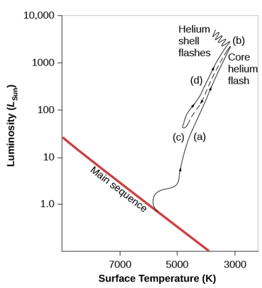
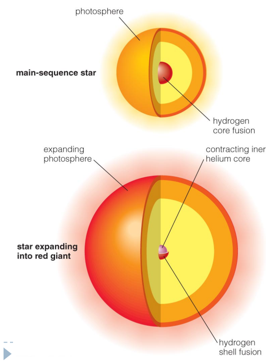
22.4 EVOLUTION OF LOW MASS STARS

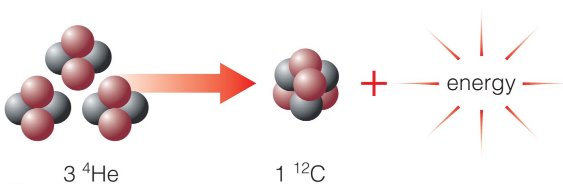


- **Evolution of a Star Like the Sun on an H–R Diagram.** Each stage in the star's life is labeled. (a) The star evolves from the main sequence to be a red giant, decreasing in surface temperature and increasing in luminosity. (b) A helium flash occurs, leading to a readjustment of the star's internal structure and to (c) a brief period of stability during which helium is fused to carbon and oxygen in the core (in the process the star becomes hotter and less luminous than it was as a red giant). (d) After the central helium is exhausted, the star becomes a giant again and moves to higher luminosity and lower temperature. By this time, however, the star has exhausted its inner resources and will soon begin to die. Where the evolutionary track becomes a dashed line, the changes are so rapid that they are difficult to model.

Broken Thermostat



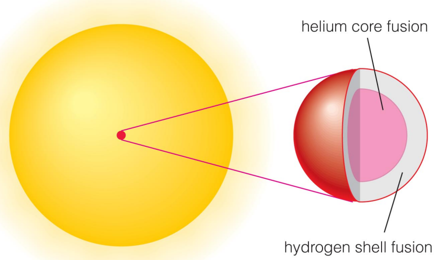
- As the core contracts, H begins fusing to He in a shell around the core.
- Luminosity increases because the core thermostat is broken—the increasing fusion rate in the shell does not stop the core from contracting.



- Helium fusion does not begin right away because it requires higher temperatures than hydrogen fusion—larger charge leads to greater repulsion.
- The fusion of two helium nuclei doesn't work, so helium fusion must combine three He nuclei to make carbon.

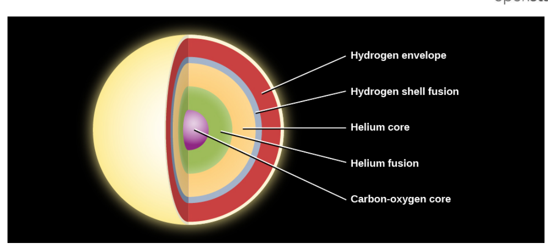
Helium Flash

- The thermostat is broken in a low-mass red giant because degeneracy pressure supports the core.
- The core temperature rises rapidly when helium fusion begins.
- The helium fusion rate skyrockets until thermal pressure takes over and expands the core again.



Helium core-fusion stars neither shrink nor grow because the core thermostat is temporarily fixed.

Figure 22.17



- **Layers inside a Low-Mass Star before Death.** Here we see the layers inside a star with an initial mass that is less than twice the mass of the Sun. These include, from the center outward, the carbon-oxygen core, a layer of helium hot enough to fuse, a layer of cooler helium, a layer of hydrogen hot enough to fuse, and then cooler hydrogen beyond.

Life Track After Helium Flash

- Models show that a red giant should shrink and become less luminous after helium fusion begins in the core.

