, neutrons, and electrons until you can answer the following question. Be as precise as you can with your answer.

To change an element into a new element, you must change the atom's

number of ____________________.

Or, to put it another way:

An atom's element is determined by its number of ______________.

This number is called the **atomic number**.

STEP 4: Press the reset button on the bottom right. Now click the plus signs '+' next to "Net Charge" and "Mass Number" and check all three of the boxes at the bottom right.

Construct a hydrogen atom with 0 neutrons.

Is a hydrogen atom with 0 neutrons stable?

Is a hydrogen atom with 1 neutron stable?

Is a hydrogen atom with 2 neutrons stable?

Unstable atoms will *decay* after a while, which means the protons and neutrons in the nucleus fly apart. Let's see why.

STEP 5: Construct a helium atom that has 2 protons and no neutrons. Is it stable?

Since "opposite charges attract and like charges repel" via the electric force, are the two protons in the Helium nucleus attracting each other or repelling each other?

Based on your previous answer, why is the helium nucleus unstable (i.e., why does the nucleus want to fly apart)?

STEP 6: Add a neutron to the unstable helium atom. Now is it stable or unstable?

Neutrons act like "glue" to help hold the nucleus together. This is due to a fundamental force of nature called the **nuclear strong force**, which is a *very* short-range but *very* strong attractive force that holds protons and neutrons together. The range of the strong force is only about the width of a nucleus. Without the strong force, two or more positively-charged protons would repel each other and fly apart, and the universe wouldn't contain any nuclei at all (and therefore no atoms) other than the simplest one (hydrogen)!

STEP 7:

Protons have a charge of +1 Electrons have a charge of -1 Neutrons have a charge of 0

In the *absence of electrons*, what is the net charge of a hydrogen atom? If needed, you can double check your answer using the simulation's Net Charge meter.

STEP 8: Now let's consider not one but two hydrogen atoms. Suppose each hydrogen atom consists of 1 proton, 1 neutron, and 0 electrons. What is the net charge of each individual hydrogen atom? If needed, use the simulation's Net Charge meter to check your answer.

Based on your previous answer, would these two hydrogen atoms attract each other or repel each other via the electric force?

Now imagine the two hydrogen atoms slam together at very high speeds so that they get closer enough that the strong force can take over and make them stick together. How many protons, neutrons, and electrons do we have now? Fill in the table below.

	# Protons	# Neutrons	# Electrons	Net Charge
Hydrogen #1				
Hydrogen #2				
Hydrogen #1 + #2				

Based on the table you've completed above, when nature slams two hydrogen atoms together hard enough that they stick together, what element has been created? Circle the single cell in the table above table that tells you this.

The process by which two smaller nuclei are smashed together to make a bigger nucleus is called **nuclear fusion**.

Because of the repulsive nature of positively-charged atomic nuclei, the atoms must be moving *very fast* to overcome the repulsive electric force and get close enough for the strong nuclear force to take over so that they can fuse together. This is called *overcoming the Coulomb barrier*.

SQ2:

(a) Based on the above statement about the Coulomb barrier, would the gas in a star have to be very hot or very cold in order for nuclear fusion to occur? Why, and which principle (1, 2, or 3) from Part 1 supports your answer?

(b) At the core of the Sun, where hydrogen + hydrogen is fusing into helium, the temperature is 15 *million* Kelvin. Does this align with what you stated in (a) above?

STEP 9: When we use the word "burning" in our daily lives we are typically referring to combustion. Combustion is a *chemical reaction* that requires an oxidant, like oxygen.

Stars are *not* burning in the sense of combustion. Stars are *fusing*, which is a *nuclear reaction* (*not* a chemical reaction) that releases much, much more energy than combustion does and requires no oxidant. A gas made of 100% hydrogen atoms is sufficient, for example, for fusion to occur.

