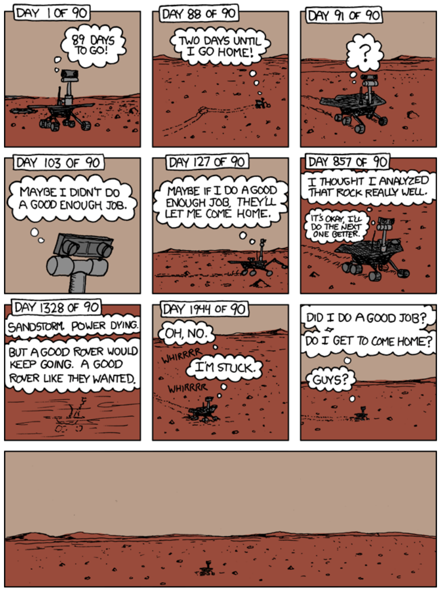


Astronomy 330

This class (Lecture 6):

Why does the Sun shine?

Next Class:

Star Formation

Synopsis Due!

Music: *Carl Sagan -Glorious Dawn*– Colorpulse

http://www.youtube.com/watch?v=zSgiXGELjbc&feature=fvw

Outline

- The first term of the Drake
- How does the Sun shine?

Drake Equation

Frank Drake

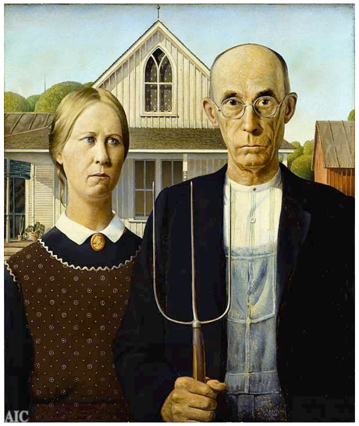
$$N = R_* \times f_p \times n_e \times f_l \times f_i \times f_c \times L$$

N	R_*	f_p	n_e	f_l	f_i	f_c	L
# of advanced civilizations we can contact in our Galaxy today	Star formation rate	Fraction of stars with planets	# of Earthlike planets per system	Fraction on which life arises	Fraction that evolve intelligence	Fraction that commun-icate	Lifetime of advanced civilizations
	? stars/ yr	systems/ star	planets/ system	life/ planet	intel./ life	comm./ intel.	yrs/ comm.

Lifecycle of a Star

- Star formation
  - Take a giant molecular cloud core with its associated gravity and wait for 10^4 to 10^7 years.
- Death
  - Exhaust hydrogen
  - Red giant / supergiant or supernova
  - White dwarfs, neutron stars, black holes

Stellar Lifestyles



Low-mass stars

Massive stars

Lifecycle of a Star

- Star formation
  - Take a giant molecular cloud core with its associated gravity and wait for 10^4 to 10^7 years.

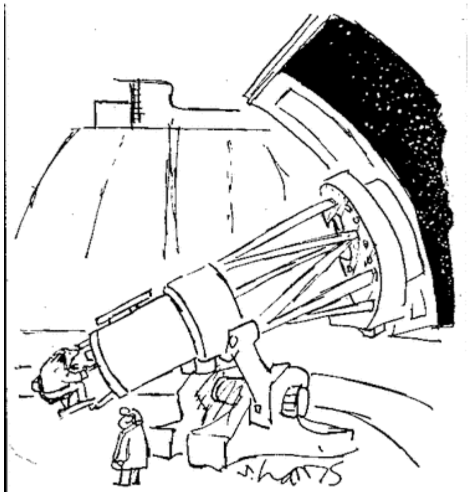
- Death
  - Exhaust hydrogen
  - Red giant / supergiant or supernova
  - White dwarfs, neutron stars, black holes
- Main sequence life (depends on mass!)
  - Few x 10^6 years to more than age of Universe
  - Thermonuclear burning of H to He

Stars

- The fundamental building blocks of the Universe.
- High mass stars are 8 to 100 solar masses
  - Short lived: 10^6 to 10^7 years
  - Luminous: 10^3 to 10^6 L_{sun}
  - Power the interstellar medium–input of energy
- Intermediate mass stars are 2 to 8 solar masses
- Low mass stars are 0.4 to 2 solar masses
  - Long Lived: $>10^9$ years
  - Good for planets, good for life.
  - Not so luminous: 0.001 to 10 L_{sun}

Estimate of R_*:
The Star Formation Rate

- We are about to start the topic of star formation and planet formation, but really the field is not well enough developed to estimate R_*.
- It is more accurate to just take the total number of stars in the Galaxy and divide by the age of the Galaxy.
- Later we will correct for the stars that are too big, too small, or too variable.



