Fusion In Stars

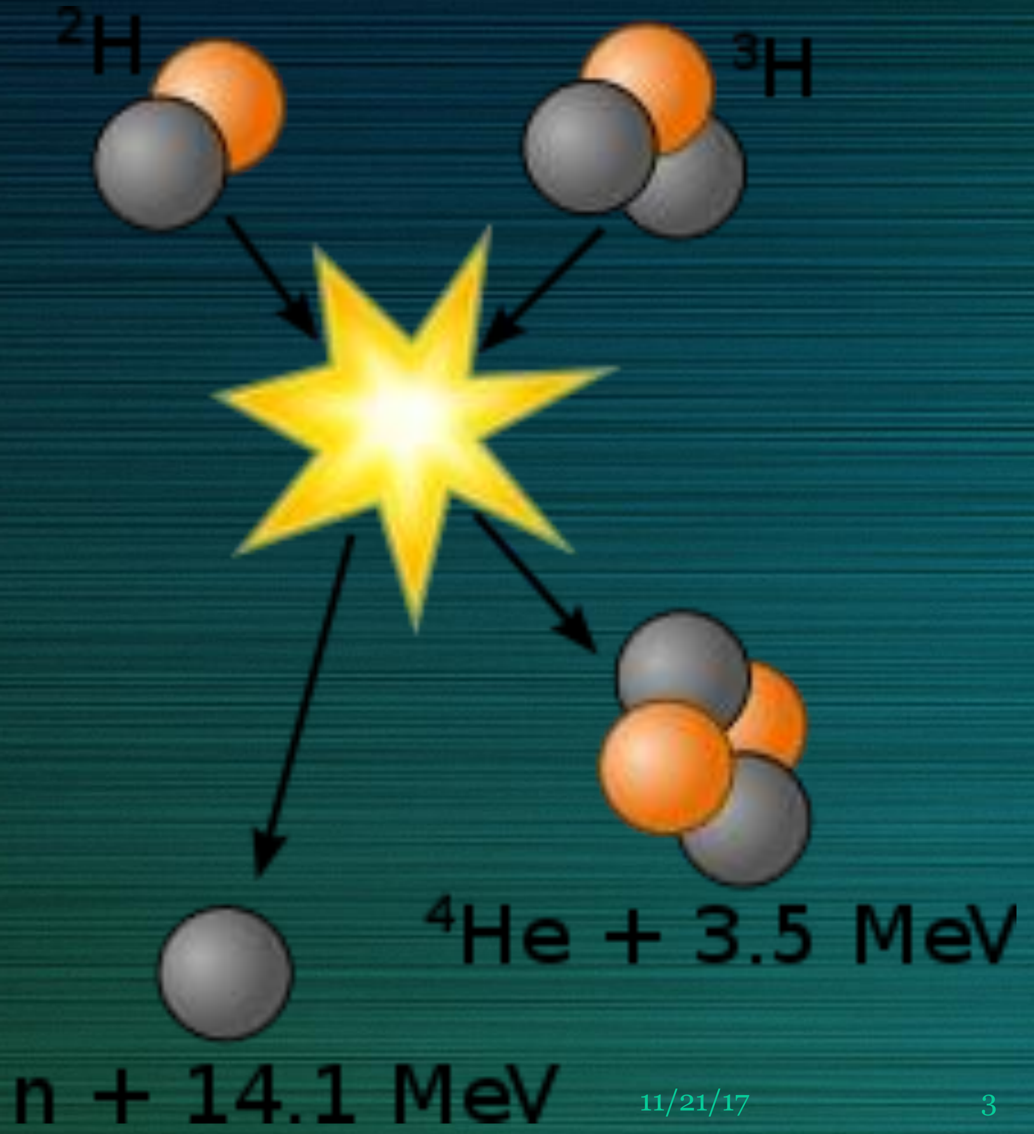
by Connor Peters

Outline

- What is Fusion?
  - Comparison to Fission
- Requirements for Fusion
  - Tunneling
- Fusion Examples
- Fusion in Stars
  - Production of Heavy Elements
  - Proton + Proton Fusion
  - CNO Cycle
- Questions

What Is Fusion?

