Astronomy 230 **Section 1– MWF 1400-1450** 106 B6 Eng Hall



This Class (Lecture 5):

by Feb 6th!

From Atoms to Molecules

Next Class:

Star Formation

Jan 30, 2004

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Oral Presentation Decisions

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• Finish discussing fusion.

• The atomic elements from the first and second generation of stars are spread out into the galaxy.

Outline

• These elements extended into the Galaxy and create molecules in areas called molecule clouds.

• Molecular clouds are these huge complexes in space.

• Molecules, even biologically important ones, can exist in these clouds.

• R_{*} estimation.

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Nuclear Reactions in the Sun



[np] = deuterium

- 1 proton + 1 neutron bound together into nucleus of element...
- hydrogen, but has n, 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



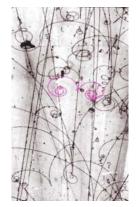
e^+ = positron

- Exactly the same as electron but charge +1:
- antimatter
- combines with normal e-
 - Both gone, release 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



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

V (Greek letter "nu") = **neutrino**

particle produced in nuclear reactions only

tiny mass: $m(v) < 10^{-6}m(e)$!

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!

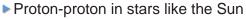
go through your body, Earth, but almost never interact

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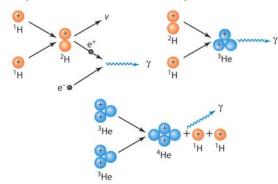
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(et) Electron (+) Photon Neutrino The CNO Cycle

Nuclear Fusion in the Sun's Interior



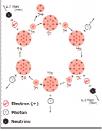
- ▶ Hydrogen fused to make helium
- ▶ 0.7% of mass converted to energy
- ▶ CNO cycle in more massive stars (BUT not the first stars!!)



The Proton-Proton Cycle



Hans Bethe



The CNO Cycle

Why Nuclear Fusion Doesn't Occur in Your Coffee

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







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So, Why is this Important to Alf?

- A star in hydrostatic equilibrium will not shrink or swell.
- It will maintain constant size, density, and temperature for more than a million years!
- At this point, the star is called a main sequence star.
- If stars were not constant, what effect would that have on life on orbiting planets. Ultraviolet light variations?



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The First Stars



- In the cores of the first stars, there is nuclear fusion where carbon and oxygen are created for the first time in the Universe.
- Higher density and temperature of the red giant phase allows for the creation of sulfur, phosphorous, silicon, and finally iron.
- Iron has the lowest nuclear potential energy, it cannot produce energy by fusion.
- The star explodes and some of the C, O, P, S, Si, and Fe get carried away. At this point, even heavier elements can be made.

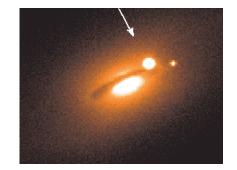
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The Second Generation



- Now, the second stars form in the ashes of the first.
- With C and N, the 2nd generation can form helium through the CNO cycle, in which most of the Universe's nitrogen is created.
- The 2nd generation also eventually explodes blowing nitrogen into the galaxy.

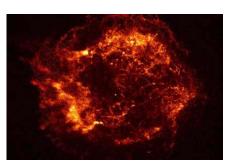


A supernova in a nearby galaxy. A single star exploding can be brighter than millions of stars in the nucleus.

The Next Stars



- The new atomic elements from the first stars are spread out into the galaxy.
- The Sun must be at least a 3rd generation star as we have nitrogen in abundance.
- Indeed, more heavy elements are found toward the center of the galaxy where the first generation of stars probably formed. (Seen in ours and other galaxies.)
- Again, we are star stuff.
- Keep in mind that this is all from the nuclear strong force



The Chandra x-ray observatory has shown that the CasA supernova has flung calcium, iron, and silicon into

Star Stuff

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- Now we have the elements crucial to life in the Galaxy.
- There are about 92 elements found in the Universe and about 20 more elements that have been created in laboratories (decay quickly).
- The 92 elements were almost all made in the interiors of massive stars or during a supernova explosion.
- Deep inside stars the electrons are stripped away, and only the nucleus (and the strong nuclear force) play roles.
- But, most of the important aspects of life depend on molecules. That involves electrons and the electromagnetic force that keeps the electron(s) with the nucleus.



