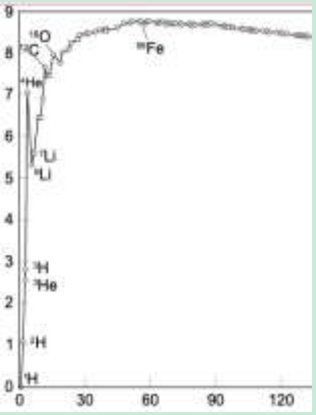
Life of Stars Unit

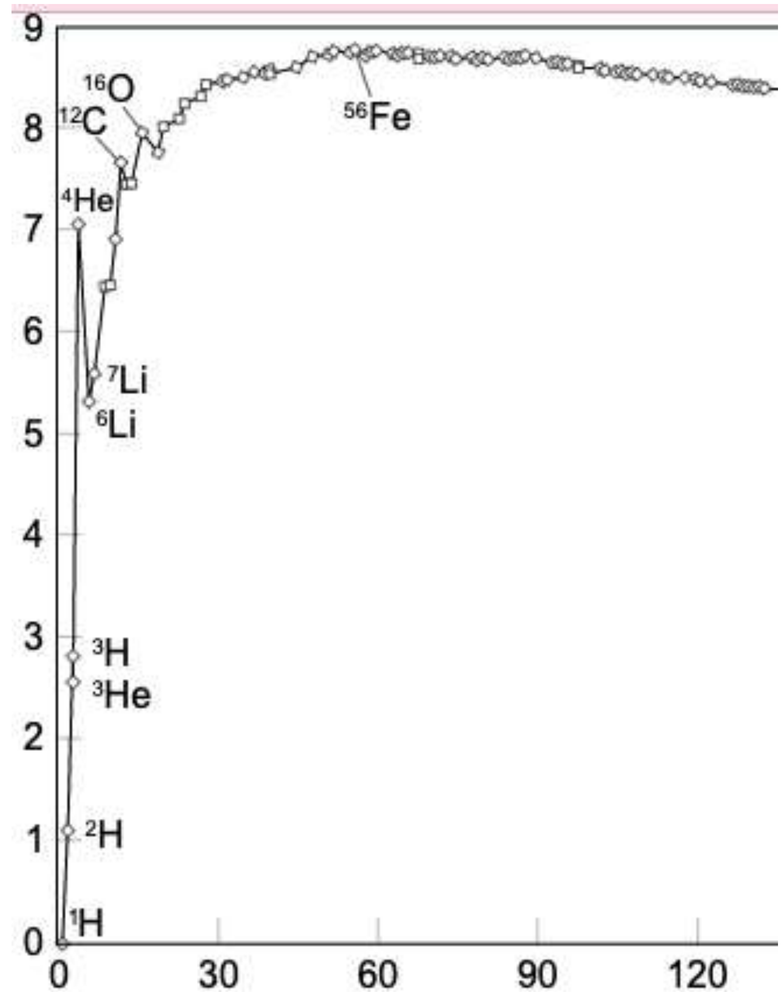
Week 2 – Why do stars die?



