Objectives

- Identify the relationship between the life cycle of stars and production of elements
- Describe how different elements were formed based on the mass of the element
- Explain the relationship of initial mass and a star's life cycle
- Describe how the electromagnetic spectrum provides evidence of a star's composition, motion, and distance

Key Terms

Nucleosynthesis
Nuclear fusion
Main sequence stage
Red giant
White dwarf
Supernova
Light spectra
HR diagram
Absolute magnitude
Apparent magnitude
Redshift
Blueshift

Figure 1

Stars and Elements

Have you ever wondered about the origin of the chemical elements? Would you believe they formed in the stars in the universe? The elements that make up all matter on Earth were created during the life cycles of stars.

Everything in the universe originated in the first few minutes after the big bang. This process, big bang **nucleosynthesis**, produced a massive amount of hydrogen as well as smaller amounts of light elements, such as helium and lithium. Heavier elements, such as carbon and neon, were formed in the cores of stars during **nuclear fusion,** the joining of two lower mass elements to form a higher mass element. Elements as heavy as iron were formed by nuclear fusion in more massive stars. Even heavier elements, such as gold and platinum, were formed in supernovas, the deaths of massive stars.

Analyzing the absorption and emission spectrum of stars provides us with evidence of the process of nucleosynthesis and the creation of all elements in the universe.

Origin of Elements

Scientists hypothesize that as soon as one second after the big bang, protons and neutrons formed. A hydrogen nucleus consists of a single proton, hence the first element was born. Protons and neutrons would have crashed into each other and formed the heavier hydrogen isotope nuclei, deuterium and tritium, as well as helium and some lithium nuclei. There were so many particles during this time that no light could pass through; it was like a dense cloud in which particles were scattering light in all directions.

What about the electrons? They were present, but the temperature of the early universe was too high for them to combine with the nuclei to form neutral atoms until sometime between 300,000 to 500,000 years after the big bang. When neutral atoms finally formed, light energy could travel outward without being scattered. This energy is called the cosmic microwave background (CMB) radiation. The CMB is still present throughout the universe and has provided us with clues about the universe's formation.

Stars had to form for most of the elements to be created. Stars are referred to as stellar ovens because they use nuclear fusion in their cores to create the lighter elements. This usually occurs in the first half of the star's life cycle. The more massive a star, the heavier the elements it can make in its core, up to the elements iron and nickel.

Big Bang Nucleosynthesis

Nucleosynthesis is the creation of new atomic nuclei from nucleons, primarily protons and neutrons, under the right conditions. Immediately following the Big Bang, the universe was a hot, dense place. As this universe expanded, it cooled down. Within the first few minutes, protons, neutrons, and electrons combined and rearranged rapidly. Hydrogen was formed from one electron and one proton joining together. This is referred to as Big Bang nucleosynthesis. During this time, hydrogen, helium and lithium formed as the building blocks for stars and galaxies. No other elements were formed at this time because the energy was used up.

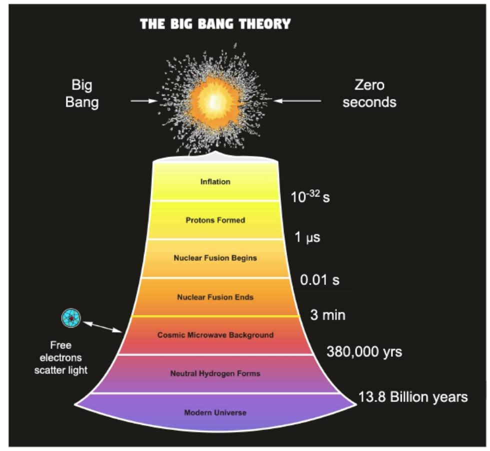

Figure 2

Stellar Nucleosynthesis

As the number of lighter elements grew, the force of gravity caused them to come together in large clouds of gas and dust and collapse into the birthplace of stars. These areas of coalescence were very hot and dense and provided a place for nuclear fusion to begin. With the force of gravity and pressure squeezing in, hydrogen nuclei combined to form helium. The byproduct of this fusion was energy release, and the newly created stars began to shine. As this energy was released, an outward pressure was created in each star. This outward pressure keeps the star from collapsing in on itself. The inward pressure of gravity keeps the star from exploding and ejecting its material into space. This time of balanced outward pressure and inward gravity is called the **main sequence stage** of a star's life.