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10 cm

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A Glass of Water

http://www.astronomyinfo.pwp.blueyonder.co.uk/s

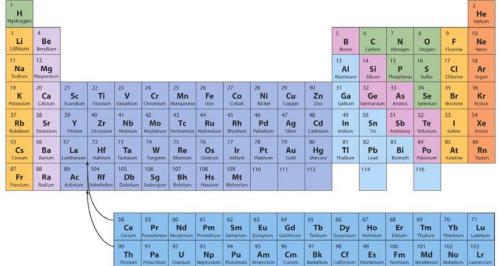
Water molecules
1 nm = 10⁻⁹ m

Oxygen atom 0.1 nm

Oxygen nucleus 1 fm = 10⁻¹⁵ m

The Periodic Table of the Elements



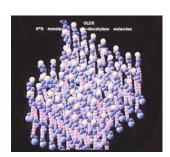


The number of protons in an atom determines the type of element, and the number of protons and neutrons determine the atomic weight.

Molecules



- Combination of 2 or more atoms such that they are bound together without their nuclei merging.
- Just like an atom is the smallest piece of an element, a molecule is the smallest piece of an compound.
- When dividing water, smallest division, before separation of hydrogen and oxygen.
- Wow! An enormous jump in complexity. There are only about 115 elements, but there are millions of known molecules and nearly infinite number of possibilities.
- Some of the key life molecules contain billions of atoms.



http://www.bris.ac.uk/Depts/Chemistry/MOTM/silly/sillymols.htm

Example H₂

- H₂ is the simplest molecule– two hydrogen atoms.
- What does that mean?
 - There are 4 particles.
 - 2 protons of the 2 nuclei, which repel each other
 - 2 electrons of the 2 atoms, which repel each
 - But
 - The electron of each atom will attract the other nucleus
- Although not obvious, the 2 attractive forces and 2 repulsion forces equal out.
- The electromagnetic force works for hydrogen, but there is no He₂.

http://www.historyoftheuniverse.com/

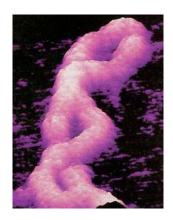
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Molecule Benefits for Life



- Molecules can easily be broken apart but are also stable.
- Flexibility in arrangement.
- Plethora of molecules.
- Electromagnetic force is much weaker than strong nuclear force, lower energies-lower temperatures.
- Perfect for life.



http://www.time.com/time/daily/special/genetics/

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How to Write Molecules



- We'll talk about H₂ or CO₂
- Or



Molecular Hydrogen

H-H

Single bond

Sharing 1 electron

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http://www.gristmagazine.com/dogood/co nnections.asp

Carbon Dioxide



Double bond

Sharing 2 electrons

Talkin' About a Revolution



- Molecules first showed up in space after enough heavy elements accumulated.
- There is a lot of interstellar molecular gas clouds in space.
- First complicated molecules found in space in 1968, and we have found even more over the last 20 years.
- They emit light in the millimeter regime.



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Orion Nebula

(near infrared)

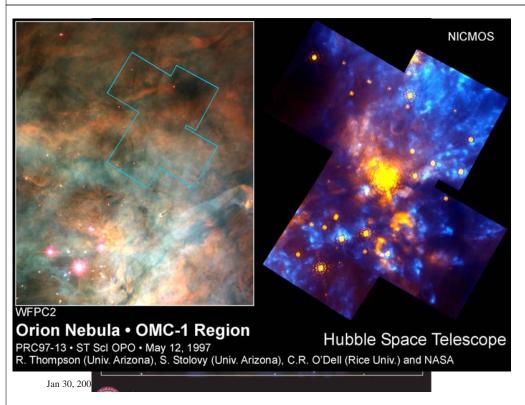
3000+ low & intermediate mass young stars

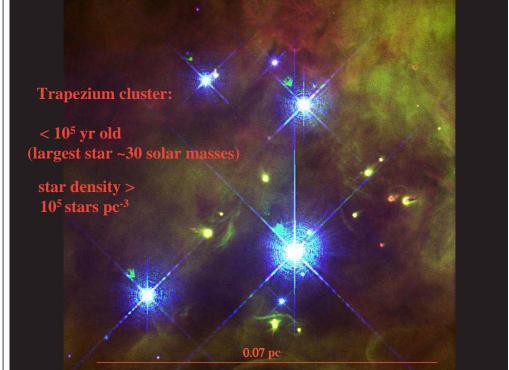
In addition, there are 10 high mass stars