- Union of atomic nuclei
- Forms heavier nuclei
- Releases enormous amounts of energy
  - Quantity of energy released depends on the binding energies of the nuclei involved



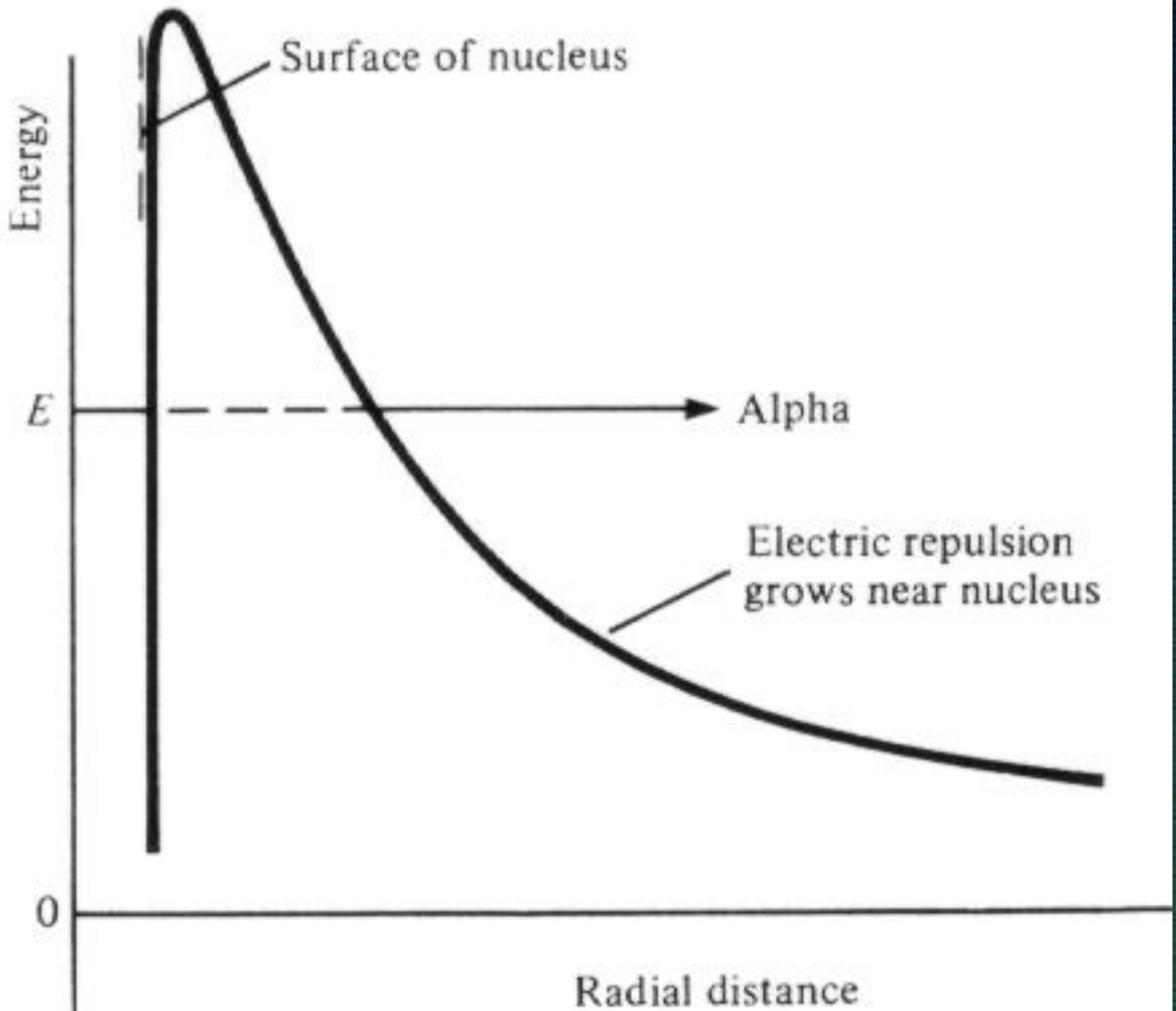
Fission vs. Fusion

Fission

- Breaks apart heavy elements
- Rare fuel
- Requires incident neutron
- Valid energy source

Fusion

- Combines light elements
- Plentiful Fuel
- Difficult to initiate
- Currently invalid as an energy source



Requirements for Fusion

- Nuclei must be in very close proximity
- Repulsion between the positively charged nuclei works against this
- Nuclei can overcome this effect by tunneling through this barrier