SQ3: Circle one answer choice for each of the following:

Stars are hot because they are combusting.	True	False
Stars require oxygen in order to undergo fusion.	True	False

The energy output from a star is the result of what kind of reaction?

chemical nuclear

Part 3: The Birth of a Star

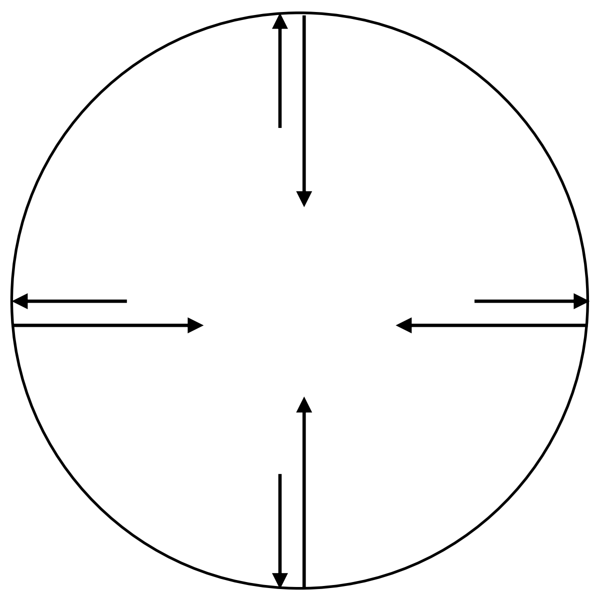
Gravity is pulling a cloud of interstellar gas together, making it hotter and denser. So what stops it from contracting forever? Why does it reach a certain size and then form a star? Let's look into that now.

Recall from Part 1 that the **pressure** of a gas can be thought of as the tendency of the gas to expand, or the tendency of the atoms of the gas to fly apart. When the pressure inside the simulated box of gas in the Pre-Lab got too large, the lid was blown off.

> Pressure is pushing the star's gas *outwards*, whereas the force of gravity is pulling the gas *inwards*.

These competing effects have been drawn schematically using inward- and outward-pointing arrows in the diagram below.

STEP 1: Based on their directions, label each of the eight arrows in the diagram as either "gravity" or "gas pressure".



In a star, gas pressure is weaker than the force of gravity. This is indicated in the diagram by using shorter arrows for smaller forces and longer arrows for larger forces. Double-check your labels: are your gas pressure arrows all shorter than the gravity arrows?

STEP 2: If the outward forces could balance the inward forces, then the star would neither contract nor expand and the star would be in equilibrium. In order to reach equilibrium, there must be an additional force. Would that additional force need to be *outward* or *inward*? Don't worry yet about where the additional force comes from, we'll get to that momentarily. What must its direction be for all of the forces to balance?

Therefore, another factor must contribute to supporting the star, and that is none other than fusion itself. Fusion releases a tremendous amount of energy in the form of electromagnetic radiation, which also has the effect of increasing the outward pressure through a phenomenon called ***radiation pressure***.

STEP 3: Add four arrows to the diagram above and label them "radiation pressure". Pay attention to both the direction and the length that you give to each arrow.

Eventually, when the gas contracts to a certain size, the competing forces will balance each other out. This state of things is called **hydrostatic equilibrium**. What you have completed in the diagram above is a schematic of a cloud that has reached hydrostatic equilibrium.

SQ4: Complete the summary below.

> A star forms from the contraction of a cloud of gas, and that contraction is powered by the force of __________________. As the cloud contracts, its temperature (decreases / increases) and therefore its atoms start moving (slower / faster). Eventually, the temperature reaches the point where it is possible for ____________ ______________ to occur. Also, while the cloud is contracting, its pressure will (decrease / increase). An additional pressure called ___________________________ is caused by the fusion that is taking place, and this helps support the star by applying another force (outward / inward). Eventually, the total (inward / outward) pressure will exactly ______________ the total (inward / outward) force of _______________. When the star reaches this state, it is in a state of
>
> ____.

Orion Constellation

STEP 4: At this point we have concluded that a star is hot (hot enough for fusion to occur!) and dense. Therefore, what type of spectrum (continuous, emission, absorption) would you expect a star to emit, ignoring its atmosphere? Does this agree with what we learned in a previous Activity?