"Let's see, now ... picking up where we left off ... one billion, sixty-two million, thirty thousand, four hundred and thirteen ... one billion, sixty-two million, thirty thousand, four hundred and fourteen ... "

Counting Stars

Estimate of R*: The Rate of star formation

Take the total number of stars in the galaxy and divide by how long it took those stars to form.

Sounds easy, but it isn't. We can't see all of the stars, interstellar dust blocks our view of most of them.

We can estimate the number of stars based on the total mass of the Galaxy and some corrections.

$$N_* = 5\times10^{10} \text{ to } 5\times10^{11} \text{stars}$$

Estimate of R*: The Rate of star formation

Age of our galaxy is around 10^{10} years (if you want to be more precise, use 13.7 billion years minus ~200 million).

$$R_* = \frac{5\times10^{10}\ to\ 5\times10^{11}\ stars}{10^{10}\ years} = 5\ to\ 50\,\frac{stars}{year}$$

Probably the best estimate for the entire Drake Equation, meaning it can only be off by a factor of 10 or so.

Estimate of R*: Discuss

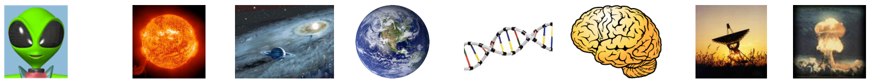
$$R_* = \frac{5\times10^{10} \text{ to } 5\times10^{11}\ stars}{10^{10}\ years} \approx 5 \text{ to } 50\,\frac{stars}{year}$$

1. Discuss the calculation of this value.
2. Choose a lower/higher number if you think that the star formation rate was biased by non-uniform star formation.
   - Did the early galaxy produce more stars in the past than it does now? Was there a starburst long ago?
   - But remember that we are constantly obtaining new gas from our satellite galaxies (around 1 solar mass per year). It might average out.

