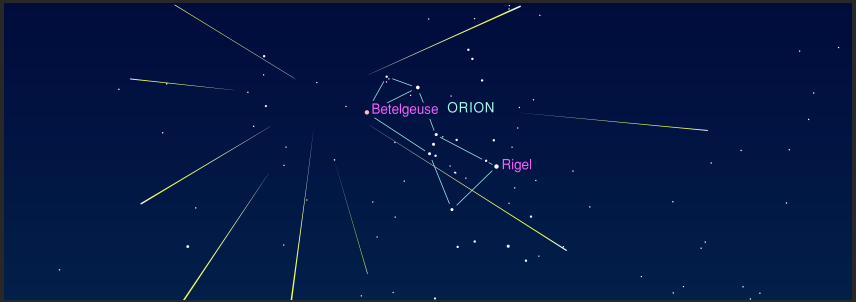
Announcements

- Webwork due on Wednesday (just a single problem)
- Nothing due on Friday because...
- Test 2 on Friday!!
  - All review materials posted (with solutions)
  - Equation page updated
  - Email me if you want to reserve one of my few calculators for Friday
- Lab Group B is meeting tonight for Exoplanets lab!
- Polling: `rembold-class.ddns.net`

The Sky Tonight

- Orionids Meteor shower!
  - Technically peaked over the weekend
  - Debris from Halley's comet
  - Appear to originate in the constellation Orion
  - Still visible (though at reduced rates) through the week



Review Question!

What was one of the early barriers in determining the energy output (Luminosity) of the Sun?

A. Determining its distance from Earth
B. Determining its angular size
C. Determining what was powering it
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Asking the Key Questions. . .

- Now that we understand the physical parameters of the Sun, we can attempt to answer some questions about it
- Most obviously:

Why does the Sun shine?

Has the Sun been shining forever?

Why so shiny?

- Shining means the Sun is giving off energy
- Where it gets this energy was a major question of the early 1900s
  - Originally thought to be some sort of chemical burning
    - First estimates of the luminosity demanded WAY too much energy
    - Would only have enough fuel for 16000 years
  - Gravitational Contraction?
    - Could burn for 25 million years...
    - But Earth's fossil record indicates Earth is older than that?

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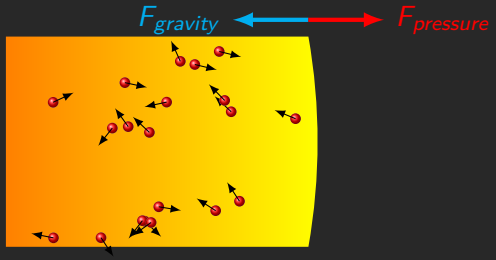
    - Gas Pressure

Under Pressure (dum dum dum bada dumdum)

- We know molecules speed up when they get hot
- Pressure is a measure of how hard those molecules hit the edges of their container
- Hotter = Faster = More Energy = Harder Hitting
- So pressure and temperature are linked! (Among other things. Ideal Gas Law)
- As the Sun contracts, the warming molecules will push back with more force
- At some point, a balance is reached!



Gotta stay Balanced

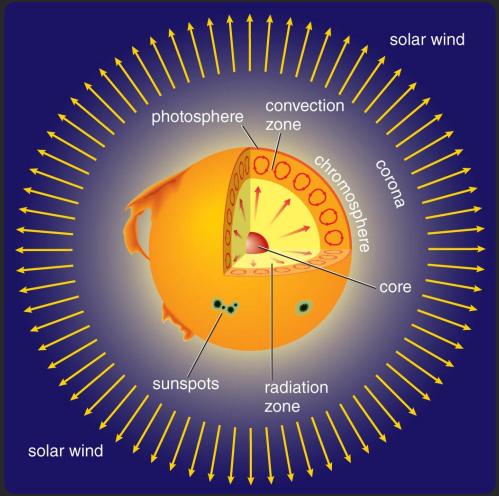
- Everywhere in the star needs to be balanced
- The weight the pressure needs to support increases as we go deeper
- Pressure must therefore increase
- And thus temperature and density must also increase

