Supernova Explosions

Summary

Students are reminded that the universe is made up of elements and that the heavier elements are created inside of a star. They are introduced to the life cycle of a star and how the mass of the star affects the process of fusion and the outcome of the star. The physical concept of balancing forces is discussed and an experiment is conducted to show what can happen to a soda can when the interior and exterior forces are not in equilibrium. An analogy is made between this experiment and core collapse in stars. Finally, it is demonstrated how mass can be ejected from a collapsed star. This is how the heavier elements are dispersed throughout the universe in a supernova explosion.

Purpose

To understand the life cycle of a star and the origin of the heavy elements in the universe.

Audience

Approximately 20 students (grade range 6^{th}-9^{th}) in a group works well

Objectives

- To introduce the life cycle of a star
- To discuss the forces at work inside a star
- To understand the role of mass in determining the extent of fusion and the fate of a star
- To learn about core collapse of a star
- To simulate mass ejection and understand how to populate the universe with the heavy elements from the interior of stars during a supernova explosion

Badge Requirements

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Materials

- colored balloons (1 of each of the following colors: red, orange, yellow, green, blue, and violet)
- empty aluminum soda can (needs to be clean; we recommend having an extra)
- hot plate (or Bunsen burner and screen/ring setup)
- large, deep bowl of cold water (the colder the better; ice helps)
- tongs or oven mitts
- Hoberman sphere
- basketball (or soccer ball)
- tennis ball
- different colored balls of clay – some to represent hydrogen, some to represent helium (optional)

Preparation

It is a good idea to practice the imploding can trick before you are called upon to perform in front of students. Make sure that you can see a good stream of steam from the can before inverting it onto the water. Ice water works best, and it's a good idea to have several empty cans set to boil in case one does not work.

Also, it may take a while for the water in the can to boil, so it's a good idea to start it heating before starting the activity, or have a helper set it up ~15 minutes before you get to that part of the activity.

Activity

This activity can be completed in 45 minutes. A sample script and flow of discussion follows.

I. Review the concept of elements (approximately 10 minutes)

As the activity begins, ask the students what they have learned about elements in the universe (if they have already participated in the Elements and You activity) or what they know about elements (if they have not participated in the Elements and You activity). Remind them that the elements of which they are made (carbon and oxygen, for instance) are very rare in the Universe and are made in stars. They should know that the stuff created inside stars needs to get out somehow (in a big explosion). Try to ask them questions and unearth any possible misconceptions before the rest of the activity begins. What is an element? What are different kinds of elements? What is an atom? What is an atom made of? (Possibly a misconception will be the distinction between an atom being the smallest unit of an element, but not the smallest unit of matter. Atoms are made of protons, and neutrons, and have electrons orbiting around them.)

In this activity, and with your help, we are going to figure out how to make a star EXPLODE in order to distribute different elements into the universe! Not all stars will become supernovae, so first we need to understand the life cycle of stars... (Be careful with this. We tend to anthropomorphize stars, and people get the impression that they are alive.)

II. Stellar Life Cycle *(approximately 10 minutes)*

How do different sized stars behave and how do they age?

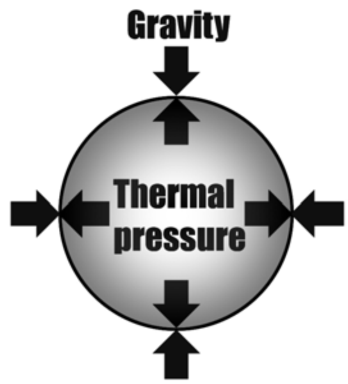
Ask the students about what they know about pressure. What is pressure? What kinds of pressure do you know about?

A key concept to reinforce is that there are different types of pressure at work in a star – two of these are pressure from gravity and gas pressure from hot material. Most important is that the (self-)gravity of a star is trying to push everything down, and other types of pressure fight it.

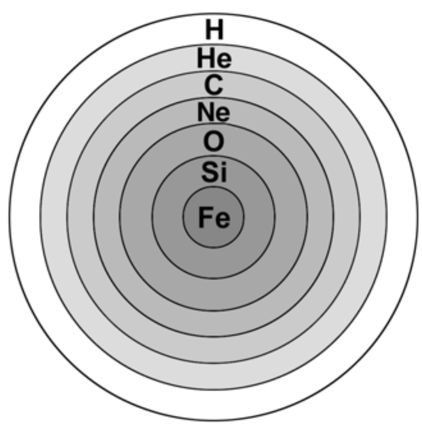
1. **What is fusion?**
   All stars start fight gravity by releasing large amounts of energy through fusion. Fusion is the process stars use to create different types of elements. Lighter atoms

join together to create heavier atoms and release energy. This is a complicated process, but we can think of it simply. Remind them of the demonstration with clay balls from the morning's Elements and You activity.