Drake Equation

The class's first estimate is

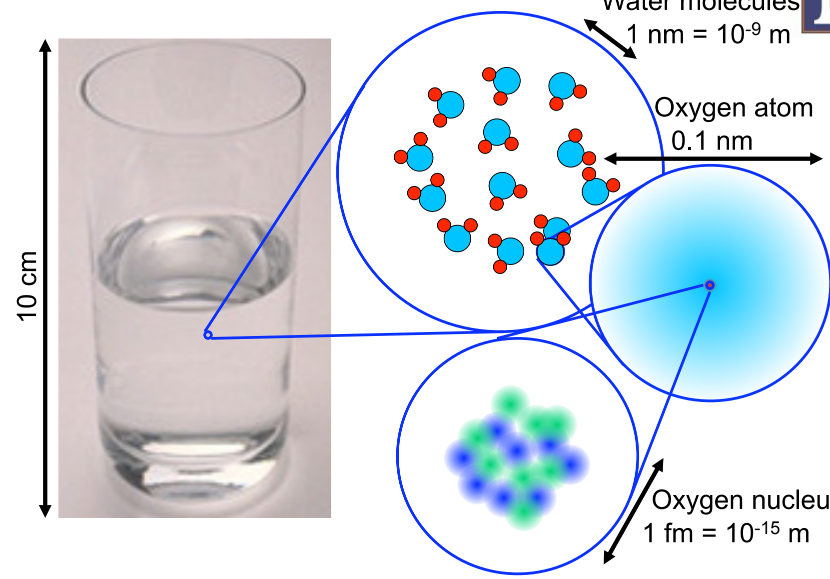

Frank Drake



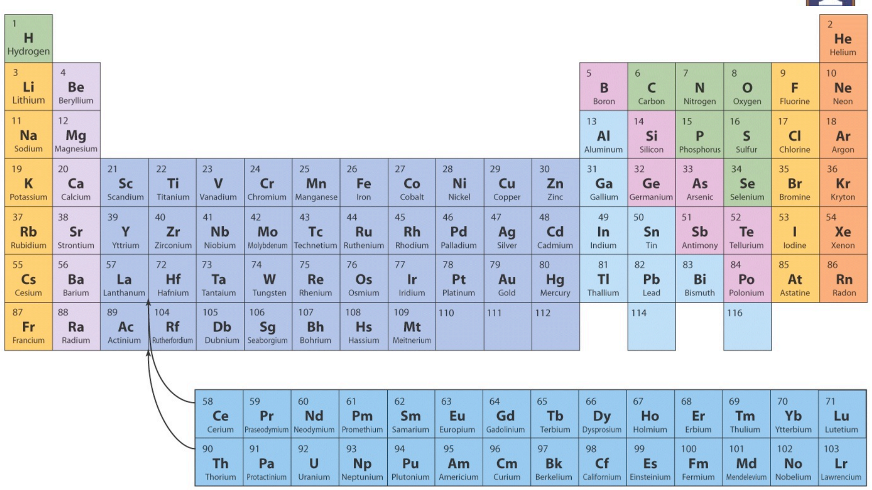
$$N = R_* \times f_p \times n_e \times f_l \times f_i \times f_c \times L$$

N	R_*	f_p	n_e	f_l	f_i	f_c	L
# of advanced civilizations we can contact in our Galaxy today	Star formation rate	Fraction of stars with planets	# of Earthlike planets per system	Fraction on which life arises	Fraction that evolve intelligence	Fraction that commun-icate	Lifetime of advanced civilizations
	? stars/ yr	systems/ star	planets/ system	life/ planet	intel./ life	comm./ intel.	yrs/ comm.

A Glass of Water



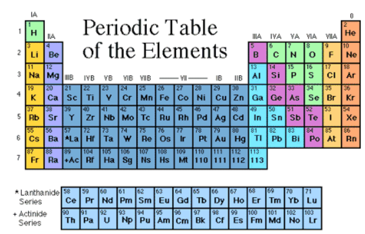
The Periodic Table of the Elements



The number of protons in an atom determines the type of element, and the number of protons and neutrons determine the atomic weight.

Chemical Basis for Life

- The average human has:
  - 6 x 10^{27} atoms (some stable some radioactive)
  - During our life, 10^{12} atoms of Carbon 14 (^{14}C) in our bodies decay.
  - Of the 90 stable elements, about 27 are essential for life. (The elements from the Big Bang are not enough!)



http://www.genesismission.org/science/mod2_aei/

Chemical Basis for Life

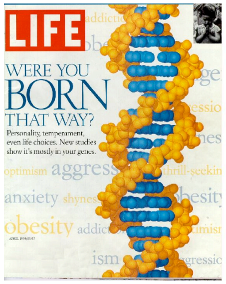
By Number…

- Life on Earth is mostly:
  - 60% hydrogen
  - 25% oxygen
  - 10% carbon
  - 2% nitrogen
  - With some trace amounts of calcium, phosphorous, and sulfur.
- The Earth's crust is mostly:
  - 47% oxygen
  - 28% silicon

- The Universe and Solar System are mostly:
  - 93% hydrogen
  - 6% helium
  - 0.06% oxygen
  - 0.03% carbon
  - 0.01% nitrogen

Little Pink Galaxies for you and me

- Life as we know it, needs more elements than the Big Bang could provide.
  - Composition of life is unique.
- Does the environment of the Galaxy nourish life?
- At the vary least we need galaxies to process the material from the Big Bang into materials that life can use.
- The Universe does this through star formation.



http://www.chromosome.com/lifeDNA.html

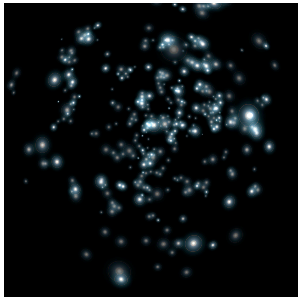
Question

What can say about the elemental make-up of life on Earth, the Earth, and the Universe?

a) All three are made up of the same elements in the same amounts.
b) The Universe is mostly hydrogen, but the Earth and life on Earth are mostly oxygen.
c) The Earth and the Universe are mostly hydrogen.
d) Life on Earth and the Universe are mostly carbon.
e) They are made up of the same elements but different concentrations.

