Investigating Stars Name:____Block:_____________

FYI: The Lives of Stars **E3:R6b**

1. Read FYI: *The Lives of Stars*

   As you read use the spaces below to write down any information you find especially interesting. Also define the bold terms used in the text. If you run across any other words that you don't know the meaning of, write those down and ask your teacher to help you with them.

Word/Term	Definition/Question
Molecular Cloud	
Protostar	
T-Tauri Stars	
Red Giant	
Helium Flash	
Planetary Nebula	
White Dwarf	
Black Dwarf	
CNO Cycle	
Red Supergiant	
Supernova	
Neutron Star	
Black Hole	
Extra space for additional words or interesting information.	

1. What is the primary difference between the evolution of a low-mass star and that of a high-mass star?

2. Why do astronomers say that we are mad of "star stuff?"

FYI The Lives of Stars

All stars begin their lives in a similar way, no matter whether they will end up as large or small stars. All stars form in a vast cloud of gas composed of hydrogen, helium, and dust, with small traces of heavier elements. These large areas are called **molecular clouds**. The process of star formation begins when a shock wave hits the gas cloud from a nearby supernova explosion, or from another star-forming cloud. The impact of the shock wave makes particles collide, and gravitational force begins to pull and squeeze the particles together, forming smaller clouds. As these smaller clouds continue to be squeezed into ever more tightly compressed clouds, they form what will eventually become a **protostar**.

Since some of the smaller clouds within the large molecular cloud have more mass than others, they will become high-mass stars, and the ones with less mass will become low-mass stars. The individual gas clouds keep collapsing in on themselves because of gravitational attraction. As they collapse, they rotate and get hotter and progressively more dense in their centers. Soon the core of the cloud is a hot, dense ball of hydrogen gas—so hot and dense that the hydrogen atoms start colliding with each other violently until they fuse into helium atoms. At this stage of their lives, at the onset of nuclear fusion, the stars are known as **T Tauri stars**.

This process of nuclear fusion (turning hydrogen into helium) generates even more heat in the core of the new star. The heat creates thermal pressure, which causes the star to push outward and slows the gravitational collapse. Now gravitational force is pulling inward on the star and the gas pressure is pushing outward. During the life of each star, its stability depends on balance between these two forces—the outward push of gas pressure and the unrelenting inward pull of gravity. When these two forces are balanced, the star enters the longest phase of its life on the main sequence. After this point, high- and low-mass stars take very different evolutionary tracks.

Figure 2-15: Image of the Eagle nebula, a stellar nursery in which stars are born in clusters

Low-Mass Stars (0.5 to 3 solar masses)

When low-mass stars reach the main sequence, they are typically yellow or red class G, K, or M stars, and are slow burning. After a long, stable main sequence life of approximately 10 billion years, the hydrogen in the core of a low-mass star starts running out, the fusion ceases, and the gas pressure gives in to gravitational force, which compresses the core. As the core collapses in on itself, it heats up and gets denser. This is the beginning of the end of the stable life of the low-mass star.

As the core of the star collapses, getting hotter and more dense, it heats up the outer layers of hydrogen nearer the surface of the star. The net result is that a shell of fusing hydrogen envelops the core of the star. Since the hydrogen shell is closer to the surface, the gas pressure exceeds the gravitational forces pushing down, and the star swells up to 50 times its original diameter and becomes a **red giant**.

Deep inside this swollen giant star is the core, made up of very dense helium, about 1/100 the diameter of the original star. As the hydrogen shell burning proceeds, the temperature in the core of the star rises. Ultimately, the temperature in the core becomes hot enough (100 million degrees K) for helium to burn within. But, because the core is so dense, the helium begins to fuse, generating an enormous amount of energy in a matter of minutes. This is called the **helium flash**.

With the onset of helium fusion, the star shrinks somewhat and becomes less red and more yellow. The fusion of helium results in a hot, dense core of carbon. But eventually, after a billion years of steady burning, the fusion of helium slows, and shell burning of both hydrogen and helium commences, again driving the outer layers of the star outward. This time the star expands to over 300 times its original size and enters a second red giant phase of its life.

The center of a low-mass star never reaches the temperature required for fusing carbon. Instead, the star continues to expand and collapse, often going through a red variable star phase. Eventually, the outer layers of the star will separate completely from the core and will continue to expand out into space. The glowing ring (or rings) of gas that this process produces is called a **planetary nebula**. This term has nothing to do with planets.