The more mass that a star has, the hotter it can get in its core, and the more it can use energy from fusion to support itself from collapse, because the pressure from the fusion energy pushes outward against the gravitational pressure pushing inward. The key here is that these forces are in balance through most of the star's life.



Bigger stars can fuse heavier and heavier elements. This process stops with Iron (Fe), if you remember from the Elements and You activity. This process creates layers of different elements like an onion skin.



(It is helpful to have the model star to refresh their memories.) We'll talk about Iron more in a few minutes.

2. **What happens at the end of Fusion?**
Ultimately, all stars will loose the ability to fuse elements, because they run out of elements that they can fuse. At this point, the core may be dense enough to support itself – the gravity pushing down is not strong enough to crush the core. (The following description (adapted from http://www.adlerplanetarium.org/) demonstrates at what

stage a star looses this ability to fuse elements and whether the star is light enough to support itself by other means.)

3. **So, what are the different kinds of stars, and what happens to them?**
The way a star changes over time (or evolves) depends completely on the mass it has when it forms. Now, we'll look at how mass affects what happens to them as they evolve. Ask the students whether they think the most massive stars will be the hottest or the coolest. (Answer: hottest.) Ask them what colors of light come from the hottest and the coolest things. (Answer: hottest stars are bluer and cooler ones are redder – they may or may not come up with this response.) Have six students blow up balloons according to the following table.

Main Sequence Star Masses, Balloon Diameters, and Balloon Colors

Spectral Class	**Relative Mass**	**Balloon Color**	**Relative Radius**	**Balloon Diameter**	**Comments:**
O	23	Violet	7.4	19 in	Fuse → Fe – run out of fuel
B	8	Blue	4.3	10.5 in	Supernova → Black Hole
A, F	1.6	Green	1.4	4 in	Supernova → Neutron Star
G (SUN)	1	Yellow	1	2.5 in	Fuse → O – stable "white dwarf"
K	0.8	Orange	0.8	2 in	
M	0.4	Red	0.6	1.5 in	Fuse → H, He – stable, cool

(Note to Astronomers: We use table B1 from Gray to roughly convert balloon color to size.)

(Note to Classroom Leader: This is a table of Main Sequence (ordinary stars that shine because of fusion) – NOT evolutionary states)

(If you want to insert another color to include A stars, use VIBGYOR=OBAFGKM, letting "indigo" be B stars [black or dark violet will do if dark blue is not available] or WVBGYOR=OBAFGKM, letting white be O stars. The A balloon should be blown up to something like 8 in.)

A common way to remember the spectral types in order is with the pneumonic, "oh be a fine girl, kiss me."

<u>Red/Orange Stars</u>: These are very cool stars. They can fuse hydrogen into helium, but not much else. The helium in the core won't get hot enough to fuse together. The star will cool off and become fairly useless. The same kind of pressure that keeps us from sinking into the ground due to gravity will hold up the star against gravity until the end of time.

Yellow/Green Stars: These stars are similar to our Sun. They can fuse hydrogen into helium. It can also get hot enough to fuse the helium in carbon and oxygen, also lithium, boron, and beryllium. But, that's all. The star can't get hot enough to fuse carbon or oxygen into heavier elements, but the star is light enough that the dense carbon/oxygen core can support the star. This is called a white dwarf. No supernova here.

Blue/Violet Stars: Now we are getting somewhere! This is a really hot and really massive star, and it can do all the things the other stars can do and more! Fusion of elements will continue until the core is iron. But here, we run into two problems: (Ask students what these might be.)

(1) Iron can't fuse into anything else (they should have learned this in the Elements and You activity).
(2) The star is too massive to be supported by the iron core in the same way the other stars are.

So we've reached a breaking point. The iron core is going to get hotter and hotter and hotter until, through a complicated process, the Iron atoms come apart into the smaller components. This leads into the next activity.

III. Implosion *(approximately 10 minutes)*

Why do Stars Collapse?

The core of the blue/violet star now has no way supporting itself against gravity. So what happens when there is a sudden decrease in pressure that supports the core?