The First Stars

- From the initial seeds of the Big Bang, our local group of galaxies probably broke into clumps of hydrogen and helium.
- First Stars may have formed as early as 200 million years after the Big Bang.
- Probably more massive than stars today, so lived quickly and died quickly.
- What happened? Why did this "raw" gas form anything?



http://www.blackshoals.net/ImageBank/gallery/gallery/huge/The-first-stars-clustering.jpg

Water Power?

- Does a bottle of water have any stored energy? Can it do work?

The water has potential energy. It wants to flow downhill. If I pour it out, the conservation of energy tell us that it must turn that potential energy into kinetic energy (velocity). The water wants to reach the center of the Earth. This is how we get hydro energy from dams.

Gas powered

- Similar to my bottle of water, these initial gas clumps want to reach the center of their clump-ness.
- The center gets hotter and hotter. The gravitational energy potential turns into heat (same as velocity actually).
- It is a run-away feature (or snowballing), the more mass at the center, the more mass that wants to be at the center.
- The center of these clumps gets hotter and denser.

http://www.rob-clarkson.com/duff-brewery/snowball/04.jpg

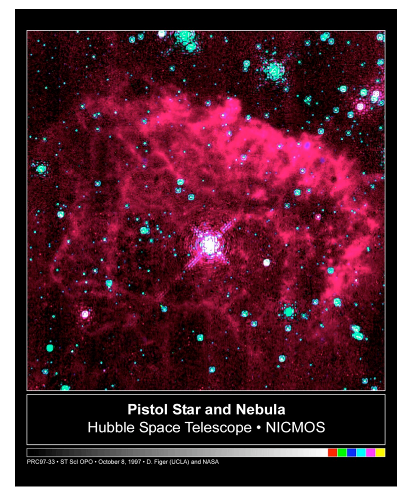
Cooking with Gas

- For the first time, since 1-month after the Big Bang, the centers of the clumps get above 10^7 K.
- Now hot enough for nuclear fusion to occur. If that had not happened, life would never have existed.
- But are things different than what we learned in Astro 100? These are the First Stars after all.

http://lgeku.energyunderground.com/images/images-deepearth/BURNERBL.jpg

The Most Massive Star in the Milky Way Today

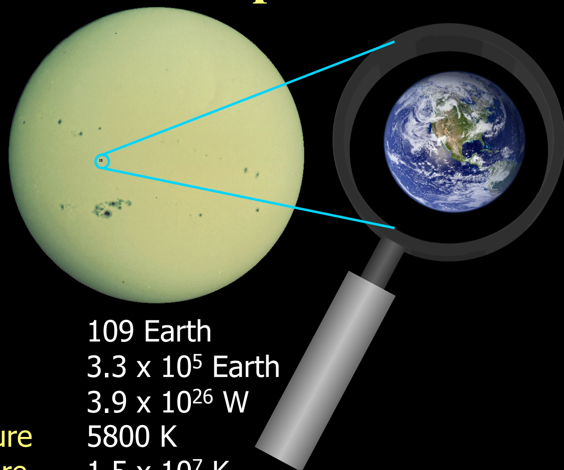
- The Pistol star near the Galactic center started as massive as 200 solar masses.
- Releases as much energy in 6 seconds as the Sun in a year.
- But it blows off a significant fraction of its outer layers.
- How did the first stars stay so massive?
- Perhaps they are slightly different than this case?



http://www.u.arizona.edu/~justin/images/hubblepics/full/PistolStarandNebula.jpg

Earth-Sun Comparison

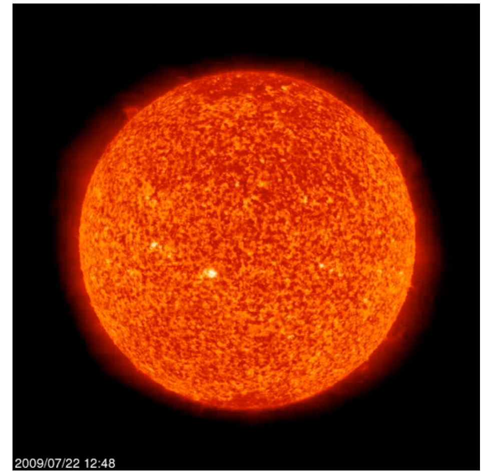
In general, a very typical star. Keep in mind that it is really a ball of gas.