Figure 2-16: X-ray image of Proxima Centauri, which is the nearest star (other than the sun) to Earth. A red dwarf star, it will exist many billions of years after our sun has evolved into a white dwarf star.

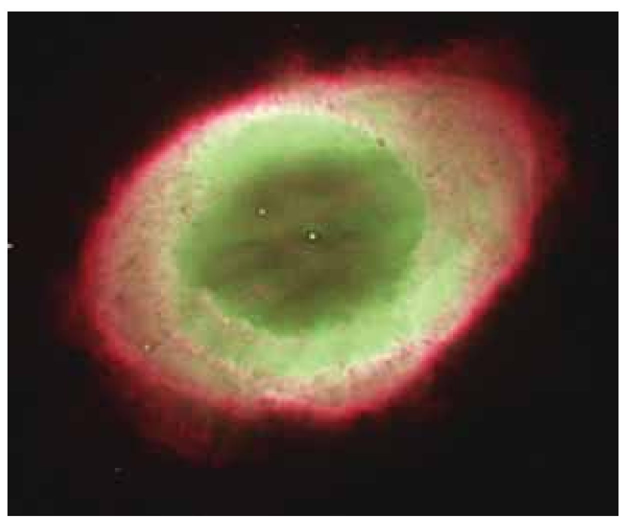

Figure 2-17: Image of The Ring—a planetary nebula in the constellation Lyra. The red light is ionized hydrogen; the green is ionized oxygen. The remainder of the star, a white dwarf, can be seen at the center of the shells of gas.

It is called a planetary nebula because the first people to observe it through a telescope thought it looked like a greenish object and figured it might be a planet. A planetary nebula will continue to glow and expand for thousands of years as the hydrogen layers of the dying star are continually thrown off, heated and pushed away by the energy from its center. After 50,000 years or so the shells of gas expand into space and dissipate into the nebula, producing the gas and dust that will form the next generation of stars.

The part of the star that remains is its profoundly dense, white-hot carbon/oxygen core. Because it is so small (less than 1/100 the diameter of the original star), this core is called a **white dwarf**. The white dwarf will slowly cool, taking up to a trillion years to turn into a **black dwarf**—what amounts to a charcoal briquette in space—about the size of Earth. The universe is still too young for any stars to have completed this process.

High-Mass Stars: (> 3 solar masses)

When high-mass stars reach the main sequence stage, they are typically very bright and very hot. They are blue or white in color, class O, B, or A stars. The more massive a star, the shorter its lifetime. A star with a mass ten times that of our sun may have a main sequence lifetime of only 10 million years, a small fraction of a red dwarf's 100-billion-year life span. High-mass stars fuse hydrogen into helium through a series of nuclear reactions called the **CNO (Carbon-Nitrogen-Oxygen) cycle**. The result is the same as for the normal proton-proton fusion reaction: four hydrogen atoms are fused into one helium nucleus plus some particles and lots of energy.

When these stars use up the hydrogen in their core, the burning slows down, and the energy developed in the core decreases. Thus, the gas pressure pushing outward from the center decreases. At this point, the gravitational force squeezes the core and makes it contract, raising its temperature. Fusion in these stars proceeds quickly from hydrogen to helium fusion, as temperatures in the core of the star are much greater than those in low-mass stars. Hydrogen will continue to fuse in the star's outer shell. No helium flash occurs in high-mass stars.

As the fusion in a high-mass star proceeds, the outer layers of the star expand and the star quickly swells to hundreds of times its original diameter, becoming a **red supergiant** star. Soon the core is so hot and dense that the fusion of heavier elements such as carbon, nitrogen, oxygen, and silicon can take place, each phase lasting a shorter period of time than the last, and each phase requiring higher and higher core temperatures. If you could look into the core of such a star, you would see layers of fusion similar in structure to that of an onion.

As high-mass stars go through these cycles of core fusion, shell fusion, and more core fusion, many of them become variable stars that pulsate as the star expands and contracts in reaction to the competing forces. Shell burning drives the outer layers outward (the star becomes larger and cooler) while gravitational force causes a collapse of the outer layers toward the core (the star's surface becomes hotter and more yellow). It is thought that almost all high-mass stars go through one or more variable stages—as a yellow giant (Cepheid variable), or as a red giant (semi-regular variable).

