Stellar evolution

2 main threads
- Coulomb barrier
- hydrostatic $\equiv^m$

Stellar lifetimes and HR diagram

Main sequence : H burning in core → He
p-p chain or CNO cycle
(low mass) (high mass)

When about 10% of star's mass burnt
→ He, structure changes

- inert He core ~~[illegible]~~ contracts & heats
- shell burns H outside core
  (energy generation ↑)
  (CNO cycle impt)

- outer layers expand, cool

  $R \uparrow$, $T \downarrow$ so $L \sim$ unchanged

  SUBGIANT BRANCH

- H shell burning gives large temperature gradient

  convective envelope

  RED GIANT

  convection hard to treat theoretically

  models on shakier ground now

- core temperature rises

  density rises, becomes degenerate

  (ie pressure does not depend on T)
  — only on density

  onset of He burning — HE FLASH

  then settles into core He burning, H shell

  HORIZONTAL BRANCH

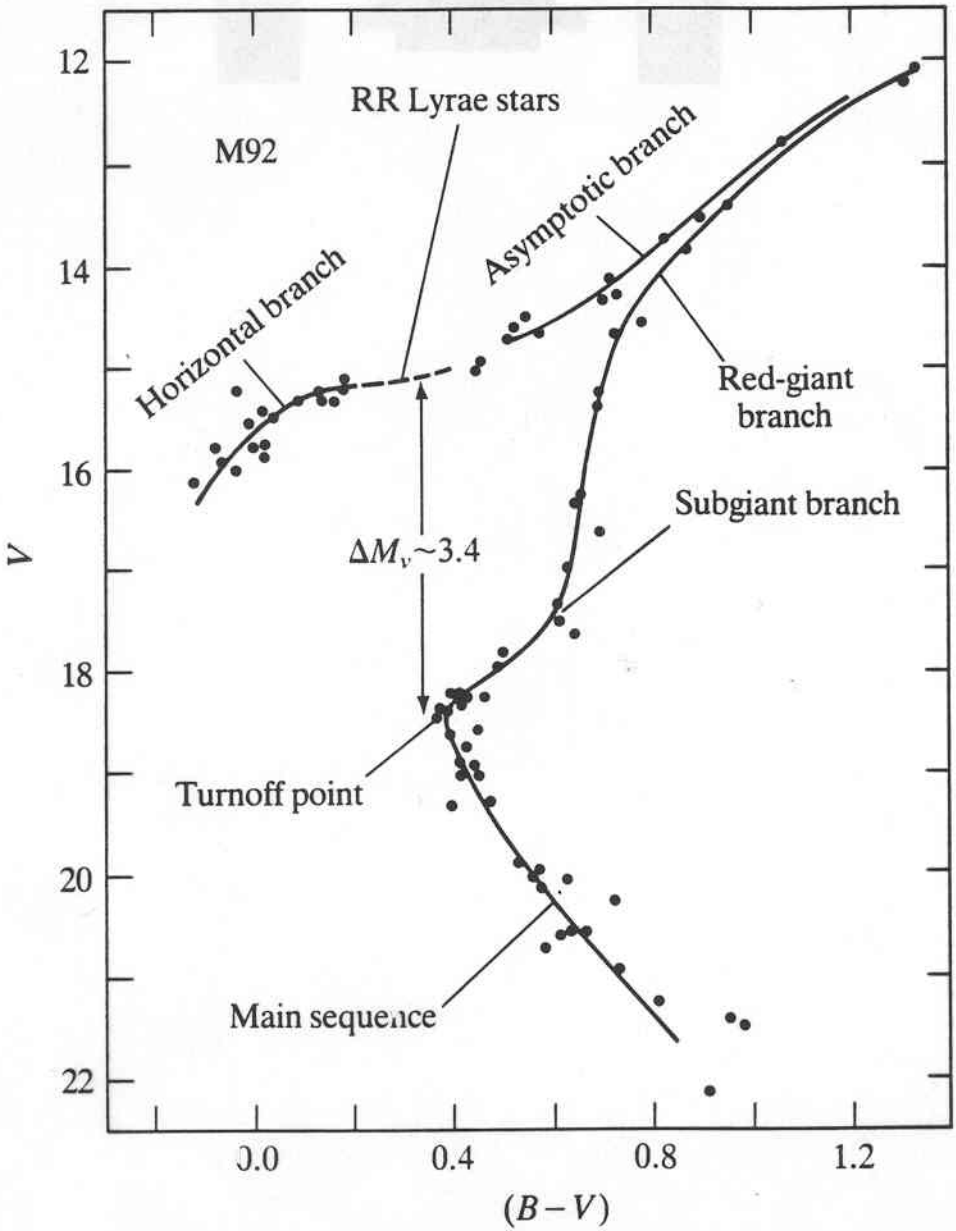


Figure 3-13. Observed color-magnitude diagram for the metal-poor globular cluster M92, with principal sequences and other important features indicated schematically. [Adapted from (**C4**, Chapter 2).]