Photograph courtesy University of Oregon

Basic Fusion

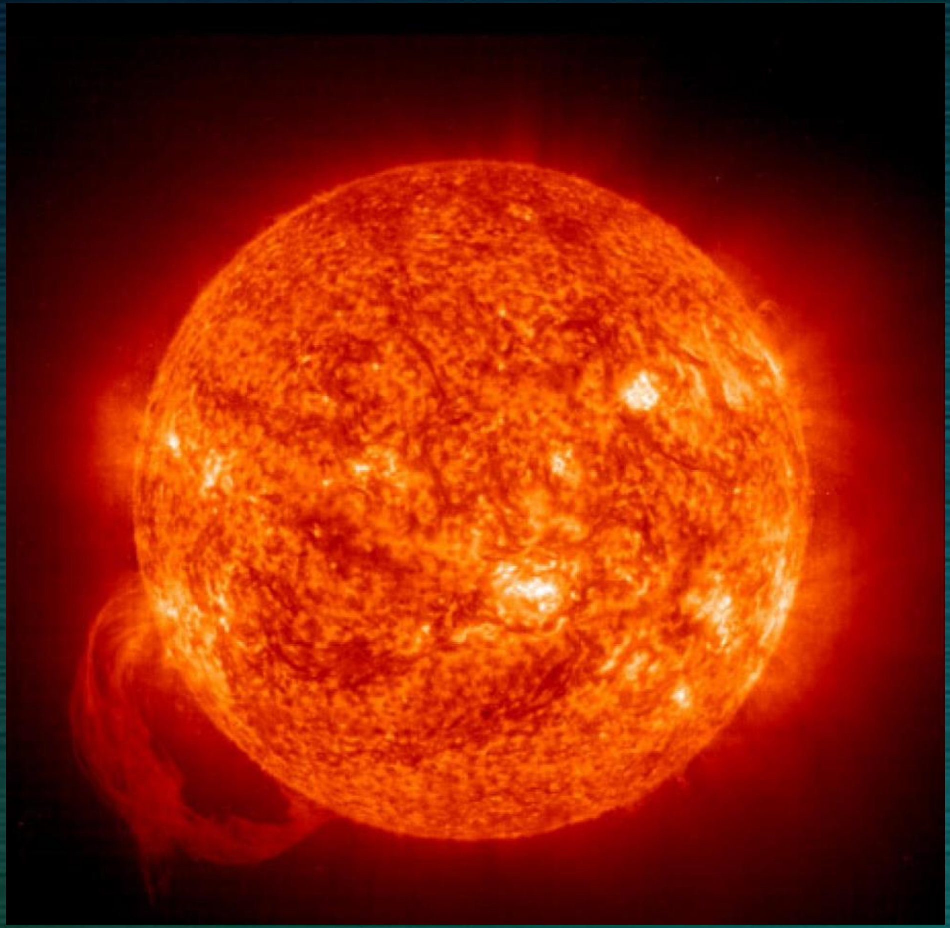
Deuterium + Tritium → Helium + Neutron + 17.6 MeV

Particle	Mass (u)	Energy (MeV)
Deuterium	2.01355	1875.62
Tritium	3.01605	2809.45
Helium	4.00260	3728.42
Neutron	1.00866	939.566

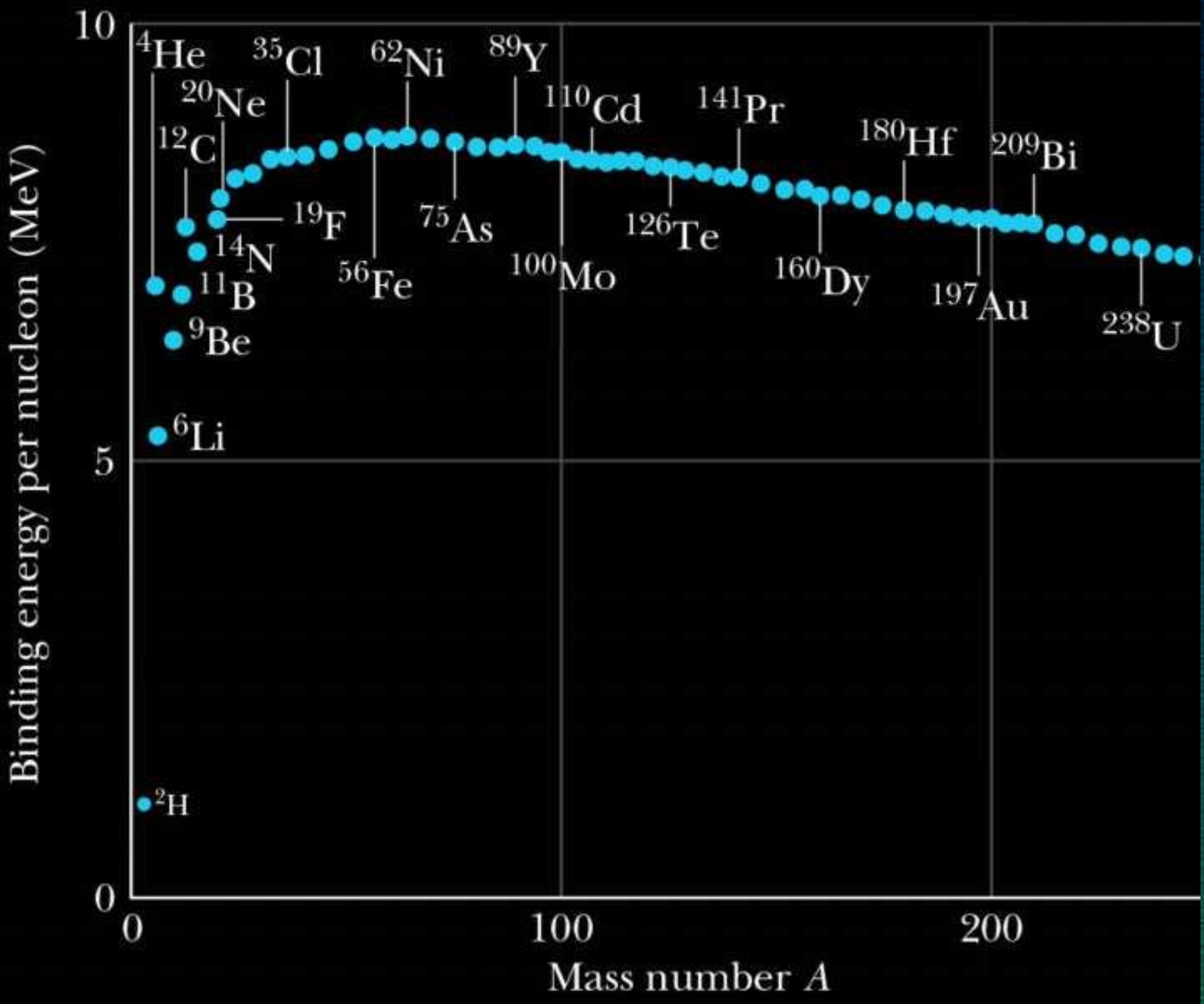
$(3728.42 + 939.566) - (1875.62 + 2809.45) \approx -17.6$ MeV