A star will stay in this state until the hydrogen fuel source begins to run out and the core shrinks due to higher mass and stronger gravity. As the star shrinks, the temperature increases and creates conditions for helium fusion to occur. Helium fuses into carbon and oxygen. What happens next depends on the size of the star. The lifetime of a star depends on how much matter the star has during its initial development. Stars formed from a massive amount of matter burn quickly and last as little as a few hundred thousand years. On the other hand, stars formed from less matter can last for billions of years, as they burn much more slowly. If the star is roughly three times the mass of the Sun or larger, the process of stellar nucleosynthesis will continue.

For stars that are closer to the Sun's size, the outer layers of the star are shed as the star dies. The star expands and cools and becomes a **red giant** (figure 3). Red giants can expand to about 100 million to 100 billion kilometers in diameter, the equivalent of 100 to 1,000 times the size of our Sun. The outer layers are rich in carbon, oxygen, and nitrogen and form a ring structure called a planetary nebula. The core, no longer kept inflated by the heat generated by fusion, contracts into a ball of super hot matter called a **white dwarf** star, roughly the size of Earth.

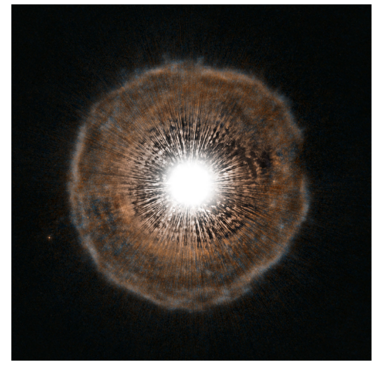

Figure 3

Massive Stellar Nucleosynthesis

Stars that are three times the mass of the Sun or greater have a greater gravitational pull that leads to greater temperatures and the ability to fuse carbon, oxygen, and nitrogen further. Elements such as magnesium, aluminum, sulfur, and chlorine are created. These elements layer upon one another such as an onion, with the lightest elements at the top and the heaviest at the core for fusion. Each stage of fusion provides less energy, which forces the star to burn its fuel faster to generate enough heat to stay in balance and resist the pull of gravity.

While a star's life is long, the final fusion processes last only about 12 hours in the most massive stars until the fusion into iron begins. In less massive stars, once iron fusion begins, the life span of the star is seconds. Fusion cannot carry on past iron because it takes more energy to fuse iron than is released. The loss of heat causes the star to begin collapsing, leading to the final stage of nucleosynthesis.

Supernova Nucleosynthesis

The core of a supermassive star rapidly collapses from tens of thousands of kilometers to only 20 kilometers in diameter. The process is so violent that the protons and electrons fuse into neutrons in the core. The outer layers collapse into the super dense ball of neutrons and rebound. This blasts the outer layers back into space. Again, size matters. The more massive of the massive stars will rebound so hard that the core collapses further and becomes a black hole. The less massive will leave behind a ball of neutrons, forming a neutron star.

During this process of contraction, collision, and rebound, the outer layers mix with one another, colliding violently and forming atoms larger than iron. This includes radioactive isotopes, gold, platinum, and uranium, which are flung far into space. This is the **supernova** stage of a massive star's life cycle and how we came to have heavier elements after the big bang.

Spectral Analysis

Scientists use the brightness and **light spectra,** or colors seen, of stars to determine their compositional elements, distances from Earth, and movements. The electromagnetic spectrum is a chart showing all forms of electromagnetic radiation in the order of increasing or decreasing wavelength, or frequency. Only a small portion of electromagnetic radiation can be seen as visible light or felt as heat, or infrared energy. Figure 4 shows the electromagnetic spectrum with the visible light spectrum highlighted.

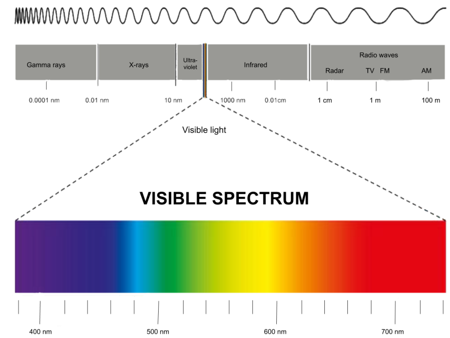

Figure 4

Any object, when heated past a certain temperature, will produce light. The color of the light changes as the temperature increases. This is referred to as Wien's law. Cool objects produce reddish light, while hotter objects produce yellow, blue, or violet light. This concept applies to stars. Cool stars are reddish in color, while hotter stars are yellow, white, and blue, with blue the hottest. Analysis of the specific wavelengths of light produced by a star is called spectral analysis. The **HR diagram** shown in figure 5 is a graph of star temperature to star brightness. Patterns emerge showing how stars group into categories by these characteristics.