Massive stars – later evolution

Stars more massive than 5 solar masses

- very high luminosity – nuclear fusion reactions go very fast
- lifetimes short.

First stages of evolution the same – hydrogen burning shell forms

Helium burning starts more gently – no helium flash

Then carbon burning:

$$^{12}_{6}C + ^{4}_{2}He \rightarrow ^{16}_{8}O + \gamma$$

carbon helium oxygen gives off energy

TABLE 18–1

Temperature Required for Nuclear Burning and Time for Exhaustion of Nuclear Fuel in Massive Stars (about 20 Solar Masses)

Energy source	Temperature (K)	Time for exhaustion (years)
Hydrogen burning	1.5×10^7	10^7 years
Helium burning	1.7×10^8	10^6 years
Carbon burning	7×10^8	10^3 years
Neon burning	1.4×10^9	3 years
Oxygen burning	1.9×10^9	1 year
Silicon burning	3.3×10^9	1 day

Have carbon-burning core

helium-burning shell

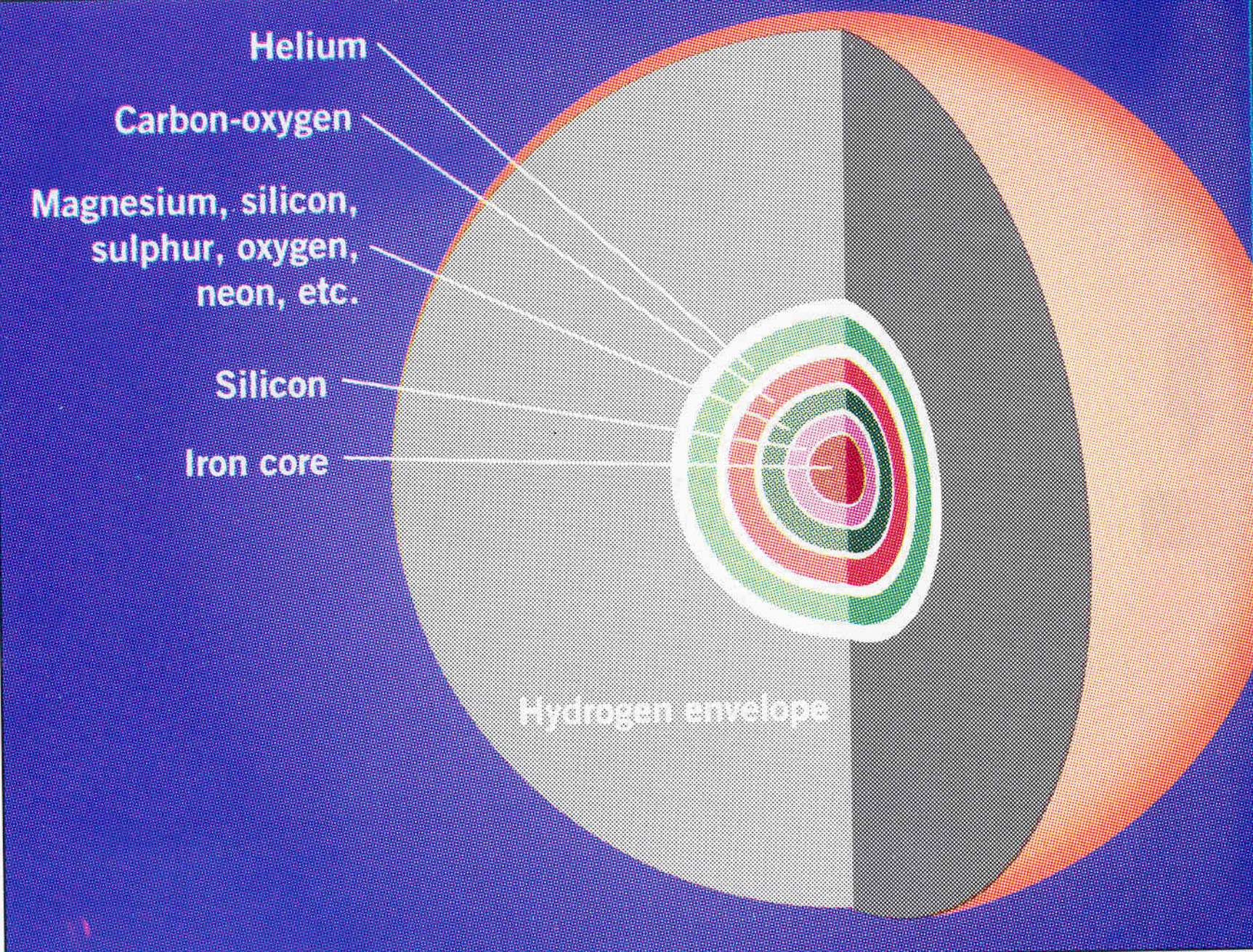
hydrogen-burning shell

At this point the star is in the red giant ~~place~~ region of the HR diagram

Then the star's core goes through successive stages of burning heavier and heavier elements : neon, oxygen, silicon, etc