WATERFORD ASTRONOMY

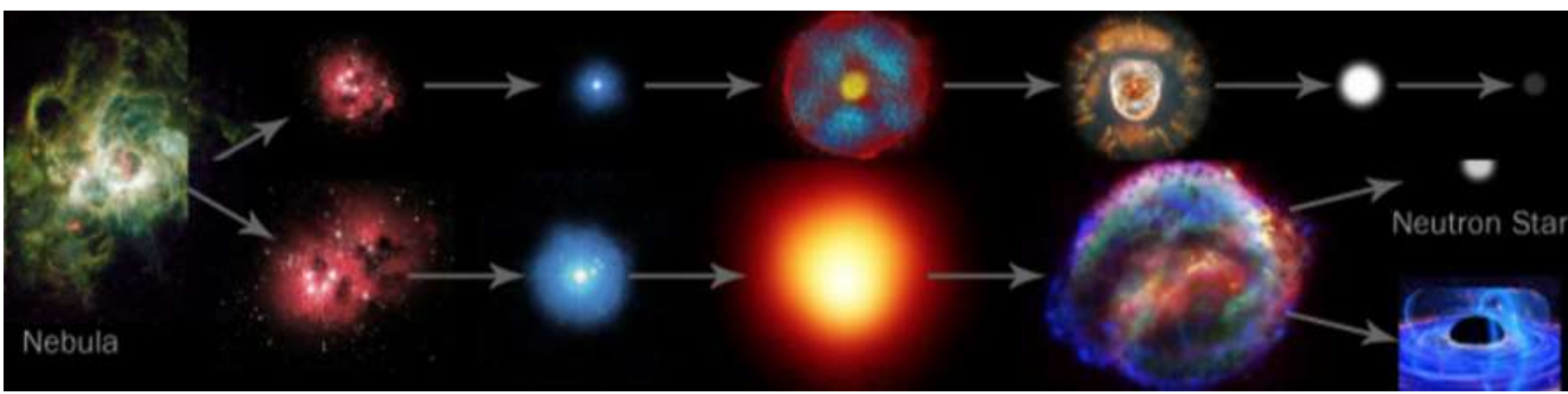
Sun Unit – W2 Driving Question

- **This week's driving question:** Why do stars die?
- Why can atoms fuse? What factors determine whether atoms can fuse or not fuse?
- Why can some elements undergo nuclear fusion whereas some other elements undergo nuclear fission?
- How do these factors affect how a star ages and why stars die?



Stars Week 1 Recap

- **We now know that the mass of stars determines their outcomes.**
  - All stars form from interstellar nebula.
  - Low mass stars enter the main sequence, become red giants, and then white dwarfs.
  - High mass stars also start in the main sequence.
    - After a supernova, high mass stars either form a neutron star or a black hole.