Even more balancing

- Without an energy source, the Sun would slowly cool
  - Radiating energy out into the universe
- With too strong an energy source, the Sun would puff up and explode!
  - It couldn't emit the energy fast enough!
- Imagine a sealed hot air balloon
  - Heat the air too little and you'll cool and sink
  - Heat the air too much and your balloon could pop
- The Sun is also therefore in *energy balance*
  - Energy In = Energy Out

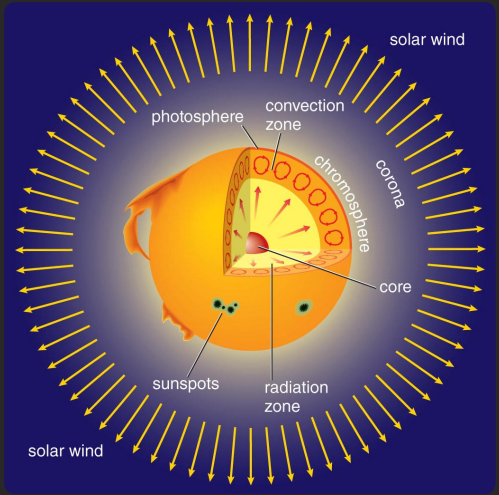
Providing Structure

- The Core
  - 15 million K
  - Where energy is created
- Radiation Zone
  - Energy moves slowly by photon emission (EM waves)
  - Think radiator heating
- Convection Zone
  - Hot gases rise, cold gases sink
  - Think boiling water



Providing More Structure

- Photosphere
  - Around 6000 K
  - Visible "surface" of Sun
- Chromosphere
  - Thin layer just above photosphere
  - Radiates mostly ultraviolet
- Corona
  - Extremely hot: around 1 million K
  - Density very low



We need more *power* Captain!

- The quest to determine from whence the Sun gains its power:
  - 1890's: Radioactivity discovered
    - Elements can transform from one to another and release energy in the process
  - 1905: Einstein's Special Relativity
    - Mass and energy are equivalent
    - $E = mc^2$
  - 1930's: Discovery of the Neutron
    - Understanding H and He nuclei
  - 1939: Hans Bethe worked out a detailed mechanism for the Sun's power source

Going Nuclear

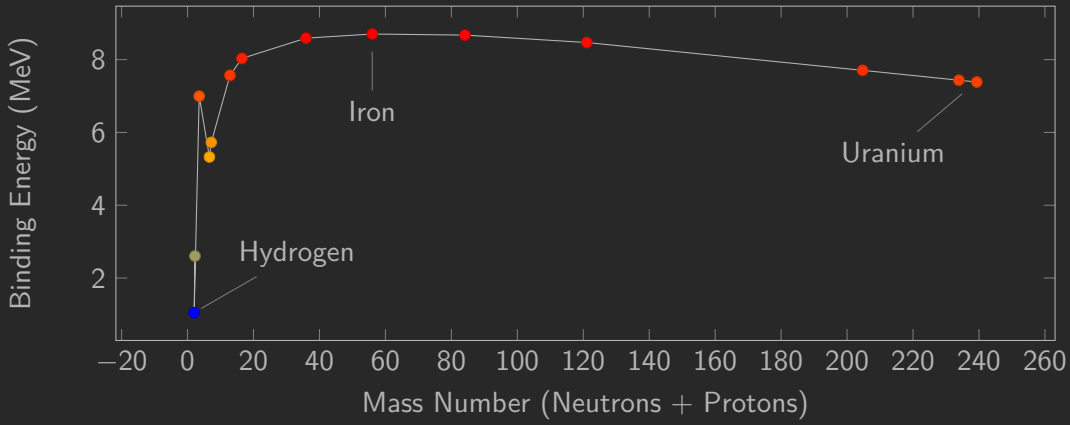
- To understand our Sun's energy production, we need to focus on the tiny:
  - Elements on the Periodic Table are comprised of Protons, Neutrons, and Electrons
  - There are 4 main forces we know that describe the universe:
    - The Strong Nuclear Force binds atoms
    - The Weak Nuclear Force governs radioactive decay
    - The Electromagnetic Force covers charges and magnets
    - The Gravitational Force covers mass attraction
  - At the atomic level, the gravitational force is irrelevant
  - The strong nuclear force is the strongest of the fundamental forces, but incredibly small in range (Think femtometers $= 10^{-15}$ meters)