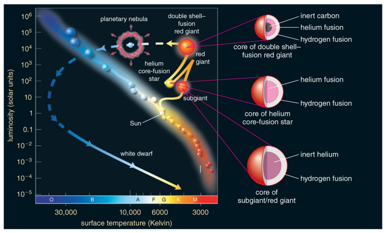
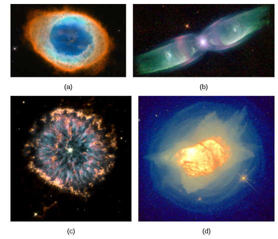


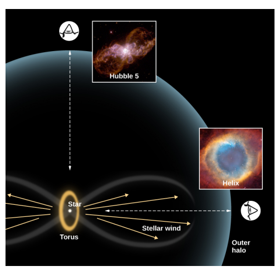
Figure 22.18



- **Gallery of Planetary Nebulae.** This series of beautiful images depicting some intriguing planetary nebulae highlights the capabilities of the Hubble Space Telescope.

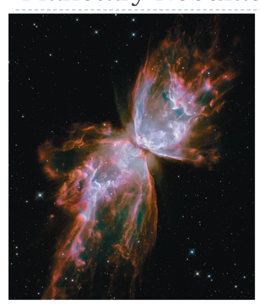
Figure 22.19

Model to Explain the Different Shapes of Planetary Nebulae. The range of different shapes that we see among planetary nebulae may, in many cases, arise from the same geometric shape, but seen from a variety of viewing directions. The basic shape is a hot central star surrounded by a thick torus (or doughnut-shaped disk) of gas. The star's wind cannot flow out into space very easily in the direction of the torus, but can escape more freely in the two directions perpendicular to it. If we view the nebula along the direction of the flow (Helix Nebula), it will appear nearly circular (like looking directly down into an empty ice-cream cone). If we look along the equator of the torus, we see both outflows and a very elongated shape (Hubble 5). Current research on planetary nebulae focuses on the reasons for having a torus around the star in the first place. Many astronomers suggest that the basic cause may be that many of the central stars are actually close binary stars, rather than single stars.



Planetary Nebulae

- Double shell–fusion ends with a pulse that ejects the H and He into space as a *planetary nebula*.
- The core left behind becomes a white dwarf.

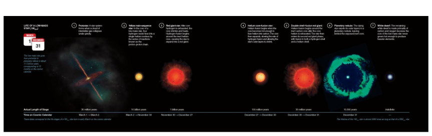


b Butterfly Nebula. The hot white dwarf is hidden in the dark ring of dust at the center.

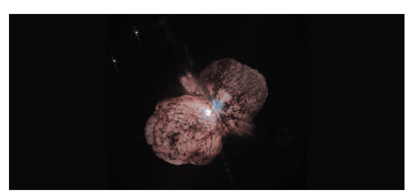
a Helix Nebula. The central white dot is the hot white dwarf.

Summary - Life Stages of Low-Mass Star

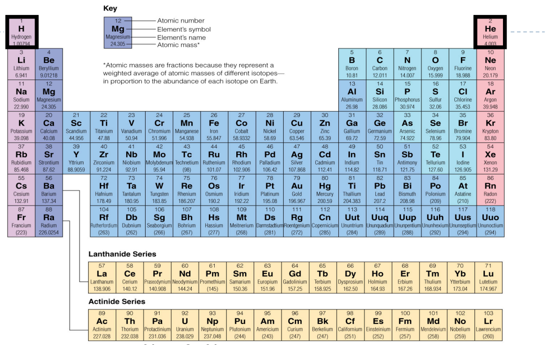
1. Main Sequence: H fuses to He in core
2. Red Giant: H fuses to He in shell around He core
3. Helium Core Fusion:
   He fuses to C in core while H fuses to He in shell
4. Double Shell Fusion:
   H and He both fuse in shells
5. Planetary Nebula: leaves white dwarf behind