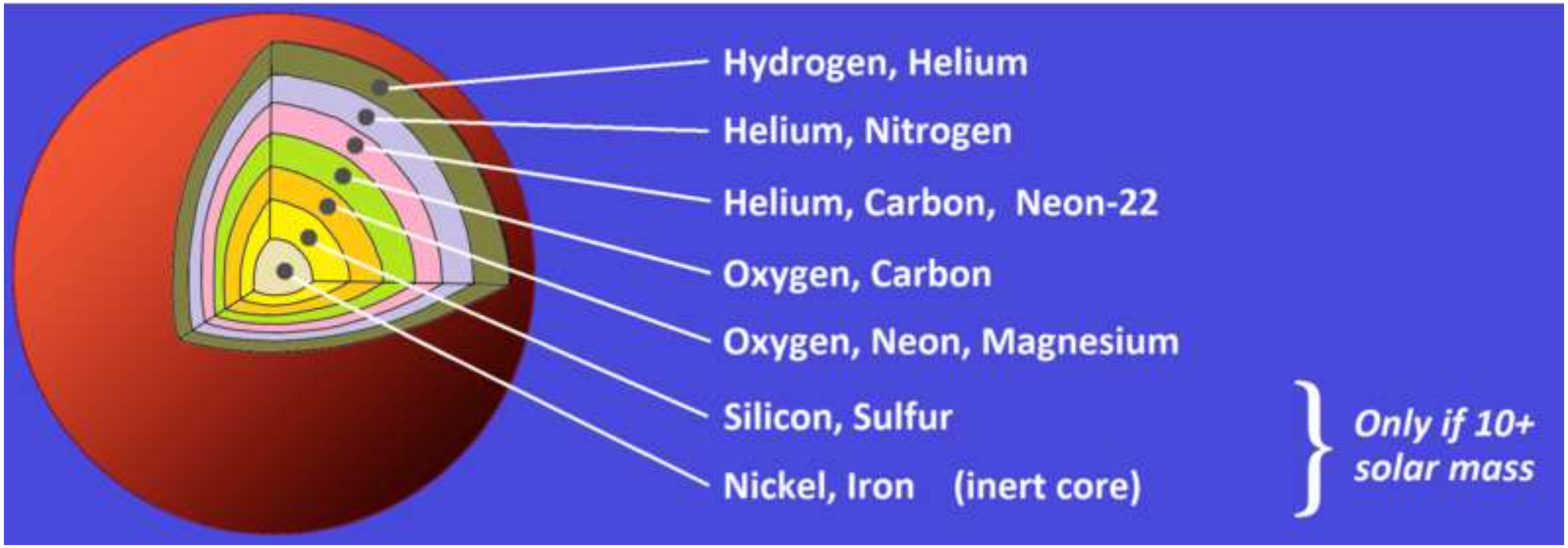


The Big Ideas

- **The mass of a star determines the extent to which nuclear fusion can occur in the star's core.**
  - In low mass stars, fusion slows as hydrogen is fused into helium and as helium fuses into carbon.
  - In the cores of high mass stars, elements can fuse up to iron before fusion eventually ends.

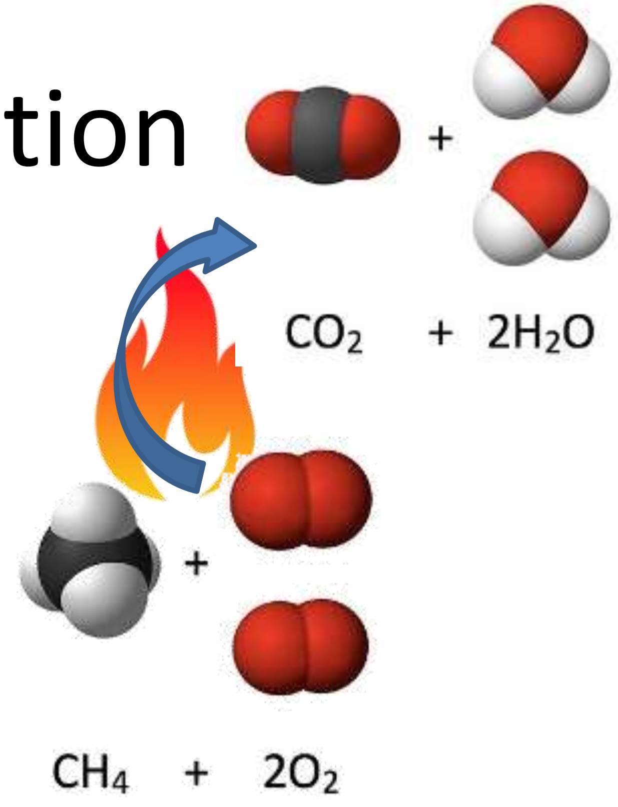
The Big Ideas

- **This week we'll focus on why fusion is possible, and why stars start to die when their cores form iron.**
  - Why would the fusion of hydrogen into helium release so much energy?
  - Why does fusion in the cores of stars stop at iron?