Visual radius	109 Earth
Mass	3.3×10^5 Earth
Luminosity	3.9×10^{26} W
Surface temperature	5800 K
Central temperature	1.5×10^7 K
Rotation period	25 days

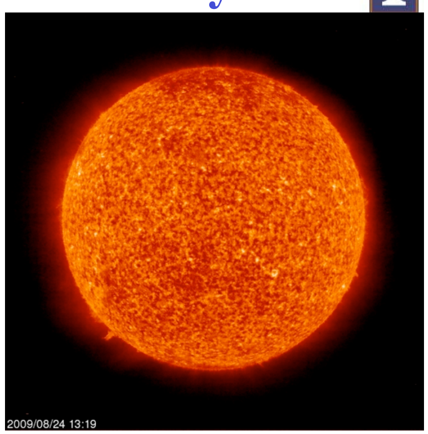
LIVE from the Sun

http://sohowww.nascom.nasa.gov/data/realtime/mpeg/



Question of Stability

- The Sun's size is constant.
- No weatherman says it will be especially hot tomorrow as the Sun's size will be increasing.
- Not expanding or collapsing.
- The Sun is stable! Why?

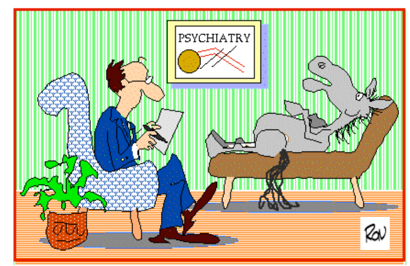


http://sohowww.nascom.nasa.gov/data/realtime/eit_304/512/

http://www.londonstimes.us/toons/index_medical.html

Question of Stability

- Not trivial, could have gone the other way
- Think: Sun is made of gas, yet not like a cloud, for example, which is made of gas but size, shape changes all of the time
- Not a coincidence: really good reason



"I just don't feel stable."

http://www.londonstimes.us/toons/index_medical.html

Why is the Sun Stable?

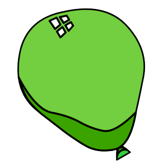
- What keeps gravity from collapsing the Sun?
- What keeps the Sun from exploding?

Pressure

- What is pressure?
  - Pressure $= \frac{Force}{Area}$

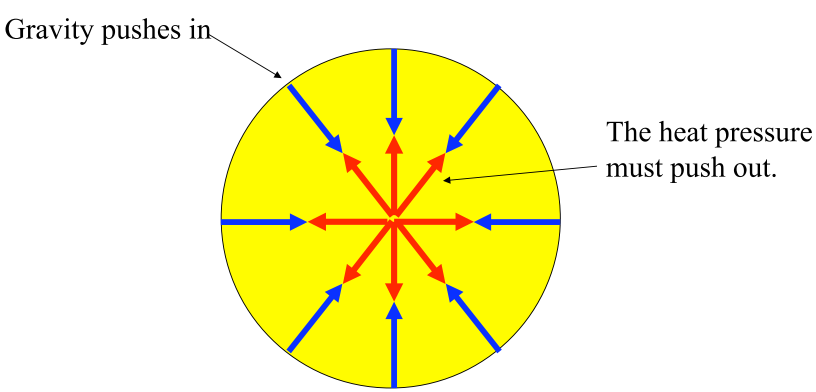
Pressure of Earth's atmosphere is 14.7 pounds per square inch

- Explain blowing up a balloon?



- http://www.phy.ntnu.edu.tw/java/idealGas/idealGas.html

The Battle between Gravity and Pressure



Hydrostatic equilibrium: Balanced forces

Question

A star is in hydrostatic equilibrium. What does that mean?

a) Keeps the Sun burning H into He.
b) Keeps the Sun from turning into a big cloud in the shape of a bunny.
c) Keeps the Sun a flattened disk.
d) Keeps the Sun a constant size.
e) Keeps the Sun unstable.

