**More high mass star fusion notes & after MS sequence phase notes**

**[1]**

* BSG fuses elements up to iron
* Iron absorbs critical energy from the core causing it to collapse under gravitational pressure
* Core pulls star matter with huge forces, heats up, compresses it, and sends a shockwave outwards from the core
* The shockwave slams into the material causing it to slow down
* Neutrinos form in the core with huge amounts of energy, due to the number density of neutrinos and the large density of the material affecting the core most of the neutrinos get absorbed.
* The neutrinos cause the material to reverse in fall and blasts it outwards causing a supernova

[2]

**Late fusion cycle**

* After the MS, during the triple alpha process (fusion of He to C), the star has wo sources of energy from nuclear reactions: He to C in the core, and H to He in the shell outside the core.
* Once He fusion diminishes and the pressure gradient due to escaping energy diminishes , the core of the star collapse under gravity. Core temp increases and at temperatures of 3x108 K the reaction of 12C +42He🡪168O + γ dominates
* The star then has three sources of energy via nuclear reactions: above equation in the core, triple alpha process in a shell around the core and H to He fusion in a shell outside the triple alpha shell.
* When He burning stops, the C and O core of the star contracts and at a temperature of about 5x108 K carbon burning commences: 12C + 12C 🡪 Mg + γ (simplest but least likely)

12C + 12C 🡪 23Na + 1H

12C + 12C 🡪 20Ne + 42He Both of these reactions are the most likely reactions

- As C becomes depleted, the core contracts and heats up and at a temperature of around 109 K a new type of process becomes very important

- At this point the core is so hot that its blackbody spectrum extends into the γ-ray part of the spectrum. Many fusion reactions that release energy (in the form of a γ-ray) can be reversed.

- Making the following reaction possible:

20Ne + γ 🡪 16O + 42He (this process is called photodisintegration)

- Photodisintegration plays an important role at the temperatures in the core after C burning.

- At temperatures greater than 1.5x109 K some the Ne will undergo photodisintegration (above reaction), the alpha particles (He atoms) that form as a biproduct of neon disintegration react with the neon that has not undergone photodisintegration:

20Ne + 42He 🡪 24Mg + γ

* This changes the core composition to a mixture of O and Mg (referred to as the neon burning stage)
* After neon burning the core contracts and heats up and at a temperature of around 2x109 K the oxygen nuclei react to form silicon (oxygen burning):

16O + 16O 🡪28Si +42He

* The alpha particles that are formed from neon and oxygen burning quickly disappear due to them being reacted in fusion reactions with heavier nuclei
* Once the O in the core is gone, the core contracts and heats up, at a temperature of around 3x109 K the photodisintegration of Si begins:

28Si + γ 🡪 24Mg + 42He

* This produces a source of alpha particles which will rapidly undergo fusion reactions with Si and lead to the following reactions:

28Si + 42He 🡪32S + γ

32S + 42He 🡪36Ar + γ

36Ar + 42He 🡪 40Ca + γ

* This reaction type will continue until an atomic mass of, A=56 is reached, i.e., the fusion of iron. This is the limit of nuclear burning; this phase is often called Si burning.
* The time spent in each core nuclear burning phase gets dramatically shorter as the burning progresses to heavier elements.
* For a 25Mʘ star the H burning phase is approximately 7x106 years, the He burning phase is approximately 5x105 years, the Carbon burning phase is approximately 600 years, Ne & O burning is approximately 1 year and 6 months, respectively. Si burning only lasts around a day
* As the star fuses heavier elements, the energy per kg of material undergoing fusion diminishes, fusion of lighter elements is exothermic, so the energy produced becomes less efficient as heavier elements are fused. To compensate for the reduced energy production, the reaction rate increases.

**The death of high mass stars**

* When the reactions that produce Fe diminish, the Fe core must contract under gravity resulting in another increase in temperature and density but there will be no more nuclear reactions, i.e., no more energy production to provide a balance force to gravity
* Core temperatures rise to 1010 K, iron nuclei begin to photo disintegrate (producing α particles, protons, and neutrons) however the energy is absorbed instead of being produced resulting in a faster core collapse which can reach supersonic speeds.
* The contracting core results in a density so high that e- become degenerate
* Further collapse leads to increasing density and increasing energy of the degenerate e- until they have enough energy to react with protons to create neutrons and electron neutrinos
* e- are removed, lowering the electron degeneracy pressure which speeds up the core collapse even more.
* The core has now reached a temperature of around 1012 K and a density of 3x1017 Kg m-3, which allows neutron degeneracy to take place
* The pressure builds up due to
* the neutron density which causes the collapse of the inner part of the core to come to a halt and rebound, the material above the inner part of the core is still moving inwards at speeds of up to 70,000 km s-1 (0.023% of the speed of light) and violently rebounds when it comes into contact with the core which results in a shock wave that travels outwards form the core.
* [1] section describes the rest of the evolution to a supernova
* The energy released from the core collapse is around 1046J which 99% of is carried away by neutrinos with the remaining energy kinetic energy of expansion (1044J) and into sudden brightening of the star (1042J).
* The star’s luminosity typically increases by a factor of 108 where it can outshine the entire galaxy in which it is situated.

**Supernova**

* Type 1 supernova do not show hydrogen lines in their spectra, type 2 supernova do show hydrogen lines in their spectra
* Type 2 supernovas are thought to be linked with stars that still retain large quantities of H at the point of explosion, supergiants are prime candidates for suitable progenitors due to their H rich outer layer.
* Type 1 supernovas are thought to be linked with stars that have completely depleted their hydrogen fuel
* Very massive stars (WR stars) are thought to lose their H through mass loss in the final stages of life.
* Binary interactions may also result in the removal of the H mantle in stars that would have ended their lives with H and therefore become type 2 supernovas.

[1] CrashCourse, 2015. *High Mass Stars: Crash Course Astronomy #31*. [video] Available at: <https://www.youtube.com/watch?v=PWx9DurgPn8&ab\_channel=CrashCourse> [Accessed 12 February 2021].

[2] Green, S. and Jones, M., 2015. *An introduction to the sun and stars*. 2nd ed. Cambridge: The Open University, pp.214-219, 227-236, 263-264.