On a clear winter night, you can find the constellation Orion (see photo at left). It is most easily spotted by looking for his belt, which are three bright stars that lie in a straight line (center of photo). Once you spot the belt you can also easily find Betelgeuse (red supergiant star, upper left) and Rigel (blue supergiant star, lower right) with the naked eye.

Hanging from Orion's belt is Orion's sword, which also consists of three bright stars in a straight line (they are the closely-spaced vertical arrangement of stars in the photo).

STEP 5: Label Orion's belt, Orion's sword, Betelgeuse, and Rigel in the photo above.

The center "star" in Orion's sword is actually not a star but the Orion Nebula (numbered M42 in the Messier catalogue). This nebula can be seen on a clear night with the naked eye and can be seen in some detail with binoculars or a backyard telescope.

The Orion Nebula is a cloud of hydrogen gas in which clumps of gas are contracting and making stars. Around 700 stars in various stages of formation have been observed inside the nebula. Star-forming regions like the Orion Nebula are sometimes called **stellar nurseries**.

At the right is the Hubble Space Telescope's highest detail photograph of the Orion Nebula.

Part 4: Life of a Star

We have arrived at the point where we have a star that is in hydrostatic equilibrium. Since the star is in equilibrium and no longer changing its size, temperature, or pressure, how long will the star remain in this stage (called the "**main sequence**")? The answer is: a very long time, but not forever.

Why not forever? Remember, the star is fusing hydrogen into helium in its core. This process is using up hydrogen and replacing it with helium. Eventually, what do you think will happen to the abundance of hydrogen in the star, and what might this do to the rate of hydrogen + hydrogen fusion?

When there's no longer enough hydrogen left to keep making helium, that marks the *end of the main sequence* stage.

STEP 1: Use the data in the table below to answer the following questions.

Mass of the Star (in units of Sun mass: M_{Sun})	**Approximate Main Sequence Lifetime of the Star**
0.5 M_{Sun}	50 billion years
1.0 M_{Sun}	10 billion years
2.0 M_{Sun}	2 billion years
6.0 M_{Sun}	110 million years
60 M_{Sun}	360 thousand years

(a) Which live longer, high-mass or low-mass stars?

(b) Based on your answer to (a), do you think that the rate of nuclear fusion in a high-mass star is greater than, less than, or equal to the rate of nuclear fusion in a low-mass star?

(c) Estimates of the age of our solar system that come from isotope dating of meteorites in the solar system put the solar system's age (and therefore the Sun's age) at roughly 5 billion years old. For about how much longer will the Sun be a main sequence star?

(d) Our galaxy (the Milky Way) and the Andromeda galaxy are moving towards each other because of their mutual gravitational pull. It is estimated that the two galaxies will collide in about 3 billion years, which will begin a very long process by which the two galaxies merge together and settle down into a new, larger galaxy. Will the Sun still be a main sequence star when the Milky Way and Andromeda meet?

STEP 2: When a star has run out of hydrogen to fuse into helium, what happens now? Let's investigate.

Is hydrogen the only element that can be fused into heavier elements? Definitely not. If you were to smash a hydrogen nucleus and a helium nucleus together, how many protons would there be in the resulting nucleus? And therefore, what element would this be? Consult your periodic table.

Earlier, we mentioned that "opposites attract and likes repel". If we dig a little deeper, it also turns out that the *strength* of the attraction or repulsion is *directly* proportional to the *number* of charges (i.e., amount of charge) present. This is known as *Coulomb's Law* (and is also the origin of the phrase *Coulomb barrier*).

Coulomb's Law: The strength of the mutual attraction or repulsion between charges is *directly* proportional to the amount of charge (number of charges) present. Opposite charges attract and like charges repel.

Historical Aside: This law is named for its discoverer, French physicist Charles-Augustin de Coulomb, who lived and worked in the latter part of the 1700's. Today, the fundamental unit for electric charge is named after him.

STEP 3: How does the mutual force of repulsion between *two* protons compare to the mutual force of repulsion between *three* protons? Explain your reasoning by using Coulomb's Law.