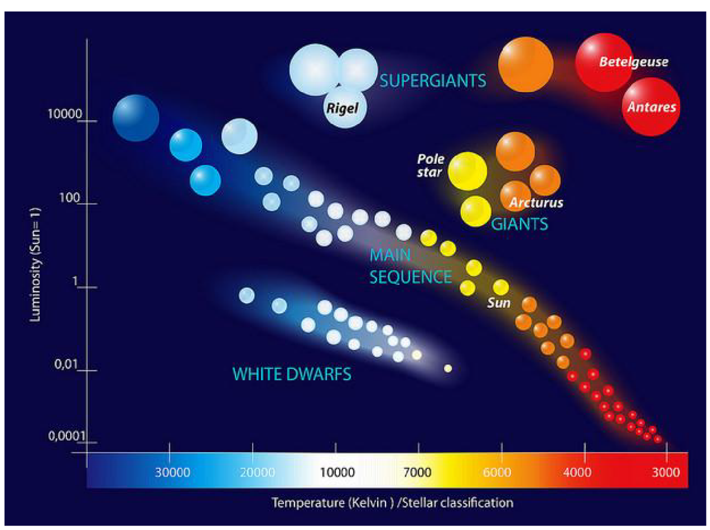

Figure 5

If light from a star is separated out to show how intense the light is at each wavelength, peaks and valleys are visible. Elements create specific wavelengths of light as they are heated and release the energy as light, called the emission spectrum. For example, sodium produces light that falls in the yellow region of the visible light spectrum. This information can be used to determine which elements are present on the surface of a star. The surface of the Sun shows that hydrogen and helium make up 75% and 24.5%, respectively, of the mass.

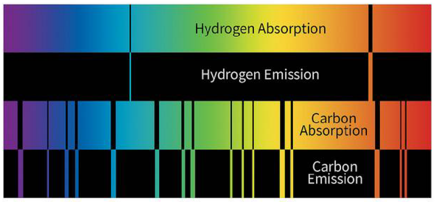

Figure 6

Light from other stars tends to show chemical compositions similar to the Sun's. But when the light from distant stars shines through clouds of dust and gas, some of that light is absorbed by the atoms present. This absorption process is similar to the emission spectrum except that, instead of bright lines, there are dark bands. This enables scientists to detect elements in the clouds of dust and gas that surround stars. Analysis of absorption bands shows that clouds of dust and gas that surround stellar corpses contain metals, carbon, oxygen, and heavier elements in abundance. These elements are not found in nearly as high of quantities in the star emission spectrum. Figure 6 shows absorption and emission spectra for two abundant elements, hydrogen and carbon.

Distance to the Stars

There are two basic techniques for determining a star's distance from Earth. The first method uses trigonometry and a phenomenon called parallax. Parallax is the apparent motion of an object according to the change in position of the observer. For example, hold your right index finger about 30 centimeters in front of your face. Close your right eye and observe your finger's apparent position with respect to what is behind it. Now quickly close your left eye and open your right eye. Your finger should appear to move. The distance your finger seemed to move is a measure of its parallax (figure 7).

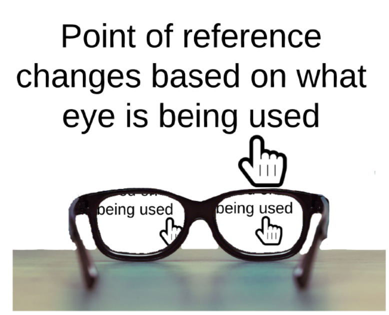

Figure 7

Since Earth makes one revolution around the Sun every year, an astronomer can observe a star on two occasions that are six months apart and that are a known distance apart since we know Earth's orbital diameter. The astronomer can then measure the apparent angles and parallax of the star from Earth. The distance of the star can be calculated from this data in a process called triangulation. This process works well for stars that are about 400 light-years or closer to Earth.

This method does not give accurate distances for stars farther than 400 light-years from Earth. Astronomers have to use an indirect method to determine the distances of these stars. Instead, they use brightness measurements, which are determined from a star's light spectrum. They determine the star's **absolute magnitude** based on the light spectrum produced by the star and compare it to the apparent magnitude of the star from Earth to estimate the distance to the star. The farther away from Earth a star is, the dimmer it appears to us, this is the **apparent magnitude.**

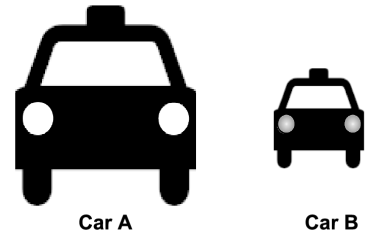

Figure 8

Think about how car headlights look dimmer the farther away they are from you and how they appear brighter as they approach (figure 8). Car A and B are the same cars with the same headlights. But as Car A is closer, the headlights appear to be brighter, that is similar to a star's apparent magnitude.