(also have reactions that produce magnesium, sulfur, etc)

This stops at iron (Fe).
Past iron (to make heavier elements) fusion reactions <u>need</u> energy, rather than giving it off.


Helium
Carbon-oxygen
Magnesium, silicon, sulphur, oxygen, neon, etc.
Silicon
Iron core
Hydrogen envelope

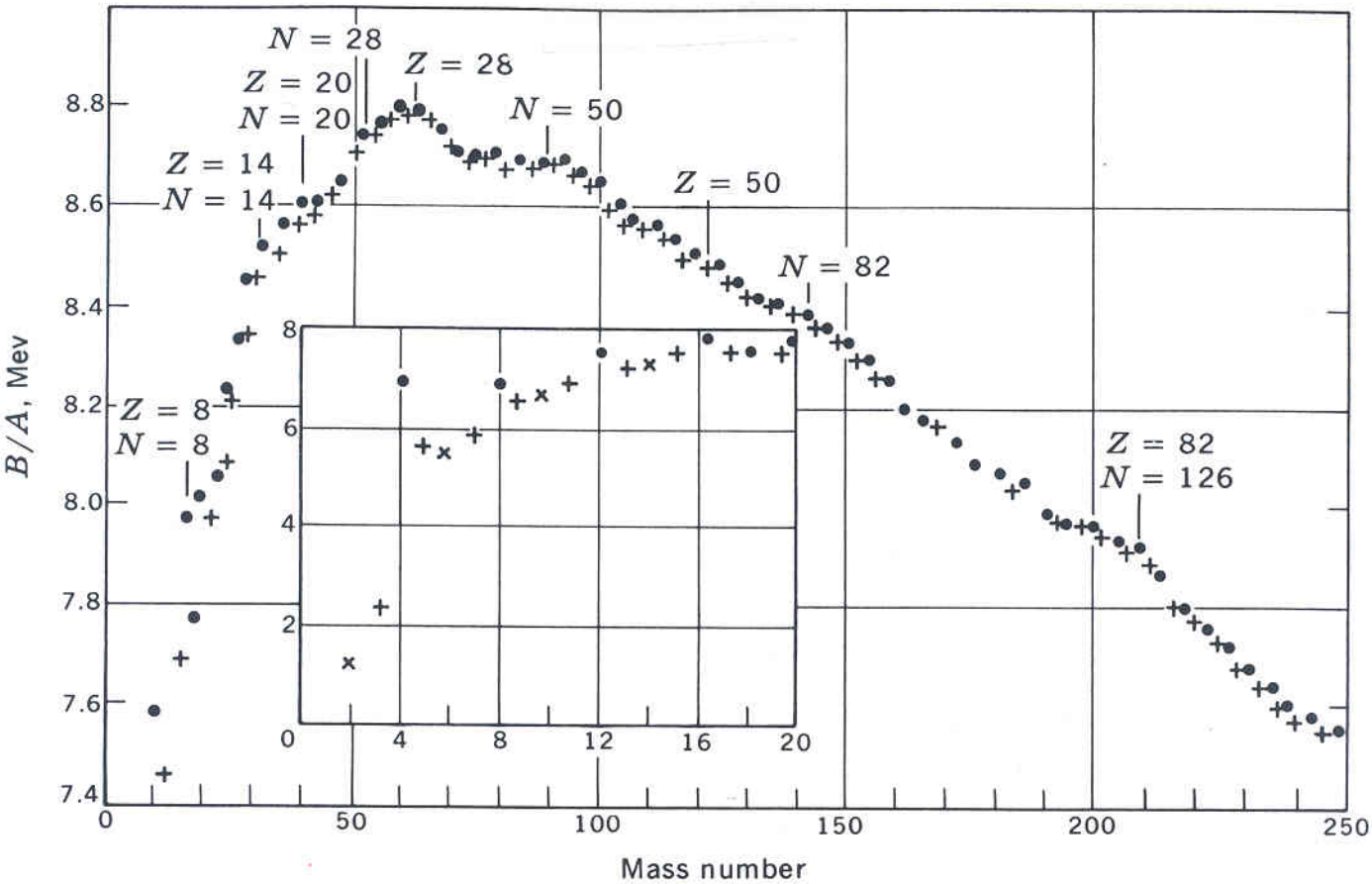


Fig. 7-1 The binding energy per nucleon of the most stable isobar of atomic weight A. The solid circles represent nuclei having an even number of protons and an even number of neutrons, whereas the crosses represent odd-A nuclei. (*M. A. Preston, "Physics of the Nucleus," Addison-Wesley Publishing Company, Inc., Reading, Mass.*, 1962.)