Demonstration of Core Collapse
(adapted from http://chandra.harvard.edu/graphics/edu/formal/demos/contraction.pdf)

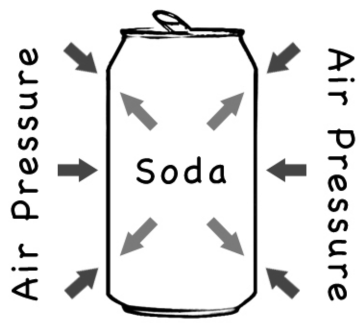
Warning: Make sure students don't get too close to this one! The hot plate remains hot for most of this session!

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.

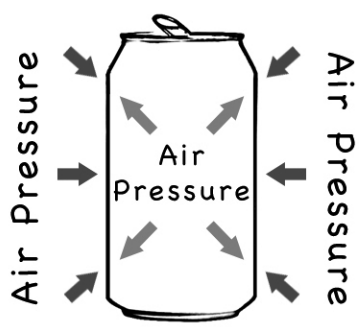
2. Place approximately two tablespoons of water in an empty aluminum soda can. Set the can on a hot plate or a screen/ring setup over a Bunsen burner. Heat the can until the water starts to boil. When plenty of steam is coming out of the opening in the top of the can, quickly pick up the can with an oven mitt or tongs and invert into a bowl of cold water. The can will instantly implode with a crunching sound.

Why does this happen?

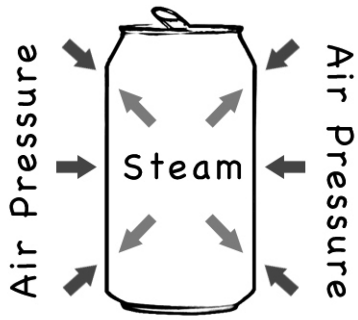
When you buy the aluminum can from the store and it still has liquid in it, the can holds its shape due to the equilibrium between the pressure from the soda inside directed outward and the pressure of the air outside of the can directed inward.

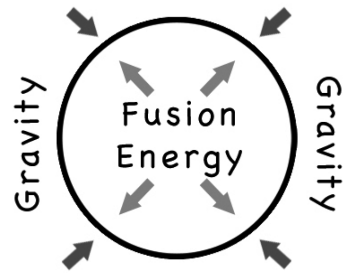


After the can has been emptied of liquid, the shape is held in equilibrium by the pressure of the air inside the can directed outward and the pressure of the air outside of the can directed inward.

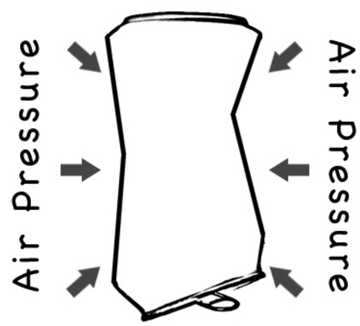


Heating the water in the can causes it to turn into steam, which drives the air out of the can because the steam has higher pressure. Now the can is held in equilibrium by the pressure of the steam pushing outwards (analogous to the radiation pressure in the core of the star) and the pressure of the outside air directed inwards (analogous to the gravity of the star directed inwards).

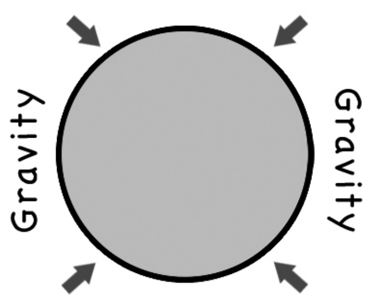




When the can is inverted over the cold water, the steam instantly condenses into water. The water occupies a much smaller volume than the steam did, resulting in much less pressure inside the can. With nothing on the inside to balance the outside pressure the can will implode (like the core of a star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



This is sort of like what happens in a supernova, the end of the line for large stars. The star collapses 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.

IV. Getting from an Implosion to an Explosion *(approximately 5 minutes)*

So we saw that the can imploded because the pressure inside the can disappeared. So why do we get an explosion?

Here we have a cool plastic sphere (show them the Hoberman sphere), and we can use it to simulate the imploding core of a star. (Open the sphere all the way, and then let it collapse under its own gravity. – You can have a student do this.) So what happened after the sphere collapsed? That is right, it "bounced" at the end. (The bounce can be a little difficult to see. You'll probably want to show them the collapse and bounce a few times.) It started to collapse, but then the collapse stopped because stuff falling in from one side collided with the stuff falling in from the opposite side.

V. Mass Ejection *(approximately 10 minutes)*

How does the material from the interior of a star find its way out?