How does the mutual force of repulsion between *three* protons compare to the mutual force of repulsion between *four* protons? Explain your reasoning by using Coulomb's Law.

Use gas law #1 and Coulomb's Law (you may utilize your previous two answers) to decide: which would require a higher temperature, fusion of hydrogen + hydrogen into helium or fusion of hydrogen + helium into lithium? Explain your reasoning.

What element would be formed by the fusing of a helium nucleus and a helium nucleus?

In each pair below, circle the one that would require a higher temperature.

Which requires a higher temperature?

	Fusion of…	vs.	Fusion of…
(a)	hydrogen + hydrogen		hydrogen + helium
(b)	helium + helium		hydrogen + helium
(c)	helium + helium		helium + lithium

Summarize the method you used to decide in the cases above.

In what follows, we will be talking about nuclear fusion that happens inside the star's *core*, which is the part of the star where the temperatures are highest.

STEP 4: Let's now put these pieces together to figure out what happens when a star's core runs low on hydrogen.

SQ5:

(a) When the rate of hydrogen + hydrogen fusion slows and stops because there's no longer enough hydrogen atoms in the core to sustain it, what will happen to hydrostatic equilibrium? Look back at your diagram that involved inward and outward arrows and ask yourself, how would the diagram change if nuclear fusion stopped?

(b) Based on (a), can hydrostatic equilibrium continue without any nuclear fusion? Why or why not?

(c) Based on (b), what will begin to happen to the *size* of the star's core once hydrogen fusion runs out? Why?

(d) And therefore, what will happen to the temperature of the star's core? Which gas law (1, 2, or 3) from Part 1 supports your answer?

And finally, the star's core will eventually reach a temperature where helium and helium can be fused together.

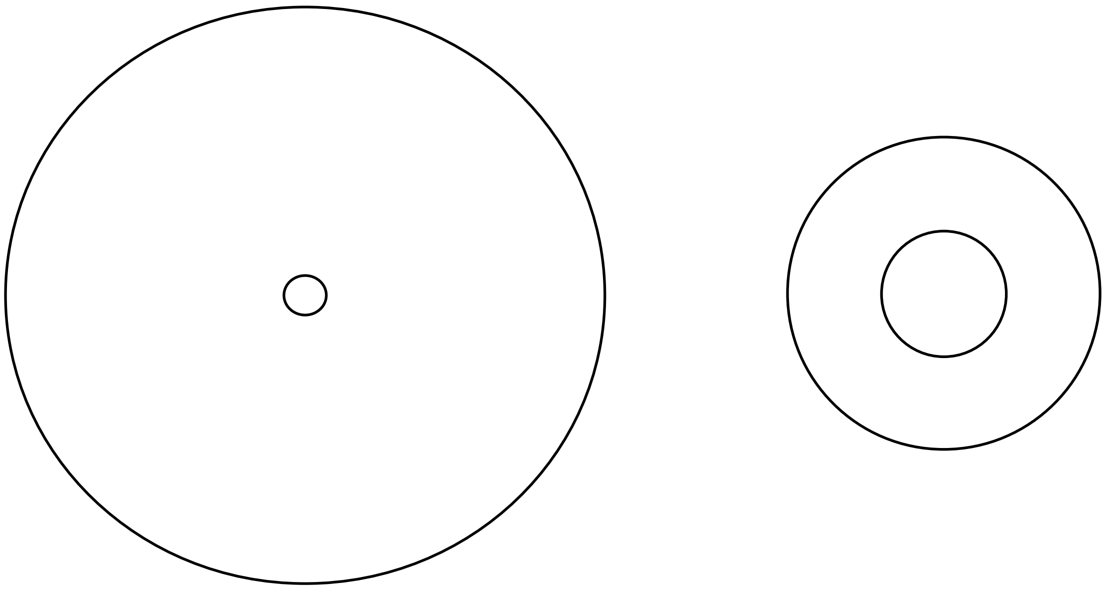
STEP 5: Over the course of a star's life it continues to fuse different elements. What pattern have you noticed? More specifically, which direction are we going on the periodic table with regard to which element is being produced by fusion in a star?