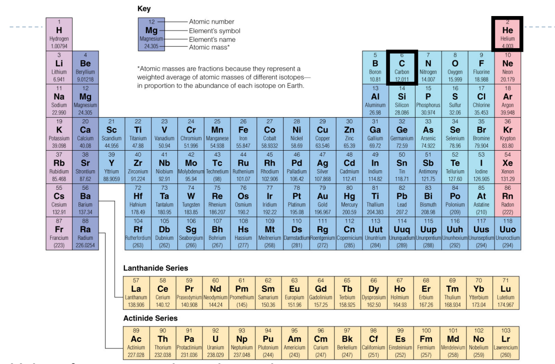
22.5 THE EVOLUTION OF MASSIVE STARS



- **Eta Carinae.** With a mass at least 100 times that of the Sun, the hot supergiant Eta Carinae is one of the most massive stars known. This Hubble Space Telescope image records the two giant lobes and equatorial disk of material it has ejected in the course of its evolution. The pink outer region is material ejected in an outburst seen in 1843, the largest of such mass loss event that any star is known to have survived. Moving away from the star at a speed of about 1000 km/s, the material is rich in nitrogen and other elements formed in the interior of the star. The inner blue-white region is the material ejected at lower speeds and is thus still closer to the star. It appears blue-white because it contains dust and reflects the light of Eta Carinae, whose luminosity is 4 million times that of our Sun.

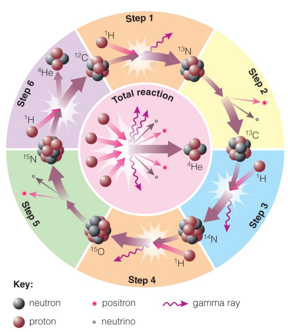


Big Bang made 75% H, 25% He—stars make everything else.

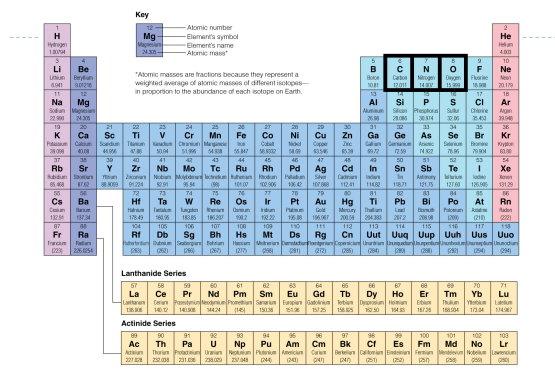


Helium fusion can make carbon in low-mass stars.

CNO Cycle

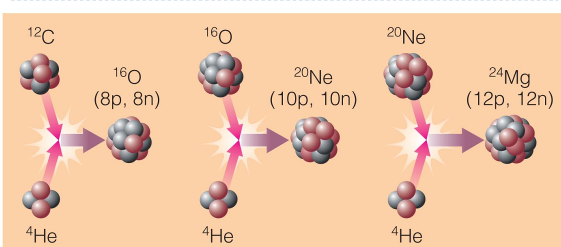


- High-mass main- sequence stars fuse H to He at a higher rate using carbon, nitrogen, and oxygen as catalysts.
- A greater core temperature enables H nuclei to overcome greater repulsion.



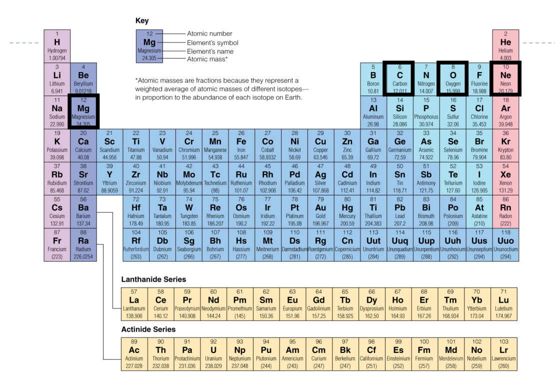
The CNO cycle can change C into N and O

Helium Capture



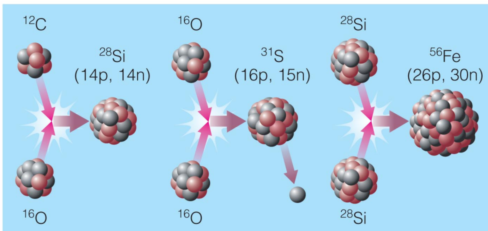
a Helium-capture reactions.

- High core temperatures allow helium to fuse with heavier elements.



