Model of the Sun—17 Oct

- Announcements on next slide
- Outline
  - Proton-proton chain
  - Model of the interior of the sun
- Outline for Wed
  - Sun will use up the hydrogen in the center in 5Byr
  - Center of sun must shrink to get hotter to balance gravity
    - Sun will become a red giant. Surface expands.
    - Sun will become a planetary nebula
    - Sun will become a white dwarf

Announcements

- Test 2 is on Wed, 26th
  - New material is Newton through class on 19th
  - Mostly on new material not on first test.
  - Practice test. See link on the syllabus.
  - Missouri Club, Tues, 25th, 7:40-8:40pm, BPS 1420
  - Send me formulas for cheat sheet by Wed, 26th, 1:00am
- Hwk 6
  - Absolute deadline is 3:10pm on Mon, 24th.
  - Ask about homework 6 in class on 24th.
  - Answers will be posted by end of day on 24th.

Proton-proton chain

- Step 1: Two protons fuse to produce a deuterium nucleus (^{2}H), a positive electron, and a neutrino.

  $p+p \rightarrow d+e^+ + \upsilon$

  - Deuterium is an isotope of H with one neutron.
  - A neutrino is almost massless, not charged, and interacts very weakly.

1. Did the number of nucleons change? Charge?

A. YY
B. YN
C. NY
D. NN

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1. Did the number of nucleons change? Charge?

- Nucleons are conserved (except in some exotic interactions in the early universe).
- Charge is absolutely conserved.

Proton-proton chain

- Step 1: $p + p \rightarrow {}^2H + e^+ + \upsilon$
- In the center of the sun, a proton survives collisions without reacting for 10Byr.
  - Electrical repulsion between protons (Coulomb repulsion; Coulomb barrier)
    - Requires fast speed or high temperature to overcome repulsion.
  - Neutrino indicates a "weak" reaction, which is weak.
- Step 2: $p+{}^2H \rightarrow {}^3He+\gamma$ (Takes 6s)
  - γ is a photon, a unit of light. This photon has lots of energy.

1. In step 2, did any protons change into neutrons? Is this a weak interaction?

   A. YY. B. YN. C. NY. D. NN.

Proton-proton chain

- Step 1: $p+p \rightarrow {}^2H+e^++\upsilon$ (Takes 10Byr)
- Step 2: $p+{}^2H \rightarrow {}^3He+\gamma$ (Takes 6s)
- Step 3: ${}^3He+{}^3He \rightarrow {}^4He+p+X$ (Takes 1Myr)

1. What is X?

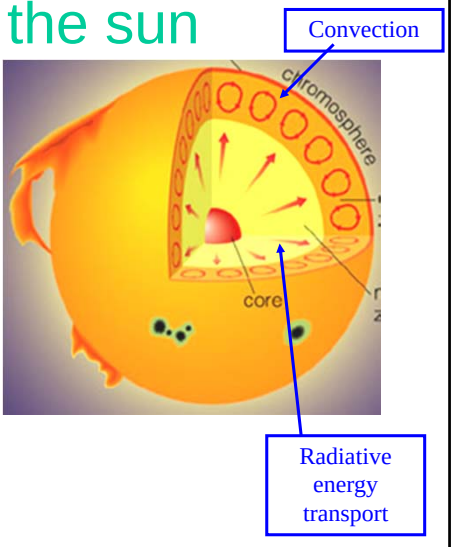
   A. Neutron.
   B. Electron.
   C. Neutrino.
   D. Proton.
   E. Positron (positive electron).

Proton-proton chain

- Step 1: $p+p \rightarrow {}^2H+e^+ + \upsilon$ (Takes 10Byr)
- Step 2: $p+{}^2H \rightarrow {}^3He+\gamma$ (Takes 6s)
- Step 3: ${}^3He+{}^3He \rightarrow {}^4He+p+p$ (Takes 1Myr)
- Where is the created energy?
  - A positron meets an electron, and the two annihilate.
    - $e^+ + e^- \rightarrow 2\gamma$
  - Light interacts with matter to heat it up.
  - Moving reactants heat the matter.
  - Neutrinos escape from the sun carrying away energy.

Interior of the sun

- Use physics to construct models
- Energy is generated by nuclear fusion, which depends on temperature and composition.
- Energy moves from center, where fusion occurs, to outside, where it radiates into space.
- Gas pressure holds the mass of the parts above.



A Balancing Act

- All astronomical objects do a balancing act.
  - Gravity pulls inward.
  - Something else pushes outward.

1. The Earth does a balancing act. What prevents the Earth from collapsing?
   A. Gas pressure
   B. The strength of the materials

2. What prevents the Earth's atmosphere from being dense at my feet but sparse at my head?
   A. Gas pressure
   B. The strength of the materials

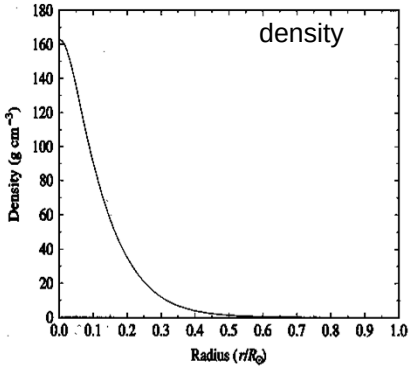
A Balancing Act: Gravity *vs*. Gas Pressure

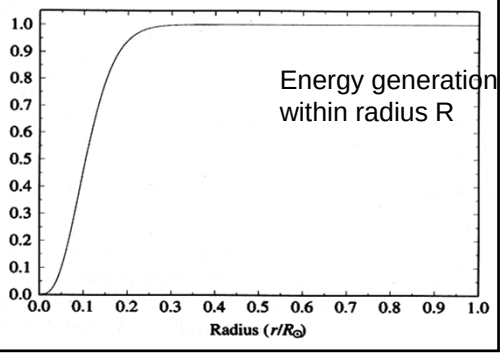
- Force of gravity balances gas pressure in the sun.
  - Force of gravity GM^2/R^2
  - Force of gas PV=nkT
    - k is Boltzmann's constant. k= R [gas constant, not radius]/(number in a mole)
    - Details (m is mass of gas particle)
      P = (nm)kT/(mV)=M kT/(mR^3)
      F = area P = R^2 MkT/(mR^3) =M kT/(mR)
  - In balance, force of gravity = force of gas motion.
    $\frac{GMm}{R} = kT$
- The idea bared
  $$\frac{M}{R} = T$$

1. We are watching the birth of the sun. The not-yet sun is a gas cloud slowly shrinking. It is getting
   A. warmer
   B. cooler

Model of the Sun

1. At what radius is the density of the sun that of water (1gm/cm^3)? 0.5R_{sun}. Same for gold (19gm/cm^3) 0.25R_{sun}.
2. 90% of the energy is produced within 0.2R_{sun} of the center.





3. Why is there so much helium at the center of the sun?
   A. It used to be hydrogen.
   B. It sunk because helium is heavier than hydrogen.
   C. The heavier helium collected in the center when the sun formed.