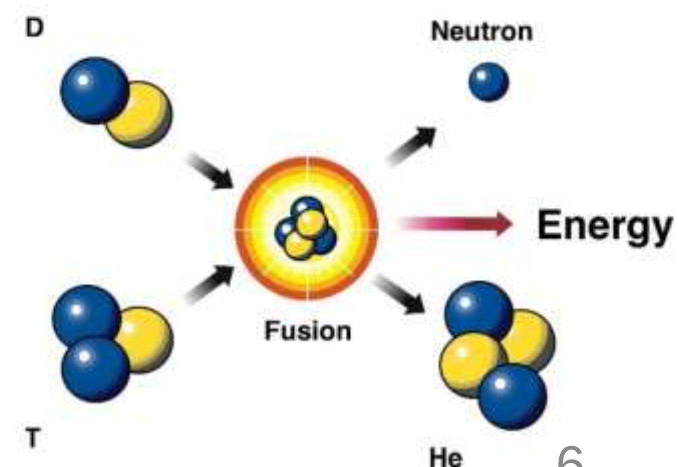


Source: Wikimedia

Fusion vs. Combustion



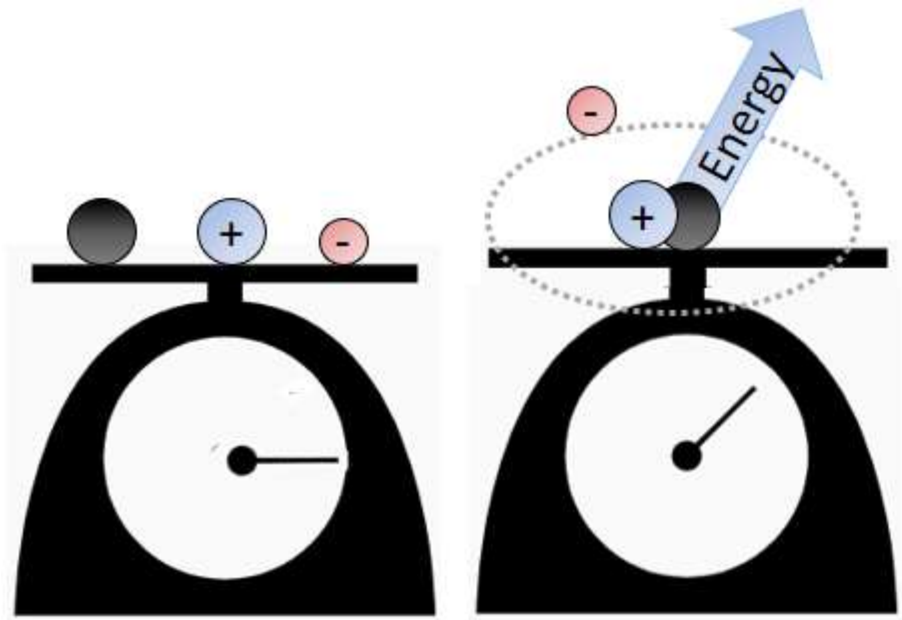
- Fusion is very different from combustion
- In combustion, chemical energy is converted into heat and light energy.
  - However, atoms are not being destroyed.
  - The mass of the products is the same as the mass of the reactants.
- In fusion, matter is converted into energy (per Einstein's equation, $E = mc^2$).
  - The products of fusion have less mass than the reactants.



Source: Energy.gov

Mass Defect

- Except for hydrogen, the mass of an atom is always less than the sum of the masses of its component particles.
  - Mass defect of a nucleus is the difference between the sum of the masses of the subatomic components and the measured atomic mass.
- When protons, neutrons, and electrons assemble into a stable atom, energy is released.
  - This is like how atoms in molecules are more stable than isolated atoms.
  - E.g., Na+ and Cl- are highly reactive, while NaCl is not.

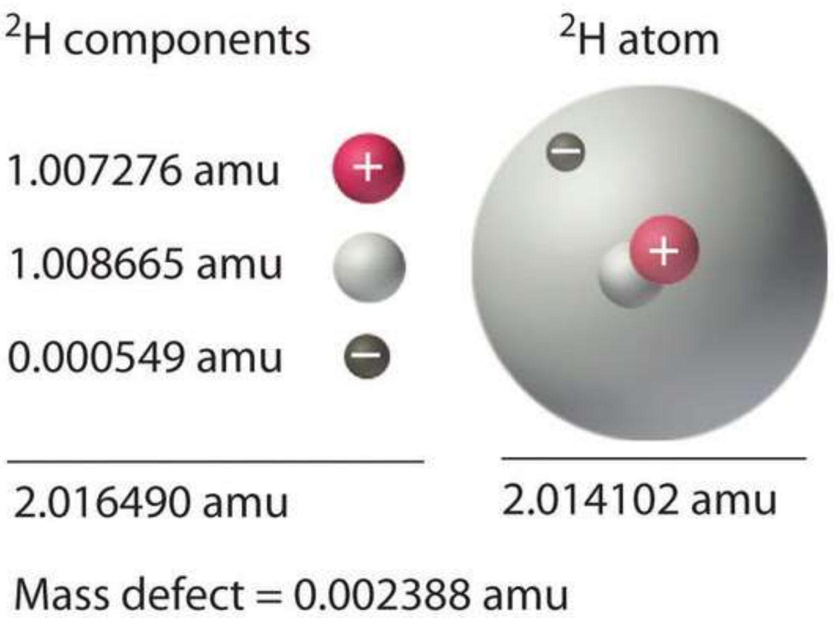


Mass defect: the difference between the masses of the subatomic components and the atomic mass of an atom.