Now the core of star collapsed, and then bounced when it collided with itself. But a star is made up of more than merely a core, it also has an atmosphere like the Earth, only much thicker. So when the core collapses, what happens to the atmosphere?

Demonstration of Atmosphere Ejection
(adapted from http://chandra.harvard.edu/graphics/edu/formal/demos/ejection.pdf)

(You can let students try this, but be careful with the tennis ball's rebound!)

First drop the tennis ball and basketball individually on the floor so that the students can see how far above the floor the basketball and the tennis ball rebound. Then place the tennis ball on top of the basketball and hold them out in front of you. Let go of both balls at the same time so that they fall towards the floor together. When the two balls hit the floor the tennis ball will suddenly rebound with enough energy to hit the ceiling.

Related Physics: The basketball represents the outer part of the core – Be careful that the students know what you mean. They might think that the basketball is the core, and the core somehow falls as a whole or moves in some direction. Also, explain that the smaller ball represents the atmospheric layers of a star. Students probably haven't thought about atmospheres in terms of stars, and we don't want them to come away with the idea that stars have clouds and air around them!).

When the core of the star implodes it contracts catastrophically, just like the imploding can. At the end of the contraction the material in the core comes together with such a large amount of force that it rebounds. As the core contracts, all the outer atmospheric layers are also contracting and following the core. They are less dense and take a little longer to contract than the core. When the core (basketball) rebounds, the atmospheric layers (tennis ball) are still in-falling towards the core. The rebounding core meets the incoming atmospheric layers with enough energy to literally blow the atmospheric layers away from the star due to the transfer of momentum from the basketball to the tennis ball. This is the supernova explosion.

V. **Wrap-up** *(approximately 5 minutes)*

- Not all stars will end their lives in a spectacular supernova. Without help, only the ones that are massive enough to try and fuse iron will do so.
- Every star is fighting against gravity, and they start doing this using the energy released by fusing hydrogen into helium. Some stars will only get this far, and those will end up fighting gravity the same way the ground fights gravity, keeping us from falling to the center of Earth.
- Other stars can get hot enough to fuse helium, etc. The hottest/most massive stars will get to the point where they have an iron core, but this is a problem because iron doesn't fuse and stars are too massive to be supported any other way.
- There is a sudden drop in the core pressure of a massive star, and the whole thing will start to implode. Stuff in the core and bottom of the atmosphere will "bounce" when it meets other stuff falling in from the other side, and this bounce will cause the outer layers of the atmosphere to violently explode (fly outward). In the remaining core, the neutrons might be able to hold up what's left. This is what's called a neutron star, and it can be observed in the X-ray wavelengths. If the remainder of the core is too massive even for neutrons, it will become a black hole.
- (Most stars have companion stars. Sometimes yellow stars can become supernovae if they have a companion which helps them by adding more mass – the same way you can collapse a table if you pile up enough stuff on it.)

Supplementary Information

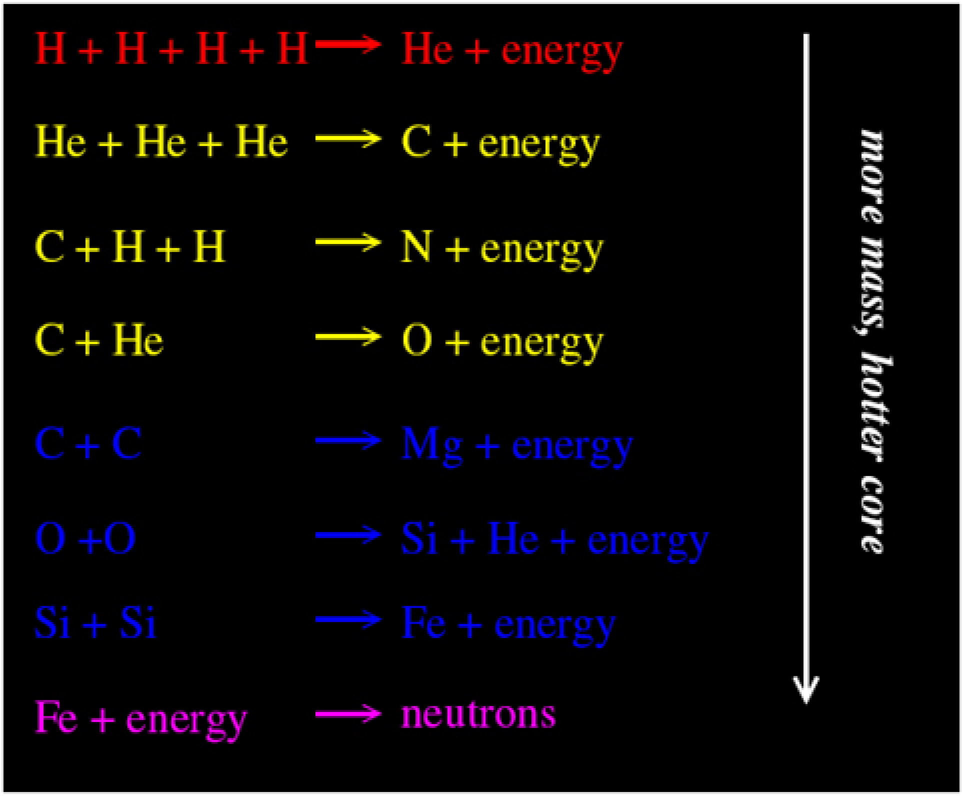
WARNING - Most of this is at a higher level than should be needed and is only for extra information for the further understanding of the instructor, answering questions, or adapting to a more mature audience.