Energy of the Stars

- Ideal systems for fusion
  - Mass of the entire star exerts pressure on the core
  - High temperatures from previous fusions sustain further fusion
- Amount of fusion material dictates lifetime and lifecycle of a star



Photograph courtesy NASA



Production of Heavy Elements

- Iron (Fe) has the highest binding energy of all elements
- Higher mass products must consume energy in their production
- Dying stars (supernovae) are the origin of the heavier elements

Image courtesy LPP Fusion

Proton + Proton Fusion

Step	Description
$^{1}H + {}^{1}H \rightarrow {}^{2}H + e^{+} + v$	Two protons come together to form deuterium, a positron, and a neutrino
$^{2}H + {}^{1}H \rightarrow {}^{3}He + \gamma$	Deuterium and a proton come together to form helium-3 and a gamma ray
$^{3}He + {}^{3}He + {}^{4}He + {}^{1}H + {}^{1}H$	Two helium-3 nuclei come together to form a helium-4 nuclei and two protons

*Steps 1 and 2 are each done twice
*Step 3 is not the only path to making helium, only the most common

CNO Cycle

Step	Description
$^{12}C + {}^{1}H \rightarrow {}^{13}N + \gamma$	Carbon-12 nuclei captures a proton, producing nitrogen-13 and emitting a gamma ray
$^{13}N \rightarrow {}^{12}C + e^{+} + v$	Nitrogen-13 is unstable, and emits a positron and a neutrino, decaying to carbon-13
$^{13}C + {}^{1}H \rightarrow {}^{14}N + \gamma$	Carbon 13 captures a proton, producing nitrogen-14 and emitting a gamma ray
$^{14}N + {}^{1}H \rightarrow {}^{15}O + \gamma$	Nitrogen-14 captures a proton, producing oxygen-15 and emitting a gamma ray
$^{15}O \rightarrow {}^{15}N + e^{+} + v$	Oxygen-15 is unstable, and emits a positron and a neutrino, decaying to nitrogen-15
$^{15}N + {}^{1}H \rightarrow {}^{12}C + {}^{4}He$	Nitrogen-15 captures a proton, producing carbon-12 and a helium-4 nuclei

Questions

Resources

- http://hyperphysics.phy-astr.gsu.edu/hbase/NucEne/fusion.html
- http://abyss.uoregon.edu/~js/glossary/quantum_tunneling.html
- http://astronomy.swin.edu.au/cosmos/C/CNO+cycle
- http://burro.astr.cwru.edu/Academics/Astr221/StarPhys/ppchain.html
- https://www.euro-fusion.org/faq/how-is-it-that-both-fission-and-fusion-produce-power-if-splitting-a-large-atom-into-two-smaller-atoms-releases-energy-it-seems-that-combining-two-smaller-atoms-into-one-larger-atom-would-require-ene/