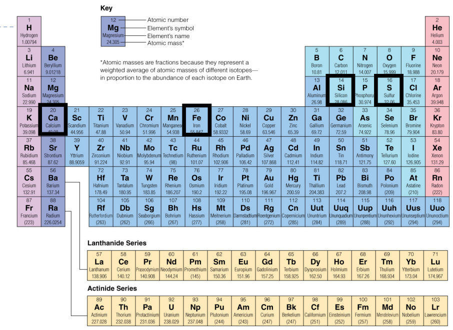
Helium capture builds C into O, Ne, Mg …

Advanced Nuclear Burning



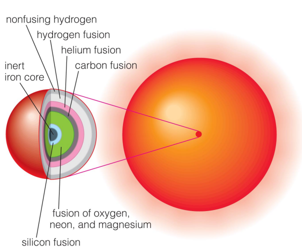
b Other reactions. (Note: Fusion of two silicon nuclei first produces nickel-56, which decays rapidly to cobalt-56 and then to iron-56.)

Core temperatures in stars with $>8M_{Sun}$ allow fusion of elements as heavy as iron.



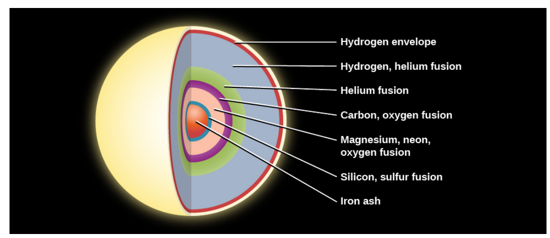
Advanced reactions in stars make elements such as Si, S, Ca, and Fe.

Multiple Shell Burning



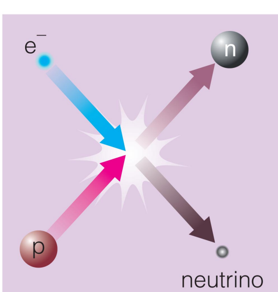
- Advanced nuclear burning proceeds in a series of nested shells.

Figure 22.21



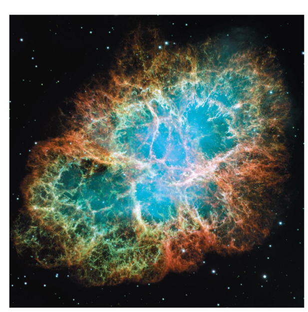
Interior Structure of a Massive Star Just before It Exhausts Its Nuclear Fuel. High-mass stars can fuse elements heavier than carbon. As a massive star nears the end of its evolution, its interior resembles an onion. Hydrogen fusion is taking place in an outer shell, and progressively heavier elements are undergoing fusion in the higher-temperature layers closer to the center. All of these fusion reactions generate energy and enable the star to continue shining. Iron is different. The fusion of iron requires energy, and when iron is finally created in the core, the star has only minutes to live.

Supernova Explosion



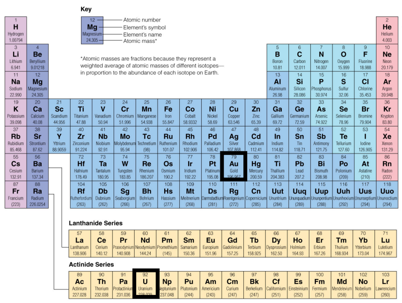
- Core degeneracy pressure goes away because electrons combine with protons, making neutrons and neutrinos.
- Neutrons collapse to the center, forming a **neutron star**.

Supernova Remnant



- Energy released by the collapse of the core drives outer layers into space.
- The Crab Nebula is the remnant of the supernova seen in A.D. 1054.

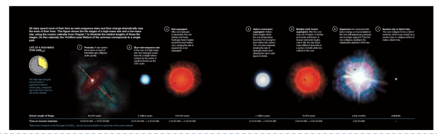
INTERACTIVE FIGURE



Energy and neutrons released in a supernova explosion enable elements heavier than iron to form, including Au and U.

Summary - Life Stages of High-Mass Star

1. Main Sequence: H fuses to He in core
2. Red Supergiant: H fuses to He in shell around He core
3. Helium Core Fusion:
   He fuses to C in core while H fuses to He in shell
4. Multiple Shell Fusion:
   many elements fuse in shells
5. Supernova leaves neutron star behind



Links

- nebula 4

Reading

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