Motion of the Stars

Scientists can study the light spectra of stars to determine their movements. When stars move away from us, the wavelengths of the light we observe from them appears to be shifted to the red end of the visible spectrum on the electromagnetic spectrum. The faster they are moving away, the farther the shift appears. This phenomenon was discovered when looking at galaxies, which are easier to see based on their size but can be applied to stars as well. This shift toward the red end of the spectrum is aptly called **redshift**. Similarly, if something is moving towards us, it is called **blueshift** (figure 9).

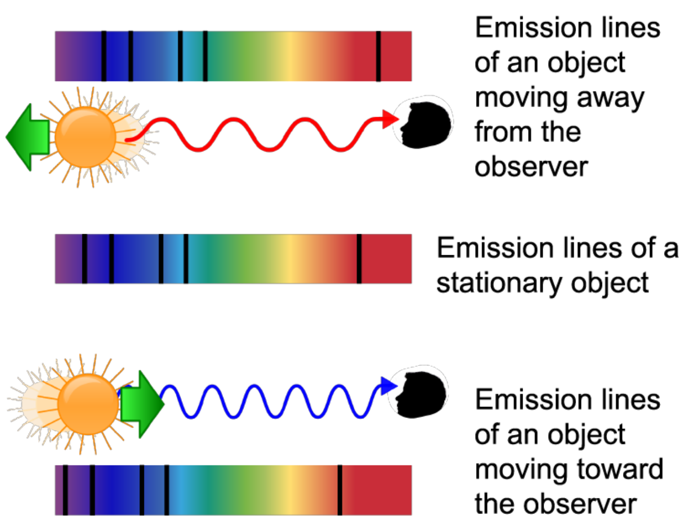

Figure 9

Beyond the Classroom

The stars have been used for centuries. Whether used for travelling across the ocean or barren desert, as a calendar for planting and harvesting crops, or to perpetuate myths and folklore, the stars have played a vital role. Ancient cultures used the visibility or disappearance of certain stars to help mark the changing seasons. The grouping of certain brighter stars into recognizable shapes made it easier to read the skies and resulted in what we refer to today as constellations.

Astronomers officially recognize 88 constellations. These constellations cover the sky from the northern to southern hemispheres. Currently the constellations include 14 men and women, nine birds, two insects, 19 land animals, 10 water creatures, two centaurs, one head of hair, a serpent, a dragon, a flying horse, a river, and 29 inanimate objects. Some constellations include more than one figure. Even though these were named as objects that would be recognizable by most, it is important to note that there is little if any resemblance to the figures they are named after. It is assumed that these names were meant to be more symbolic than literal, but it is always fun to try and figure out just how they got the names they did.

Using reliable internet resources, research the following:

1. Who invented the constellations?
2. Are there any constellations that no longer exist?
3. How are individual stars named?
4. Are any constellations considered permanent?

Stars and Elements Review

Reviewing Key Terms

Use each of the following terms in a separate sentence.

1. Supernova
2. Nucleosynthesis
3. Redshift
4. Main sequence star
5. Nuclear fusion

Use the correct key term to complete each of the following sentences.

1. ________ is the range of light waves emitted by a celestial body including visible light and other electromagnetic radiation.
2. The formation of heavier elements from lighter elements is called stellar ________.
3. A ________ is what a small to medium-sized star becomes late in its life when it has used up its hydrogen in nuclear fusion and starts burning heavier elements.

Reviewing Main Ideas

1. If a star is more massive, it will:
    a. have a longer life.
    b. have a shorter life.
    c. have no life.
    d. live forever.

2. Which element is the most abundant in the universe?
    a. Helium
    b. Iron
    c. Hydrogen
    d. Oxygen

3. What is the final stage of a supermassive star?
    a. Neutron star
    b. Black hole
    c. Supernova
    d. White dwarf

Making Connections

1. Describe the relationship between star mass and lifetime.

Open Ended Response

1. Describe how we measure the distance to other stars.

2. How does stellar mass impact the life of a star?

3. What does the color of a star tell us about it?

4. Describe the process of nucleosynthesis and the order of element production.