SPECTRAL TYPES:

*** If you mention the names of the spectral types, the students might ask about OBAFGKM. ***Astronomers classify stars by their spectra – the colors of light they emit. Most stars actually emit many kinds of light, but a star can look one color, because that is the brightest part of its spectrum. When people first started looking at the spectra of stars, they looked especially at the amount of light coming from Hydrogen. They called the stars with the most Hydrogen emission type A, then type B, C, and so on. Later, people realized that thinking of classes of stars by what color they were made more sense and gave more information, because the bluest are also the hottest, brightest, and most massive, while the reddest are the coolest and least massive. So, the classes (A, B, C…) were reordered, and some of them dropped out, and we ended up with OBAFGKM (from blue to red, hot to cool, high mass to low mass).

Some kinds of stars or other astronomical objects are brightest in colors that we cannot see with our eyes, but that does not mean that they do not put out some light in the optical. (They may have talked about different kinds of light in the Rainbow Analysis Activity.) Astronomers have special cameras and telescopes that can look at different kinds of light to study different astronomical objects. Sometimes people also use these cameras on Earth. "Night Vision Goggles" might let people see infrared light.

FUSION Processes :
This table shows simplified versions of the fusion processes that occur in different mass stars. The colors mostly correspond to the colors in the table Stellar Life Cycle section of this description. However, violet in the Stellar Life Cycle table represents the very largest, hottest, most massive stars. Here, violet represents the end stage of these very massive stars, in the Super Nova collapse.



Red stars are the coolest and can only fuse Hydrogen to Helium (also some Lithium, Beryllium, and Boron).

*** Students are likely to ask what will happen to the Sun. Here is a bit more than is included in the main description *** Stars of intermediate are yellowish (like the Sun) and can fuse Hydrogen to Helium and then fuse to Carbon, Nitrogen, and Oxygen (also some Lithium, Beryllium, and Boron). Stars with masses less than about 1.44 times the mass of the Sun "explode" and become Red Giants. The part that collapses cannot fuse past Carbon, Nitrogen, and Oxygen, so it collapses more. Eventually, it stops collapsing because of laws dealing with electron energy states.
The very hottest stars appear Blue and can continue the process of fusion (in shells, as described in the Elements and You activity) until they fuse to Iron in their cores.

Iron is the most stable element, so it is very difficult to fuse into more massive elements. More energy is needed to start the process than comes out of the fusion. These fusions do occur sometimes in the cores of stars, but their net result is to absorb energy rather than release it. They cannot happen very often, and they definitely cannot make a star shine. We know they happen once in a while, because we have elements that are heavier that Iron (which is only number 26 on the Periodic Table). This is why these heavier elements are *so* rare in the universe (on average).

Once the core of one of these very massive stars has enough Iron, the core cannot support the weight of the outer parts of the star, and collapse occurs as described above. The collapse adds energy to the left over core of the star. This makes the electrons and protons in the Iron atoms combine to form neutrons (the Violet step in the table above). Since neutrons are much smaller than the Iron atoms as a whole, the whole thing collapses even more.

Stars that are heavier than about 3 Solar masses become Black Holes. There is so much pressure and energy in these collapses that they overcome the neutron degeneracy pressure, pushing the neutrons closer and closer together, until there is no pressure pushing outward to fight the gravitational pressure that pushes inward. When this balance of pressure is unbalanced, the star explodes. Depending on its mass, it can become either a supernova or other type of stellar remnant.