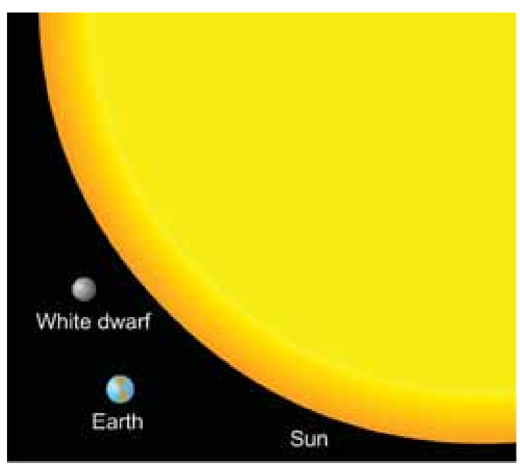

Figure 2-18: Diagram of a scale comparison among a typical white dwarf star, Earth, and the sun

The cycle of expansion and collapse proceeds as heavier and heavier elements are fused, until the moment that iron is made in the core. Iron is the most stable nucleus in nature. Iron absorbs energy in the core and will not fuse at the temperatures reached inside a star's core. As iron is produced in the core, fusion comes to a halt. In seconds, layers of the star come crashing down on the iron core. Just as quickly, the entire star rebounds, producing a violent outward explosion. This spectacular event is called a **supernova**. The entire process takes only seconds (literally!) and produces an explosion so violent—with temperatures reaching 100 billion degrees K—that even elements such as iron will fuse, creating all the rest of the 92 elements that exist naturally in our universe.

$$
\begin{aligned}
{}^{1}_{1}\mathrm{H} + {}^{12}_{6}\mathrm{C} &\rightarrow {}^{13}_{7}\mathrm{N} \\
{}^{13}_{7}\mathrm{N} &\rightarrow {}^{13}_{6}\mathrm{C} + e^{+} + \nu \\
{}^{1}_{1}\mathrm{H} + {}^{13}_{6}\mathrm{C} &\rightarrow {}^{14}_{7}\mathrm{N} \\
{}^{1}_{1}\mathrm{H} + {}^{14}_{7}\mathrm{N} &\rightarrow {}^{15}_{8}\mathrm{O} \\
{}^{15}_{8}\mathrm{O} &\rightarrow {}^{15}_{7}\mathrm{N} + e^{+} + \nu \\
{}^{1}_{1}\mathrm{H} + {}^{15}_{7}\mathrm{N} &\rightarrow {}^{12}_{6}\mathrm{C} + {}^{4}_{2}\mathrm{He}
\end{aligned}
$$

Figure 2-19: In the CNO cycle, carbon, nitrogen, and oxygen are used over and over again to aid in the process of fusing hydrogen into helium.

The supernova explosion propels heavy elements out into space. When new stars and solar systems form from the gas and dust left over from these explosions, they will include some of these heavier elements in their original composition. Every atom in your body, and every atom on our Earth, was once formed inside a star during fusion or during the process of a supernova.

Figure 2-20: Image of the white-hot stars in the Pleiades cluster, which will exist only for millions of years instead of billions like our sun

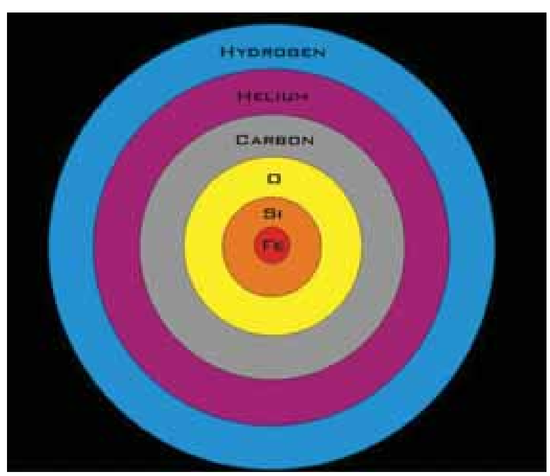

Figure 2-21: Diagram of elements in a star. As a massive star evolves, shells of successively more massive elements fuse at ever higher temperatures until iron is produced in the core, when fusion ends suddenly—with disastrous consequences for the star.

After a supernova explosion, the original star is either blown to pieces, or a tiny remnant of the core, squeezed to unimaginable densities, is left. The remnant is either a **neutron star** (a very dense star made up of neutrons) or a **black hole**, depending on how massive the original star was. The gravitational force of a black hole is so great that even light cannot escape from its grasp.