Based on what you learned in Step 4, what happens to the size and temperature of the *star's core* when it moves from fusing one element to fusing the next element on the periodic table?

Size: increases / decreases

Temperature: increases / decreases

Below are two schematics of stars that show the relative sizes of their cores and their "envelopes" (the region around the core). If one of these stars is fusing hydrogen + hydrogen in its core and the other is fusing hydrogen + helium, which is which? Label them below.



SQ6:

(a) The star on the left is similar to a red giant star (not drawn to scale). A red giant's core is very small and hot, but its envelope expands greatly and becomes red. Reading off your previous answer, what elements are being fused in the core of a red giant star?

(b) The star on the right is similar to a main sequence star (again not to scale). If these schematics were both of the *same star* at different points in its life, which stage occurred first, main sequence or red giant? Explain your reasoning.

For reasons that will be discussed in the next part, iron (Fe) is the last element on the periodic table that can be produced by fusion in a star. How many protons does iron have?

<u>Part 5: The Death of a Star</u>

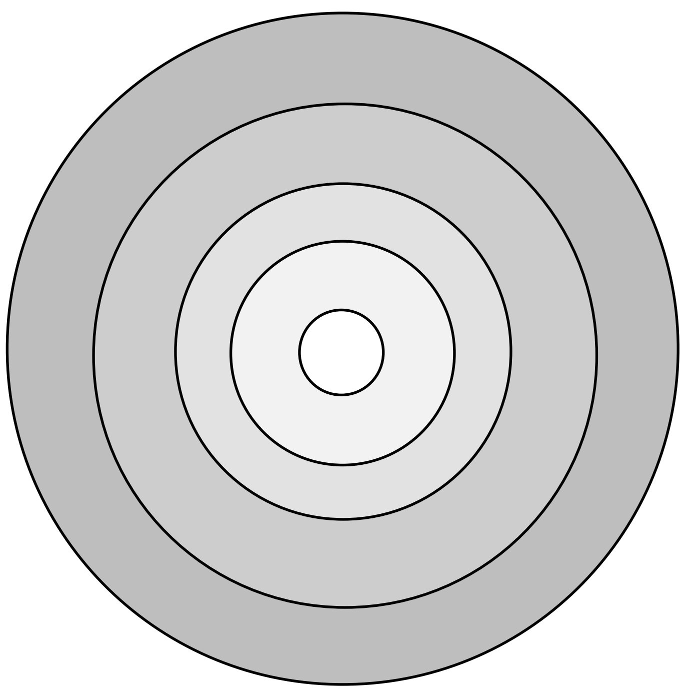
Because of the laws of nuclear physics (which arise from quantum physics), iron occupies a special place on the periodic table, as follows:

- Fusion of all of the elements up to and including iron is an *exothermic reaction*, meaning the nuclear reaction has a *net output* of energy.
- Beyond iron, however, fusion switches from being exothermic to being an *endothermic reaction*, meaning it requires a *net input* of energy.

So stars can't make heavier elements beyond iron on the periodic table without some *additional* energy input. And we know that elements beyond iron exist, so they must've been made at some point. *So where did this extra input of energy come from?* We'll answer that by the end of this Part.

STEP 1: Towards the end of a star's life, it will have fused a variety of elements, ranging from hydrogen up to iron, but nothing beyond iron. The heaviest element that has been fused will be found in the *center* of the star and the lightest element will be at the *surface* of the star. The different elements therefore make up layers within the star like the layers of an onion.

Suppose a generic star that's near the end of its life is now made mostly of iron (Fe), oxygen (O), hydrogen (H), helium (He), and carbon (C). In the diagram below, label each layer of the star with the appropriate chemical symbol. Hint: Look at the *atomic mass* of each element as shown on the periodic table and use that to help you decide. Remember, heavier things sink to the center and lighter things float to the top.



Consulting your diagram above, what element makes up the core? Why, at the end of a star's life, will this always be the case?

STEP 2: When no more fusion can happen in the star, it will collapse under its own weight. Gravity takes over. This results in all layers of the onion compressing downwards until they meet the core.