The Sun’s Energy Output

3.85 x 10^{26} Watts, but how much is that?

A 100W light bulb…

…the Sun could supply 4 x 10^{24} light bulbs!

U.S. electricity production in 2006: 4.1 trillion kWh…

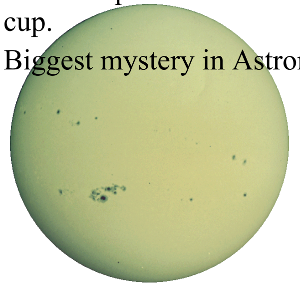
… Sun = 3 x 10^{7} times this *every second*

World’s nuclear weapons: 3 x 10^{4} megatons…

… Sun = 4 million times this *every second*

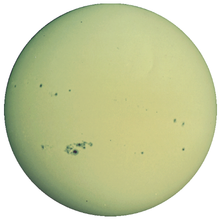
So, What Powers the Sun?

- The Sun does not collapse nor even change it’s radius.
- Gravity pushes in, but what pushes out?
  - Okay, heat, but what makes the heat?
- What is its power source?
- What keeps the Sun hot? It doesn’t cool like a hot coffee cup.
- Biggest mystery in Astronomy up until 20th century.



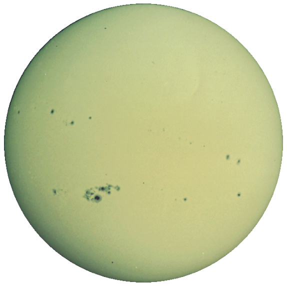
How to Test?

- Without an energy source, the Sun would rapidly cool & contract
  - Darwin: evolution needs Sun & Earth to be > 10^{8} years old
  - Lyell: geological changes also need > 10^{8} years
- Process must be able to power Sun for a long time! At least 4.5 Byrs.



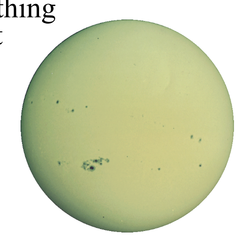
So, What Powers the Sun?

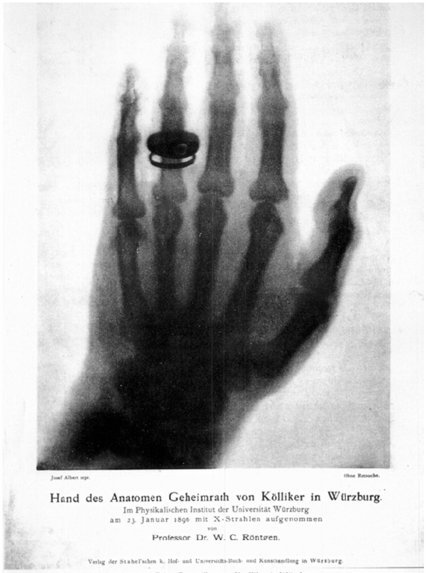
Discuss with neighbors possible heating possibilities. List at least 2 possibilities, even if you know the correct one. List all feasible ideas.



How to Test?

- Gravity:
  - Seems like a good idea. Remember Jupiter gives off heat.
  - A contracting Sun releases gravitational energy.
  - But only enough for 20 million years
- Chemical:
  - If the Sun was made from TNT, something that burns very well, then it would last for only 20,000 years
- Need something more powerful!





Radiograph of the hand of the anatomist Privy Councillor von Koelliker in Würzburg, taken by W. C. Röntgen in Würzburg on January 23, 1896

Eyes began to turn to the nuclear processes of the Atoms

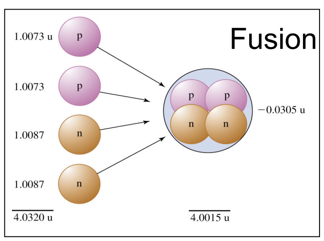
What is Fusion?

$$4p \rightarrow {}^{4}\mathrm{He}\ (2p,2n)$$

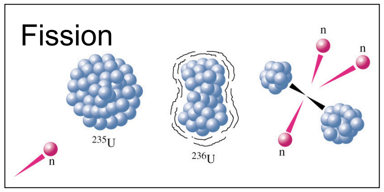
Basic idea is to take 4 protons (ionized hydrogen atoms) and slam them together to make an ionized helium atom.

