Astronomy 150:
Killer Skies

This Class (Lecture 12):
Why does the Sun Shine?

Next Class:
Why is the Sun Yellow?

HW5 due Monday
Exam 1 next Friday!

Music: *The Sun Always Shines on TV*– A-Ha

Exam 1

- Exam 1 in this classroom in 1 week (Oct 1st)
- 40 Multiple choice questions
- Will cover material up to and including today.
- May bring 1 sheet of paper with notes
  - Both sides
  - Printed/handwritten/whatever.. I don't really care
- Major resources are lecture notes and homeworks
- Try to understand major points more than anything.
- Have created and posted a study guide

Night Obs

- Dates:
  - Monday, Oct. 4th
  - Tuesday, Oct. 5th
  - Wednesday, Oct. 6th
  - Thursday, Oct. 7th
  - Monday, Oct. 11th
  - Tuesday, Oct. 12th
  - Wednesday, Oct. 13th
  - Thursday, Oct. 14th

Go to assignment page on class website for more info.

You **MUST** download worksheet before you go.

Can be cloudy, so check webpage before you go.

Outline

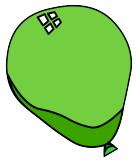
- Why does the Sun shine?
  - Gravity pushes in and heat pressure pushes out.
- Neutrinos prove nuclear fusion
- To understand the death of our Sun, we have to look at other stars…
- Stars are Suns too…

Pressure Stable

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

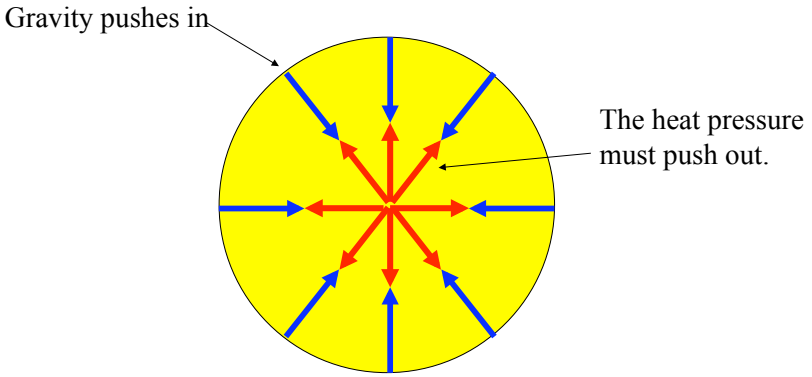
Pressure of Earth's atmosphere is 14.7 pounds per square inch

- 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

What does hydrostatic equilibrium do?

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 stable size.
e) Keeps the Sun unstable.

The Sun's Energy Output

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

A 100W light bulb…

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

U.S. electricity production in 2009: 4.1 trillion kWh…

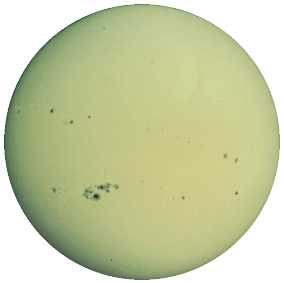
… Sun = 3×10^{7} times this *every second*

World's nuclear weapons: 3×10^{4} megatons…

… Sun = 4 million times this *every second*

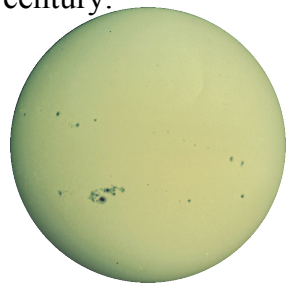
So, What Powers the Sun?

- 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?



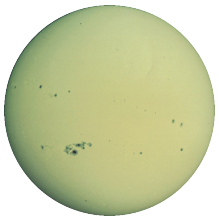
So, What Powers the Sun?

- 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?

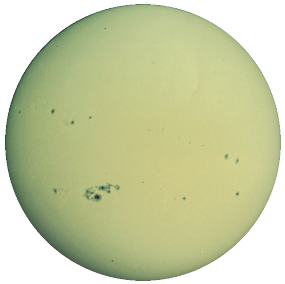
- Without an energy source, the Sun would rapidly cool & contract
  - Darwin: evolution needs Sun & Earth to be > 10^8 years old
  - Lyell: geological changes also need > 10^8 years
- Process must be able to power Sun for a long time! At least 4.5 Byrs.



So, What Powers the Sun?

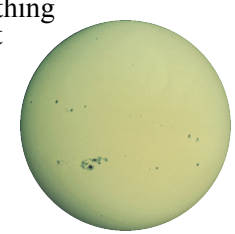
Discuss with neighbors possible heating possibilities. List at least 2 possibilities, even if you know the correct one. List all feasible ideas.

