High-Mass Stars
> 8 \(M_{\text{Sun}}\)

Intermediate-Mass Stars

Low-Mass Stars
< 2 \(M_{\text{Sun}}\)

Brown Dwarfs

Helium fusion requires higher temperatures than hydrogen fusion because larger charge leads to greater repulsion

Fusion of two helium nuclei doesn’t work, so helium fusion must combine three He nuclei to make carbon

Helium Flash

- Thermostat is broken in low-mass red giant because degeneracy pressure supports core
- Core temperature rises rapidly when helium fusion begins
- Helium fusion rate skyrockets until thermal pressure takes over and expands core again
Helium burning stars neither shrink nor grow because thermostat is temporarily fixed.

A star like our sun dies by puffing off its outer layers, creating a planetary nebula. Only a white dwarf is left behind.
A star like our sun dies by puffing off its outer layers, creating a *planetary nebula*.

Only a white dwarf is left behind.

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**High-Mass Star’s Life**

Early stages are similar to those of low-mass star:

- Main Sequence: H fuses to He in core
- Red Supergiant: H fuses to He in shell around inert He core
- Helium Core Burning: He fuses to C in core (no flash)
CNO cycle is just another way to fuse H into He, using carbon, nitrogen, and oxygen as catalysts.

CNO cycle is main mechanism for H fusion in high mass stars because core temperature is higher.

High-mass stars become **supergiants** after core H runs out.

Luminosity doesn’t change much but radius gets far larger.

Iron is dead end for fusion because nuclear reactions involving iron do not release energy.

(Fe has lowest mass per nuclear particle)

Beyond Carbon, fusion continues via Helium capture, where nucleus captures a Helium nucleus.

Evidence for helium capture:

Higher abundances of elements with even numbers of protons.
Core degeneracy pressure goes away because electrons combine with protons, making neutrons and neutrinos. Neutrons collapse to the center, forming a neutron star. Energy and neutrons released in supernova explosion enables elements heavier than iron to form. Elements made during supernova explosion.

Crab Nebula: Remnant of supernova observed in 1054 A.D.
Supernova 1987A is the nearest supernova observed in the last 400 years.

The next nearby supernova?

Low-Mass Star Summary

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

Reasons for Life Stages

- Core shrinks and heats until it’s hot enough for fusion
- Nuclei with larger charge require higher temperature for fusion
- Core thermostat is broken while core is not hot enough for fusion (shell burning)
- Core fusion can’t happen if degeneracy pressure keeps core from shrinking
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 Burning: He fuses to C in core while H fuses to He in shell
4. Multiple Shell Burning: Many elements fuse in shells
5. Supernova leaves neutron star behind

Life with a Companion

Stars in Algol are close enough that matter can flow from subgiant onto main-sequence star

Star that is now a subgiant was originally more massive

As it reached the end of its life and started to grow, it began to transfer mass to its companion

Now the companion star is more massive