When an "onion layer" meets the core, there is a collision between the layer and the core. But, the core can't go anywhere because it is being impacted by the onion layer on all sides simultaneously! *So the core effectively acts like a backstop.* When each layer meets the core, the layer will then rebound into an outward direction.

Consulting your diagram above, as the layers of the star's onion-like structure collapse, which layer will rebound off the core first? And which would be second to reach the central region of the star? And which would be last? To help you answer this, imagine the concentric layers of the "onion" are contracting simultaneously and at the same rate (i.e., gravitational free fall) and ask which layer will reach the central region first, second, etc.

First:

Second:

Last:

STEP 3: Let's model the rebounding of layers with a simple classroom model. The floor of the classroom will be the iron core of the star. The floor is an appropriate stand-in for the core because, like the core, it will provide a backstop that does not move during our experiment.

We will represent two of the rebounding layers using two balls, one heavier than the other. As the balls fall, they will strike the floor and rebound, just like the star's layers would when they strike the core.

If we are modeling just the *first two layers to reach the center*, the heavier ball (the basketball) best represents which layer of the star? And the lighter ball (the tennis ball) best represents which layer of the star?

Basketball:

Tennis ball:

Drop the basketball from chest height. Or watch the video "basketball only.mp4" on Canvas. Take note of how high it bounces (back to chest height? Waist height? Knee height? Something else?).

Drop the tennis ball from chest height. Or watch the video "tennis ball only.mp4" on Canvas. Take note of how high it bounces.

STEP 4: If we are mimicking what happens during stellar collapse, the balls should be falling simultaneously because the layers of the star are collapsing simultaneously. Furthermore, they won't reach the center at the exact same time. One layer will get there first, and will be "in the way" of the next layer as it tries to fall onto the core.

To model stellar collapse, which ball should land and rebound first, the heavier ball or the lighter ball? Why?

Let's prepare to drop the basketball and tennis ball simultaneously. Hold them at chest height so that they are in contact with each other, and hold them so that they are aligned vertically. You can hold them in one of two orientations:

OR

When the balls drop, which orientation would better imitate the structure of the collapsing star? Why? Hint: Look at your previous answer.

STEP 5: Try dropping the two balls together, vertically aligned, in contact with each other, and oriented the way you chose in the previous question. Or watch either video "tennis ball on top.mp4" or "basketball on top.mp4" on Canvas.

What happens to the rebound height of the tennis ball, as compared to when the tennis ball was dropped by itself?

Why does this happen? To find out, do the drop (or watch the video) again and notice what happens to the rebound height of the *basketball*. How does the basketball's rebound height compare to when the basketball was dropped by itself?

Energy cannot be created or destroyed. If the basketball didn't bounce as high this time as it did on its own, where did the basketball's missing energy end up going?

STEP 6: This models the basic mechanism of a **supernova** explosion. However, we've only modeled the rebound of the *first two* layers. You could try the experiment again with three balls, but it is very difficult to keep them all in a vertical line as they fall. What would make it easier to do more than two balls would be to have the balls strung along a straight wire, like beads. To see a demonstration of this, open the following URL in which physicist Brian Greene appears on the Late Show with Stephen Colbert (and sets a Guinness world record in the process):

https://youtu.be/75szwX09pg8?t=207

As you can see from our stack-of-balls model of a collapsing star, a lot of energy gets transferred from the star's heavier layers to the star's lighter layers. The lightest layer gets thrown *very* far away from the star's core (just as the lightest ball bounced very high above the floor, in our model).

Which layer (Fe, O, H, He, or C) of the star in Step 1 would be thrown the farthest by a supernova?

> Now we have an answer to where the extra energy comes from that a star needs to make elements on the periodic table that are heavier than iron. It comes from the stellar collapse itself. Elements heavier than iron are made in stars as a result of their death.

SQ7:

(a) Which fundamental force of nature provides the energy for a star to heat up and begin nuclear fusion? Hint: Think back to Part 1 about what was the initial cause for a star to get hot.