Fusion vs. Fission

- Light nuclei: fusion
  - Fuse together light atoms to make heavier ones
  - Happens in the Sun
  - H-Bomb

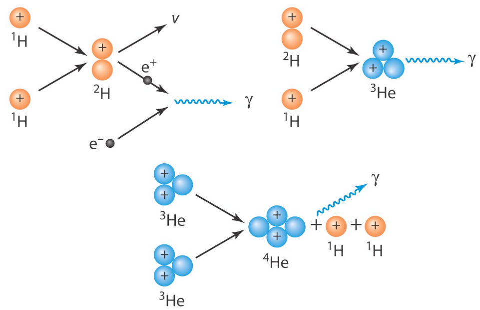


- Heavy nuclei: fission
  - Break apart heavier atoms into lighter ones
  - Used in power plants
  - A-Bomb



Nuclear Fusion in the Sun's Interior

- Proton-Proton Chain
  - 4 hydrogen atoms fuse to make 1 helium atom
  - Requires very high density and temperature (at least 7 million K)



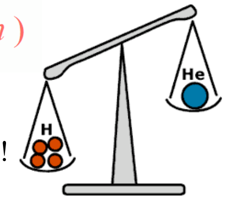
The Proton-Proton (p-p) Chain

Why does fusion release energy?

Fusion: $4\,p \rightarrow {}^4\text{He} \quad (2\,p, 2\,n)$

Fact: **4m(*p*) > m(^{4}He)** !

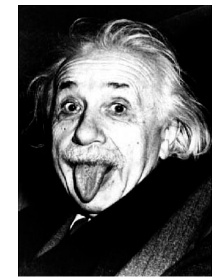
<u>mass of whole < mass of parts</u>!



Einstein says ***E = mc²***:

- Mass is a form of energy!
- Each ^{4}He liberates energy:

$$E_{\text{fusion}} = m_{\text{lost}}c^2 = 4m(p)c^2 - m({}^4\text{He})c^2 \; > 0!$$

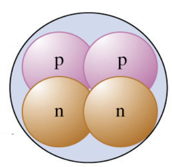


The Nucleus

- Okay, so we know that the nucleus can have numerous protons (+'s) very close.

Helium

- **Something is odd here!**
- **What is it?**

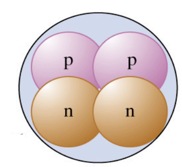


The Nucleus

- **Why doesn't the nucleus of the atom fly apart?**
- **Discuss with neighbor.**

Helium

- **Something is odd here!**
- **What is it?**



4 Fundamental Forces

- Gravity
- Electromagnetic
- **Strong Nuclear**
  - **The strongest of the 4 forces**
  - **The force which holds an atom's nucleus together, in spite of the repulsion between the protons.**
  - **Does not depend on charge**
  - **Not an inverse square law– very short range.**
- Weak Nuclear

Question

Why does the Sun shine?

a) Nuclear burning.
b) Nuclear burning of helium to carbon.
c) Nuclear burning of dreams to pure energy.
d) Nuclear burning of hydrogen to helium.
e) Nuclear burning of carbon to helium.

Nuclear Fusion in the Sun's Interior

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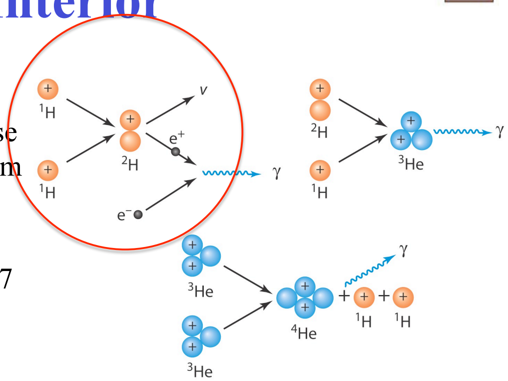
  - 4 hydrogen atoms fuse to make 1 helium atom
  - Requires very high density and temperature (at least 7 million K)



The Proton-Proton (p-p) Chain

http://www.youtube.com/watch?v=Czbh_sdqX84