Mass Defect

- Mass defect is evident in deuterium (heavy hydrogen, or hydrogen with a neutron).
  - The electron, proton, and neutron individually weigh a total of 2.0165 amu (amu = atomic mass unit = 1/12 the mass of a carbon atom).
  - However, a deuterium atom weighs 2.0141 amu.
  - This equates to a mass defect of ~0.0024 amu

- When subatomic particles form a stable atom, they release energy converted from matter.
  - Mass defect value is proportional to the nuclear binding energy (the energy needed to divide a nucleus into separate protons & neutrons).
  - Both values are measures of the stability of the nucleus of an atom.

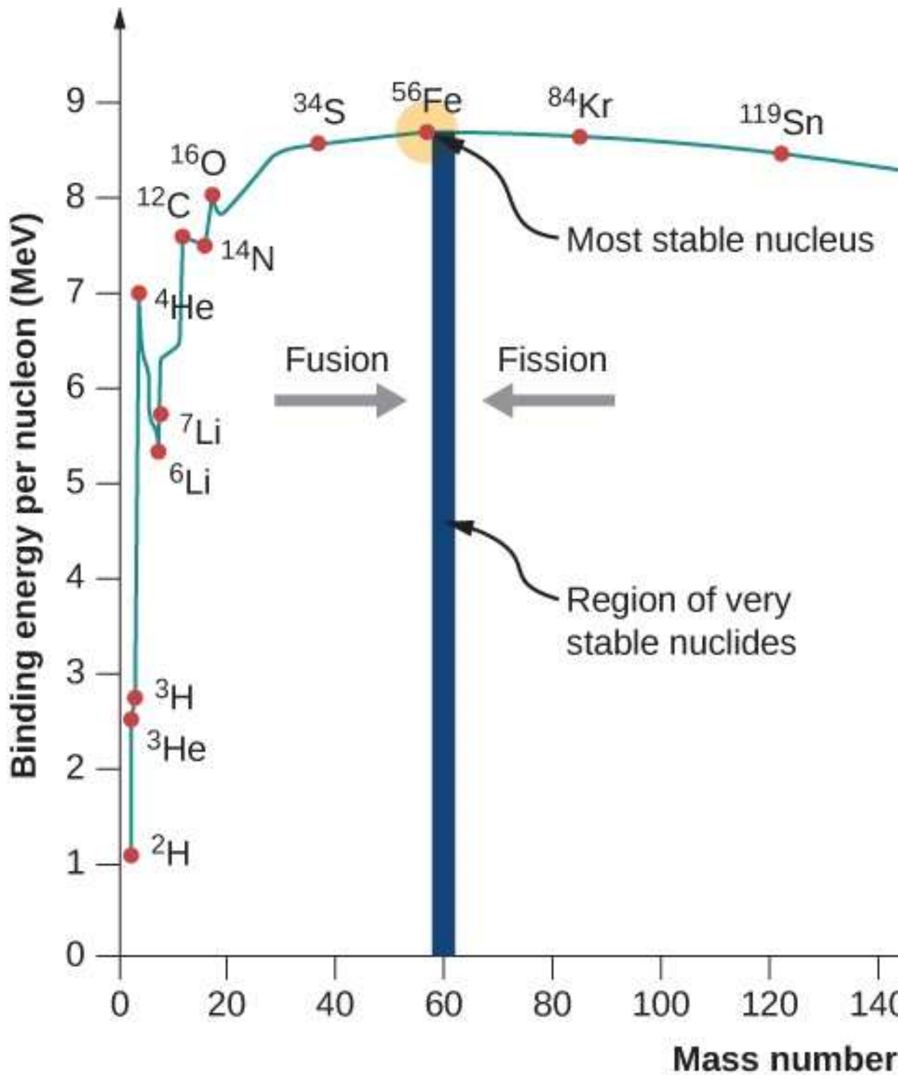


Source: chem.libretexts.org

Mass Defect Curve

- Not all nuclei are equally stable.
  - The ratio of binding energy to neutrons & protons determines the stability of an element.