Proton Packing

- Protons are positively charged
- Putting positively charged things next to each other makes them want to repel (Electromagnetic force)
- So to make an atom, you need to manage to squeeze them close enough together to let the stronger nuclear force "grab" them, despite the electromagnetic force pushing them away
- If your atom gets too large, then your strong nuclear force will weaken, making it easier for protons to escape
- Since $E = mc^2$, you can actually measure this "energy of binding" by comparing the masses of the individual atoms to the mass of the combined element!

Binding Energy

The amount of energy needed to hold elements together varies!



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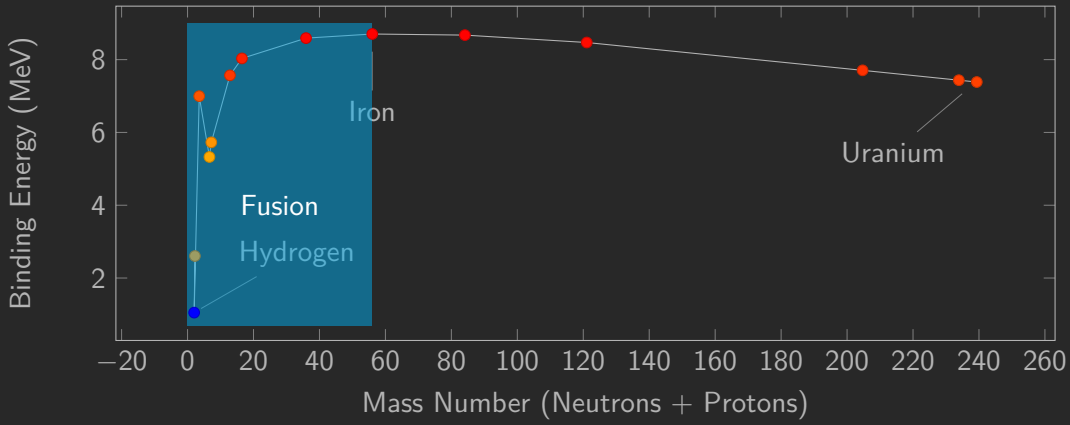

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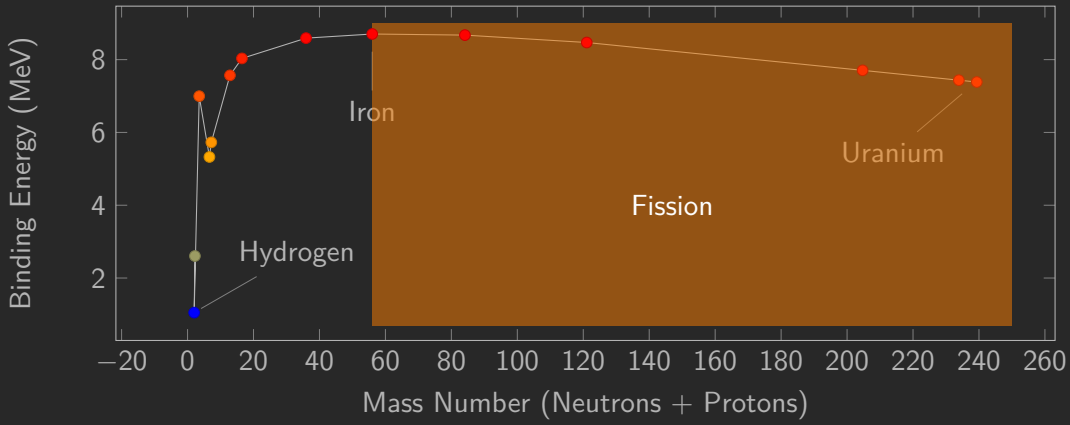

Fusion Power!

- The interior of the Sun is very dense, very hot, and very Hydrogen
- Packs lots of protons close together and moving real fast
- When protons get close enough:
  - Bang! Fusion happens!
  - Energy is given off!
  - The cycle continues...