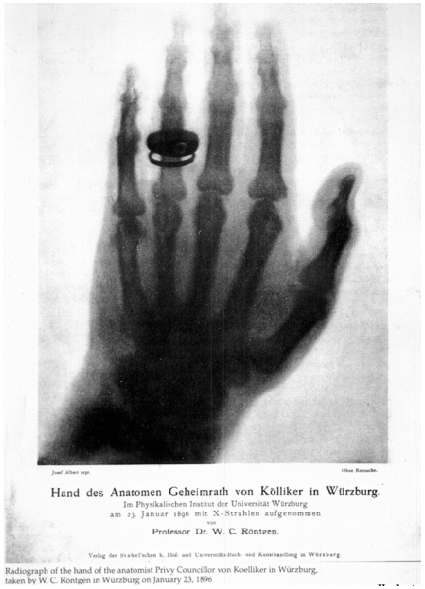
Then, click A on your iclicker.



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!





Hand des Anatomen Geheimrath von Kölliker in Würzburg.
Im Physikalischen Institut der Universität Würzburg
am 23. Januar 1896 mit X-Strahlen aufgenommen
von
Professor Dr. W. C. Röntgen.

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

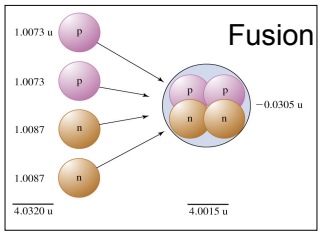
What is Fusion?

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

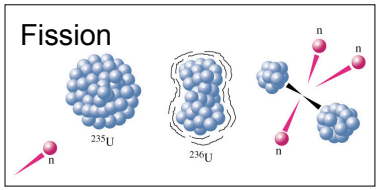
Basic idea is to take 4 protons (ionized hydrogen atoms) and slam them together to make an ionized helium atom.

Fusion vs. Fission

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

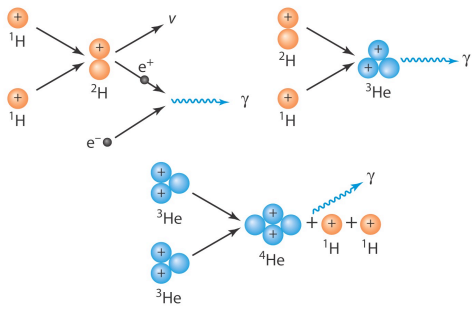


- Heavy nuclei: fission
  - Break apart heavier atoms into lighter ones
  - Used in power plants
  - A-Bomb



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)

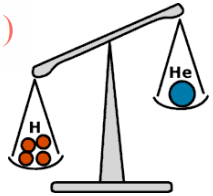


The Proton-Proton (p-p) Chain

Why does fusion release energy?

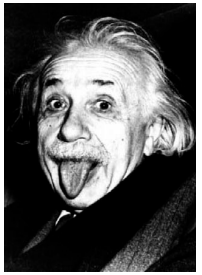
Fusion: $4\ p \rightarrow {}^4\mathrm{He}\ \ (2\ p, 2\ n)$

Fact: **4m(*p*) > m(^{4}He)** !
mass of whole < mass of parts!



Einstein says ***E* = *mc*^{2}**:
- Mass is a form of energy!
- Each ^{4}He liberates energy:

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

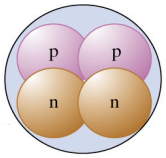


The Nucleus

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

Helium

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

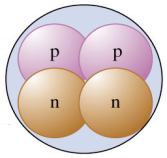


The Nucleus

- **Why doesn't the nucleus of the atom fly apart?**
- **Discuss with neighbor, then click A on your iclicker**

Helium

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

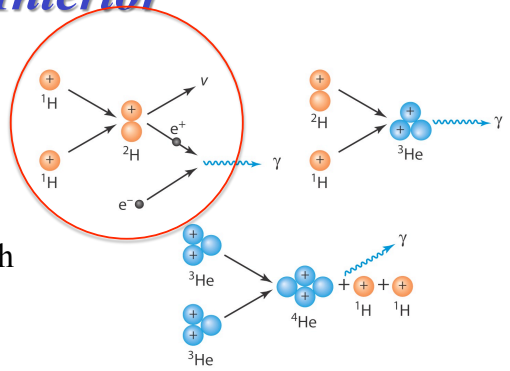


4 Fundamental Forces

- 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

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

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

Nuclear Reactions in the Sun

- Chain: 4 protons ⟹ helium
- First step in chain (2 protons combine):

$$p + p \rightarrow [np] + e^+ + \nu$$

- Start with 2 particles (protons)
- End up with 4 particles (two of which are glued together)
- each of products is very interesting in its own right....