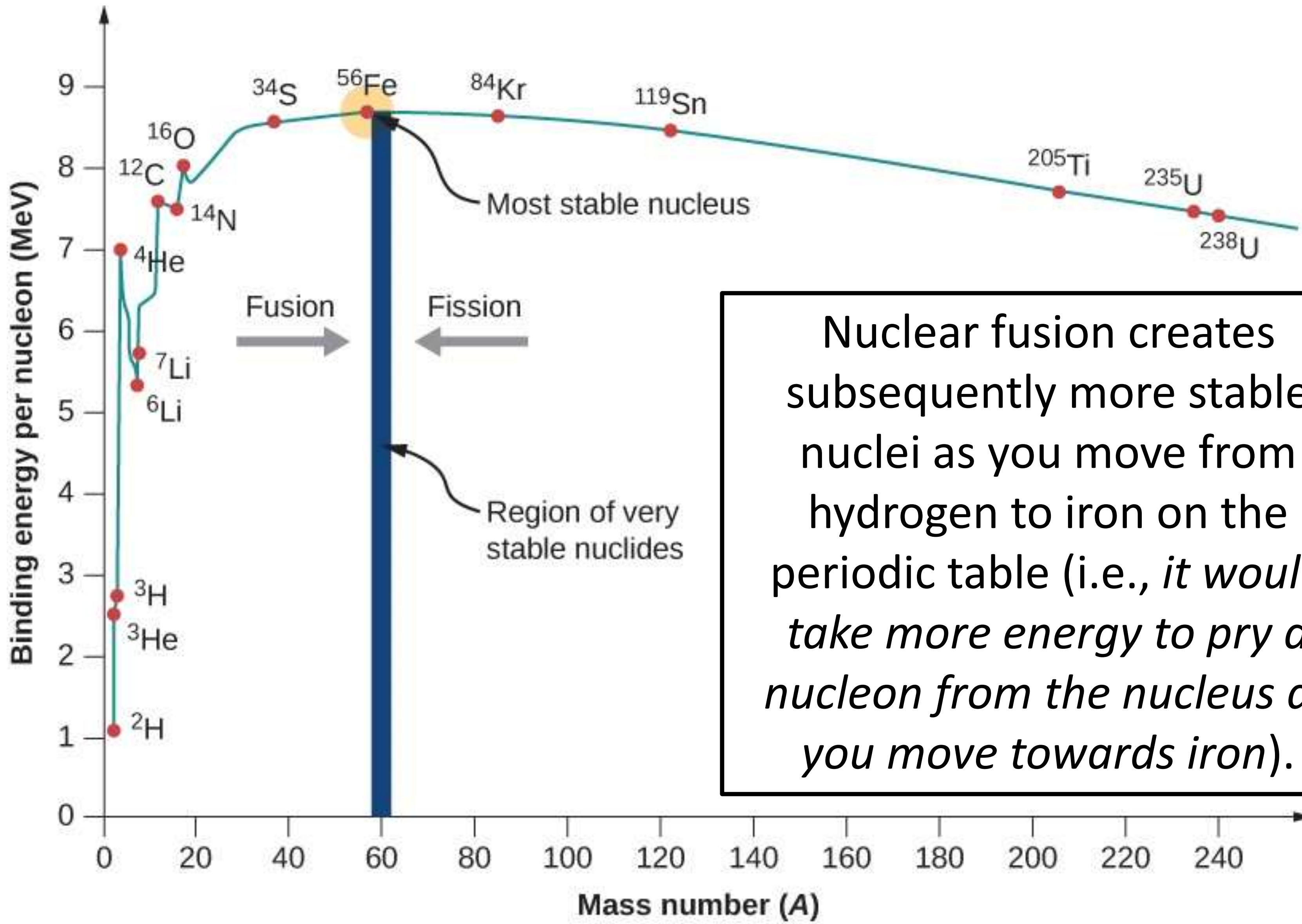
- As hydrogen fuses into helium, the binding energy to nucleon* ratio increases.
  - It takes more energy to separate the nucleons of helium compared to those of hydrogen.
  - Similarly, binding energy increases as helium fuses into carbon.