(b) Which fundamental force of nature provides the energy for a supernova explosion? Hint: Think about what force was the initial cause that ultimately results in the "rebounding" of the star's layers.

Part 6: Elemental Abundances

Right after the Big Bang, when our universe was young, the atoms in the universe consisted of mostly hydrogen and helium (and a tiny bit of lithium) which were created in the Big Bang. Based on careful analysis of the radiation signature left over from the Big Bang, we estimate that of the universe's first atoms, about 75% were hydrogen and about 25% were helium.

The universe's atoms *are still* mostly hydrogen and helium. Spectroscopic analysis of the Milky Way tells us that the Milky Way is about 74% H and 24% He. The remaining 2% of atoms in the Milky Way encompass the entire rest of the periodic table. Complete the following table by filling in the appropriate percentages. (Instead of 0% you can write <1% to account for round-off)

Percent Abundances	**Hydrogen**	**Helium**	**Rest of Periodic Table**
Young universe			
Universe today			

If, in the early universe, the atoms in the universe were predominantly just hydrogen and helium, then where did all of the other elements come from that now make up 2% of the atoms in our galaxy? We've already seen two mechanisms: (1) nuclear fusion inside stars and (2) stellar collapse leading to supernovae.

Metals like copper (Cu), nickel (Ni), zinc (Zn), lead (Pb), tin (Sn), mercury (Hg), silver (Ag), and gold (Au) are found in the Earth's crust. How were these elements likely made? Explain your reasoning. Hint: Find them on the periodic table first.

The following 12 elements make up 99.9% of our bodies and all are necessary for us to live. For each element in your body, where was it most likely created (circle one)?

Elements in the Human Body:

65%	Oxygen (O)	Big Bang	Fusion in a Star	Stellar Collapse
18%	Carbon (C)	Big Bang	Fusion in a Star	Stellar Collapse
10%	Hydrogen (H)	Big Bang	Fusion in a Star	Stellar Collapse
3%	Nitrogen (N)	Big Bang	Fusion in a Star	Stellar Collapse
1.4%	Calcium (Ca)	Big Bang	Fusion in a Star	Stellar Collapse
1.1%	Phosphorous (P)	Big Bang	Fusion in a Star	Stellar Collapse
< 1%	Potassium (K)	Big Bang	Fusion in a Star	Stellar Collapse
< 1%	Sulfur (S)	Big Bang	Fusion in a Star	Stellar Collapse
< 1%	Sodium (Na)	Big Bang	Fusion in a Star	Stellar Collapse
< 1%	Chlorine (Cl)	Big Bang	Fusion in a Star	Stellar Collapse
< 1%	Magnesium (Mg)	Big Bang	Fusion in a Star	Stellar Collapse

SQ8: Carl Sagan famously said, “We are made of star stuff.” Explain what he meant.

Biographical Aside: Carl Sagan was a Cornell astrophysicist that was known around the world in the 1980s for being the host of the TV show *Cosmos* (recently re-launched and hosted by Neil DeGrasse Tyson). He also wrote the novel *Contact*. Within the scientific community he was known for his work on the greenhouse effect, extraterrestrial life, and SETI (Search for Extraterrestrial Intelligence).

How do you think the atoms that were made by fusion inside a star ever left the star so that they could go on to one day make up planets and you and me?

At the right is a Hubble photograph of the Crab Nebula. The Crab Nebula is the aftermath of a supernova explosion.

Crab Nebula

In the photo, you are seeing the outer layers of a star that have been thrown off in a supernova explosion. Astronomers call this a **supernova remnant**.

The radius of this supernova remnant is about 6.5 light years in its longest dimension.

For comparison, the Sun to Pluto distance is 5.5 *light hours*. And our nearest neighboring star system, Alpha Centauri, is 4.2 light years from the Sun. This supernova blast wave *from a single star* would encompass all of our solar system and even our neighboring solar system. And, it's still expanding at a rate of 930 miles *per second*. It's difficult to imagine the incredible power of a supernova explosion.

SQ9: Stellar collapse and supernovae play two extremely important roles with regards to the elements we find on Earth and in our bodies. What are they?