Q What does the trend of binding energy with mass number imply about the energetics of fusion & fission for different elements?

High mass evolutionary tracks

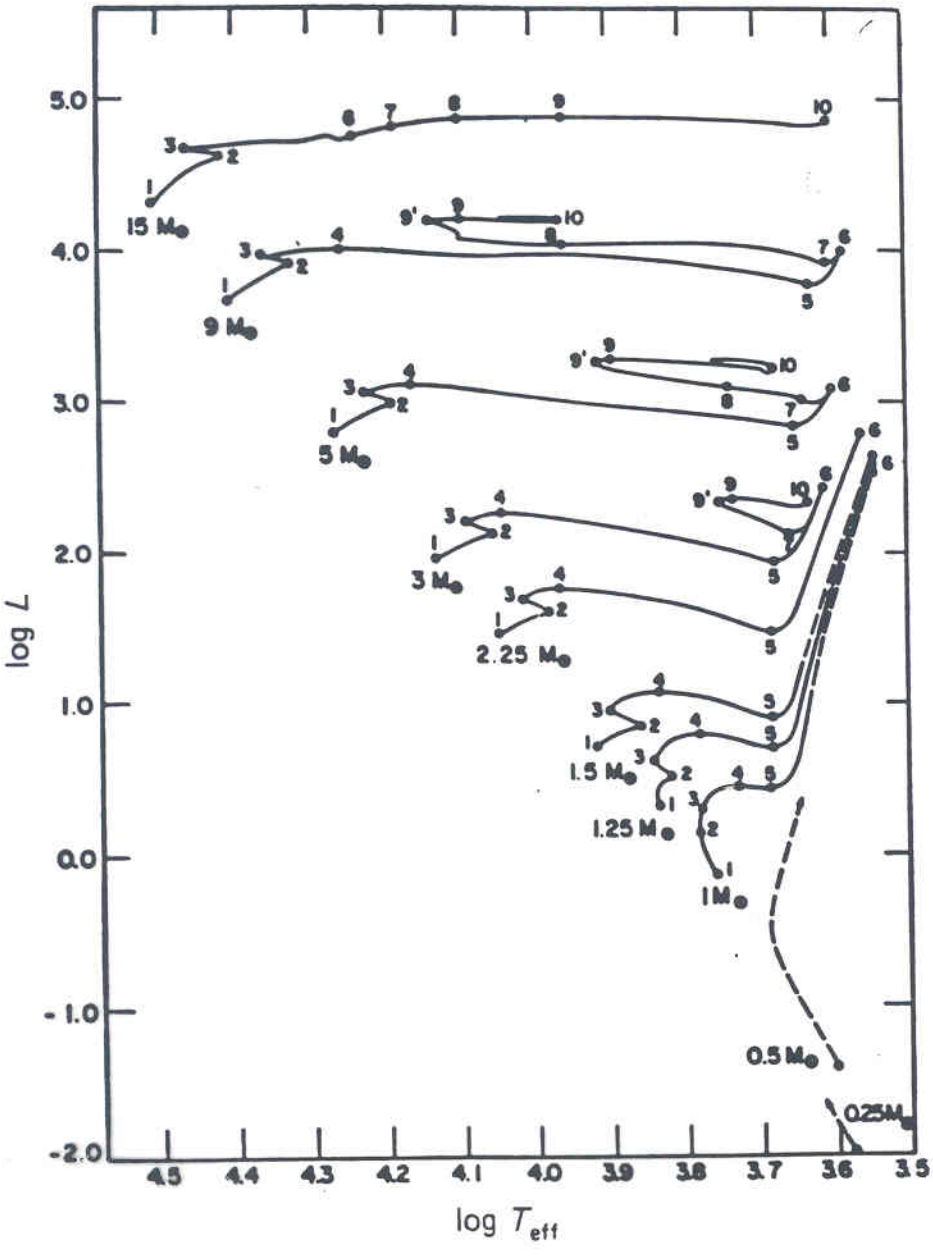


Fig. 15.1. Evolutionary tracks for stars of different masses. For more massive stars the luminosities of the red giants do not increase as much as those for lower mass stars. For the more massive stars the triple-alpha reaction starts soon after they reach the red giant region. The points with the numbers indicate the position for the onset of helium burning. The other numbers indicate other stages of evolution. From Iben (1967).