Nuclear Reactions in the Sun

$$p + p \rightarrow [np] + e^+ + \nu$$

$[np]$ = **deuterium**

- 1 proton + 1 neutron bound together into nucleus of element…
- Hydrogen, but has neutron, so 2 times mass of normal H
  - "Heavy Hydrogen"
- Simplest composite nucleus

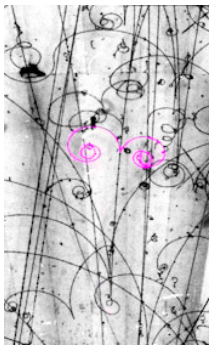
Discovery of D in lab: ***Nobel Prize***
about 0.01% of all H on earth is D
✓ including in your body:
you contain about 10 kilos (20 lbs) of H, and about 2 grams of D
✓ Water (normally H_2O) with D is D_2O : "heavy water"

Nuclear Reactions in the Sun

$$p + p \rightarrow [np] + e^+ + \nu$$

e^+ = **positron**

- Exactly the same as electron but charge +1
- **Antimatter**
- Combines with normal e^-
  - Both are gone, release of energy
  - ***Annihilation***



Discovery of positron in lab: ***Nobel Prize***
Because of this reaction

➢ The Sun contains a small amount of antimatter!

Nuclear Reactions in the Sun

$$p + p \rightarrow [np] + e^+ + \nu$$

ν (Greek letter "nu") = **neutrino**

- Particle produced in nuclear reactions ***only***
- Tiny mass: $m(\nu) < 10^{-6} m(e)$!
- Moves at nearly the speed of light
- ***Very*** weakly interacting

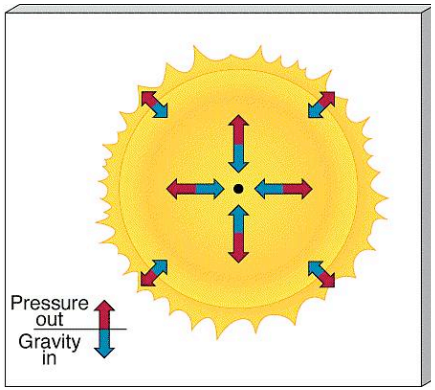
Discovery of neutrino in lab: ***Nobel Prize***

10 billion from Sun go through hand every sec

➢ Reach out!
➢ Go through your body, Earth, but almost never interact

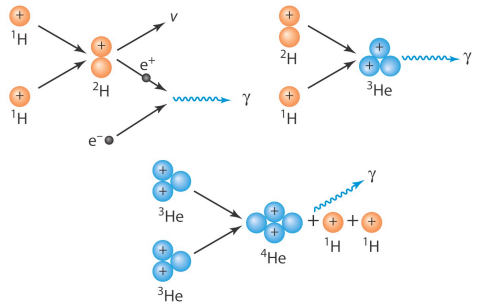
Why Doesn't The Sun Shrink?

- Sun is currently stable
- Pressure from the radiation created by fusion balances the force of gravity.
- Gravity is balanced by pressure from fusion!



Nuclear Fusion in the Sun's Interior

- Proton-proton in stars like the Sun
  - Hydrogen fused to make helium
  - 0.7% of mass converted to energy



The Proton-Proton Cycle

They Might Be Giants
Why Does The Sun Shine

The Sun is a mass of incandescent gas
A gigantic nuclear furnace
Where hydrogen is built into helium
At a temperature of millions of degrees

The Sun is hot, the Sun is not
A place where we could live
But here on Earth there'd be no life
Without the light it gives

We need its light
We need its heat
The Sun light that we seek
The Sun light comes from our own Sun's atomic energy

The Sun is a mass of incandescent gas
A gigantic nuclear furnace
Where hydrogen is built into helium
At a temperature of millions of degrees

The Sun is hot

The Sun is so hot that everything on it is a gas: Aluminum, Copper, Iron, and many others

The Sun is large... If the sun were hollow, a million Earth's would fit inside
And yet, it is only a middle-sized star

The Sun is far away... About 93,000,000 miles away
And that's why it looks so small

But even when it's out of sight
The Sun shines night and day
We need its heat, we need its light
The Sun light that we seek
The Sun light comes from our own sun's atomic energy

Scientists have found that the Sun is a huge atom smashing machine
The heat and light of the sun are caused by nuclear reactions between Hydrogen, Nitrogen, Carbon, and Helium

The Sun is a mass of incandescent gas
A gigantic nuclear furnace
Where Hydrogen is built into Helium
At a temperature of millions of degrees

Interesting Question

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

a) Pressure from fusion is pushing back against the force from planetary orbits.
b) The star's radius does not change much.
c) Pressure from fusion is winning the war against gravity.
d) Gravity is perfectly balanced with electromagnetism.
e) None of the above.

Why Nuclear Fusion Doesn't Occur in Your Coffee

- Fusion requires:
  - High enough temperature (> 5 million K)
  - High enough density
  - Enough time