**Nucleon* = neutrons & protons

Source: https://opentextbc.ca/universityphysicsv3openstax/chapter/nuclear-binding-energy/

Mass Defect Curve

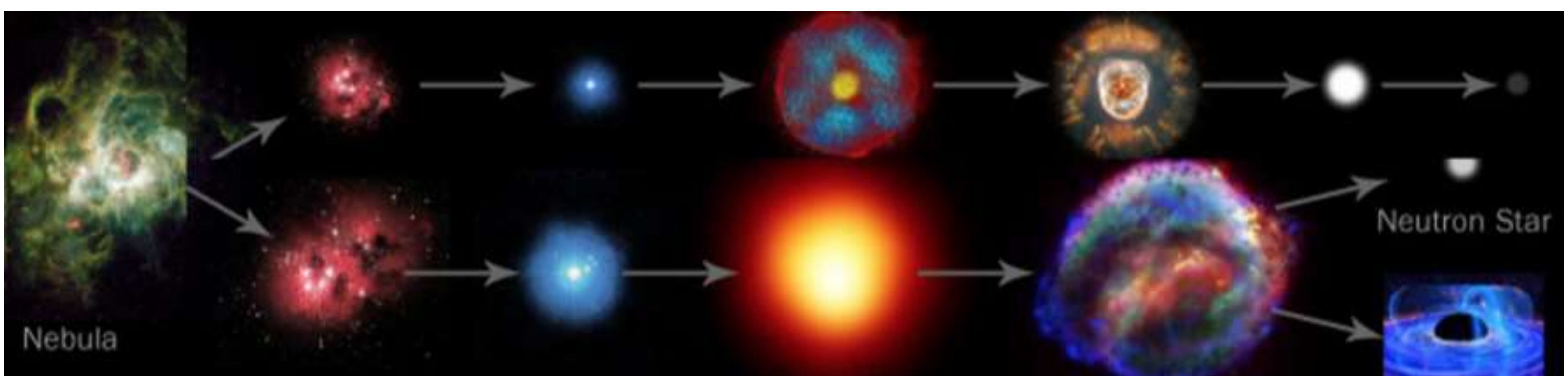


Nuclear fusion creates subsequently more stable nuclei as you move from hydrogen to iron on the periodic table (i.e., *it would take more energy to pry a nucleon from the nucleus as you move towards iron*).

Source: https://opentextbc.ca/universityphysicsv3openstax/chapter/nuclear-binding-energy/

