Star Life Cycle

I. Star Birth and Life

Imagine an enormous cloud of gas and dust many light-years across. Gravity, as it always does, tries to pull the materials together. A few grains of dust collect a few more, then a few more, then more still. Eventually, enough gas and dust has been collected into a giant ball that, at the center of the ball, the temperature (from all the gas and dust bumping into each other under the great pressure of the surrounding material) reaches 15 million degrees or so. A wondrous event occurs.... nuclear fusion begins and the ball of gas and dust starts to glow. A new star has begun its life in our Universe.

So what is this magical thing called "nuclear fusion" and why does it start happening inside the ball of gas and dust? It happens like this..... As the contraction of the gas and dust progresses and the temperature reaches 15 million degrees or so, the pressure at the center of the ball becomes enormous. The electrons are stripped off of their parent atoms, creating a plasma. The contraction continues and the nuclei in the plasma start moving faster and faster. Eventually, they approach each other so fast that they overcome the electrical repulsion that exists between their protons. The nuclei crash into each other so hard that they stick together, or *fuse*. In doing so, they give off a great deal of energy. This energy from fusion pours out from the core, setting up an outward pressure in the gas around it that balances the inward pull of gravity. When the released energy reaches the outer layers of the ball of gas and dust, it moves off into space in the form of electromagnetic radiation. The ball, now a star, begins to shine.

New stars come in a variety of sizes and colors. They range from blue to red, from less than half the size of our Sun to over 20 times the Sun's size. It all depends on how much gas and dust is collected during the star's formation. The color of the star depends on the surface temperature of the star. And its temperature depends, again, on how much gas and dust were accumulated during formation. The more mass a star starts out with, the brighter and hotter it will be. For a star, everything depends on its mass.

Throughout their lives, stars fight the inward pull of the force of gravity. It is only the outward pressure created by the nuclear reactions pushing away from the star's core that keeps the star "intact". But these nuclear reactions require fuel, in particular hydrogen. Eventually the supply of hydrogen runs out and the star begins its demise.

II. Beginning of the End

After millions to billions of years, depending on their initial masses, stars run out of their main fuel - hydrogen. Once the ready supply of hydrogen in the core is gone, nuclear processes occurring there cease. Without the outward pressure generated from these reactions to counteract the force of gravity, the outer layers of the star begin to collapse inward toward the core. Just as during formation, when the material contracts, the temperature and pressure increase. This newly generated heat temporarily counteracts the force of gravity, and the outer layers of the star are now pushed outward. The star expands to larger than it ever was during its lifetime -- a few to about a hundred times bigger. The star has become a red giant

What happens next in the life of a star depends on its initial mass. Whether it was a "massive" star (some 5 or more times the mass of our Sun) or whether it was a "low or medium mass" star (about 0.4 to 3.4 times the mass of our Sun), the next steps after the red giant phase are very, very different.

III. The End

A. The Fate of Sun-Sized Stars: Black Dwarfs

Once a medium size star (such as our Sun) has reached the red giant phase, its outer layers continue to expand, the core contracts inward, and helium atoms in the core fuse together to form carbon. This fusion releases energy and the star gets a temporary reprieve. However, in a Sun-sized star, this process might only take a few minutes! The atomic structure of carbon is too strong to be further compressed by the mass of the surrounding material. The core is stabilized and the end is near.

The star will now begin to shed its outer layers as a diffuse cloud called a planetary nebula. Eventually, only about 20% of the star's initial mass remains and the star spends the rest of its days cooling and shrinking until it is only a few thousand miles in diameter. It has become a white dwarf. White dwarfs are stable because the inward pull of gravity is balanced by the electrons in the core of the star repulsing each other. With no fuel left to burn, the hot star radiates its remaining heat into the coldness of space for many billions of years. In the end, it will just sit in space as a cold dark mass sometimes referred to as a black dwarf.

B. The Fate of Massive Stars: Supernovae! and Then...

Fate has something very different, and very dramatic, in store for stars which are some 5 or more times as massive as our Sun. After the outer layers of the star have swollen into a red supergiant (i.e., a very big red giant), the core begins to yield to gravity and starts to shrink. As it shrinks, it grows hotter and denser, and a new series of nuclear reactions begin to occur, temporarily halting the collapse of the core. However, when the core becomes essentially just iron, it has nothing left to fuse (because of iron's nuclear structure, it does not permit its atoms to fuse into heavier elements) and fusion ceases. In less than a second, the star begins the final phase of its gravitational collapse. The core temperature rises to over 100 billion degrees as the iron atoms are crushed together. The repulsive force between the nuclei overcomes the force of gravity, and the core recoils out from the heart of the star in an explosive shock wave. As the shock encounters material in the star's outer layers, the material is heated, fusing to form new elements and radioactive isotopes. In one of the most spectacular events in the Universe, the shock propels the material away from the star in a tremendous explosion called a supernova. The material spews off into interstellar space -- perhaps to collide with other cosmic debris and form new stars, perhaps to form planets and moons, perhaps to act as the seeds for an infinite variety of living things.

So what, if anything, remains of the core of the original star? Unlike in smaller stars, where the core becomes essentially all carbon and stable, the intense pressure inside the supergiant causes the electrons to be forced inside of (or combined with) the protons, forming neutrons. In fact, the whole core of the star becomes nothing but a dense ball of neutrons. It is possible that this core will remain intact after the supernova, and be called a neutron star. However, if the original star was very massive (say 15 or more times the mass of our Sun), even the neutrons will not be able to survive the core collapse and a black hole will form!