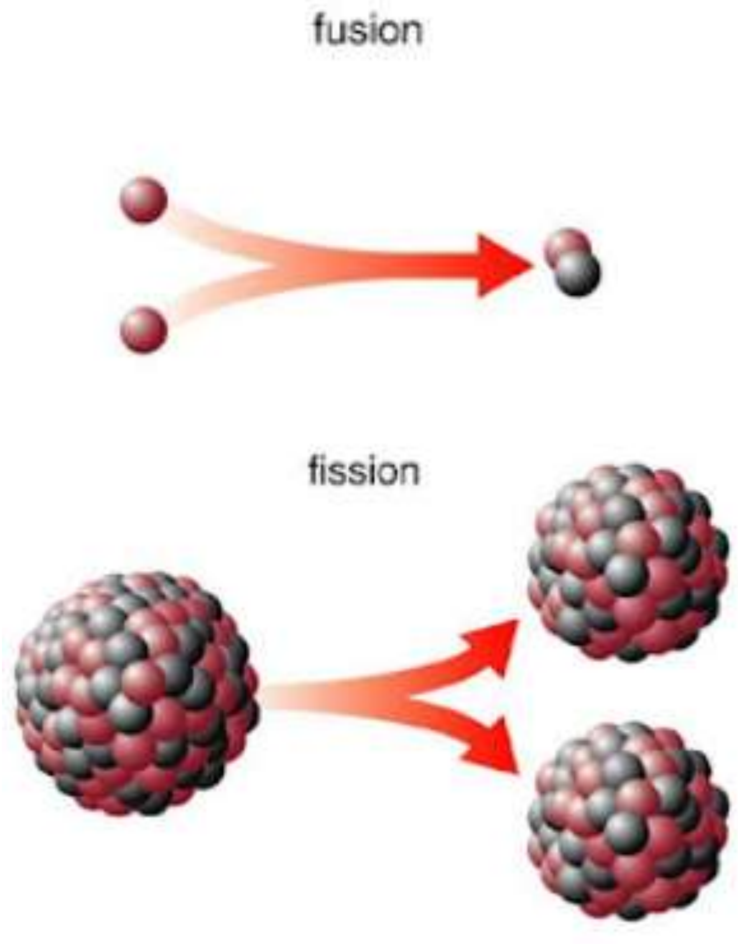
Mass Defect & Star Death

- Mass defect causes the demise of high-mass stars.
  - Unlike low mass stars, high mass stars have enough heat and pressure to continue nuclear fusion up to iron.
- Iron is the stopping point because of properties of atoms as described by the mass defect curve.
  - The fusion of elements that are lighter than iron releases energy, but the fusion of elements heavier than iron would require an input of energy.



Fusion vs. Fission

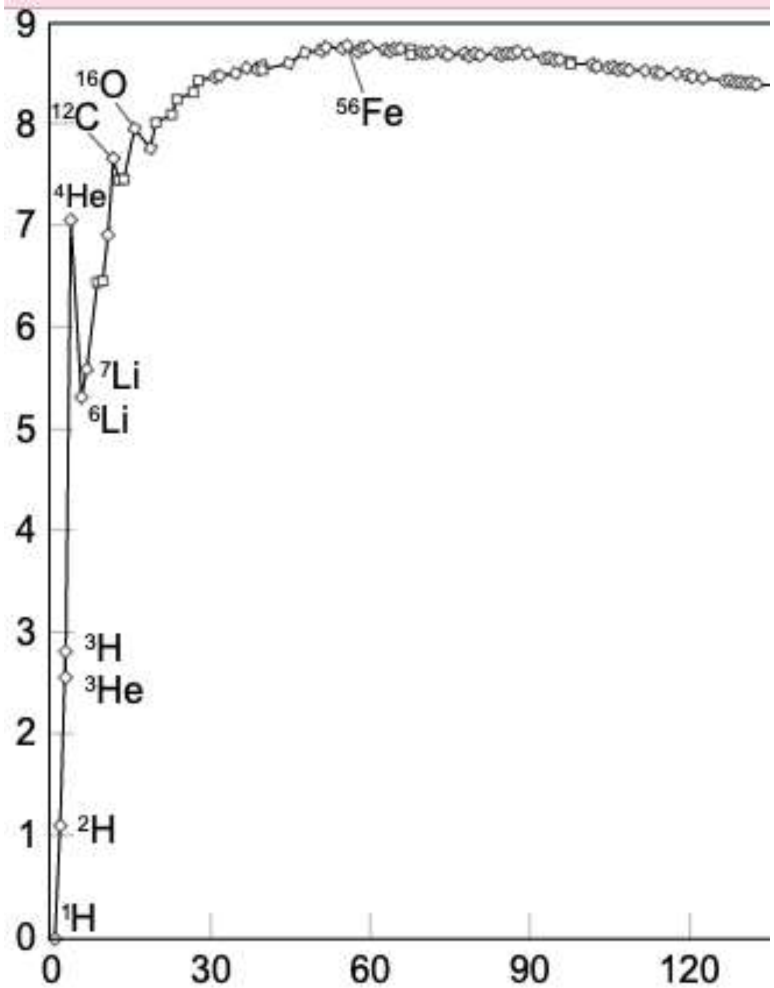
- This also explains why both nuclear fusion and fission are possible.
  - Nuclear fission occurs when a neutron breaks apart an atomic nucleus into two smaller atoms.
  - Elements above iron give off energy when split.
  - Elements below iron give off energy when fused.



Source: Duke Univ

Revisions to W2 Driving Question

- **Can we now improve our answers to our driving questions?**
- Why do stars die?
- Why can atoms fuse? What factors determine whether atoms can fuse or not fuse?
- Why can atoms undergo both nuclear fusion OR nuclear fission?
- How do these factors affect how a star ages and why stars die?



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