Nearest massive star forming region at 1500 lys



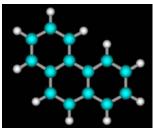




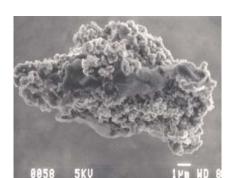


Other Things Besides Hydrogen in Molecular Clouds

- ► Molecules (e.g.)
 - ► Carbon monoxide (CO)
 - Water (H₂O)
 - Ammonia (NH₃)
 - ▶ Formaldehyde (H₂CO)
 - ► Glycine (NH₂CH₂COOH)
 - ► Ethyl alcohol (CH₃CH₂OH)
 - ► Acetic Acid (CH₂COOH)
 - ▶ Urea [(NH₂) ₂ CO]
- Dust particles
 - Silicates, sometimes ice-coated
 - Soot molecules



Polycyclic aromatic hydrocarbons (PAH)



Dust particle (interplanetary)

So?



- Complex molecules (>13 atoms) have evolved in places other than the Earth.
- Maybe there are more? The more complex molecules are harder to detect.
- Seen in other galaxies too.

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In Dust We Trust

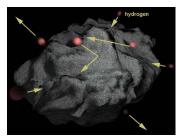
- Small (< 1 micron), solid particles
- Two types:
 - Primarily carbon (sort of like what we call soot)
 - Silicates, minerals of silicon and oxygen (sort of like what we call dust)
- Produced in material flowing from old stars, but mixed in space.
- When concentrated can protect molecules from ultraviolet light, which destroy molecules.
- Dust plays a role in formation of molecules.



Molecule Formation



- When molecules form, they must release energy by emitting light or colliding
- Difficult to do in the gas phases, need dust grains as a catalysis.
- H on dust grain, gets hit by another H, then extra energy ejects the newly formed molecule H₂ from the dust grain.
- For more complicated molecules, they need to be ionized to get easy reaction in space.
- What ionizes the molecules?
 Ultraviolet light would work, but then the molecules would get destroyed.



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Complex Molecules

- Best answer is that the rare cosmic rays ionizes molecules inside of a molecular cloud.
- For example:

$$\begin{split} &H_2^+ + H_2 \rightarrow H_3^+ + H \\ &H_3^+ + CO \rightarrow HCO^+ + H_2 \end{split}$$

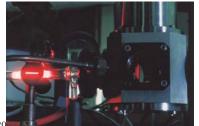
- HCO+ can then be involved in other reactions, building bigger and bigger molecules.
- These ion molecules can form more complex molecules.

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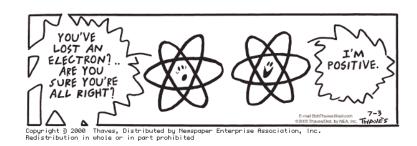
More to the Story

- But if H₂ can stick to the dust grains, shouldn't larger molecules stick too? In fact, we see water (H₂O), ammonia (NH₃), methane (CH₄), and methanol (CH₃OH) frozen to the dust grains.
- Hey, that's the most important bioelements (H, O, N, and C) on the dust grains.
- Mayo Greenberg and co-workers studied these ices in the lab and by adding a little of ultraviolet light, would get what he called "Yellow Stuff" on the dust grains. This stuff is similar to products from experiments designed to study the origin of life.
- Others have taken this a step farther, postulating that life originated on these dust grains, and even today new life is raining down on the earth.









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Panspermia

- Some have stated that perhaps life-important molecules formed in these clouds and spread to planets. Infection!
- Comets could have carried molecules to Earth's surface. Or ordinary meteors.
- Maybe epidemic outbreaks on Earth related to comet landings?
 - Incidentally, it has been observed that peaks in the influenza cycle matches the 11 year solar cycle (see William Corliss' work)
- http://www.panspermia.org/

http://www.strw.leidenuniv.nl/~greenber

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Molecular Clouds

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- Interstellar clouds are important molecular factories.
- Analogous to clouds in our atmosphere
- Primarily molecular hydrogen (~93%) and atomic helium (~6%) with (~1%) heavy molecules—molecules or dust.
- H₂ is not good at emitting photons, so easier to see molecules emitting— especially CO (which tells the temperature of these clouds).
- Other molecules (mostly H₂CO, HCN, or CS) are used to derive estimates of density.

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3 Lessons of Interstellar Molecules



- Molecules with as many as 13 atoms have evolved in places other than Earth.
 - In our Galaxy and beyond.
 - Hard thing is getting the lab data for searching for more complicated molecules.
 - Evidence for polycyclic aromatic hydrocarbons (PAHs) links of carbon atoms with hydrogens on the outside in space.
 - Also found in the exhaust of cars and may play a role in early life.
- Dominance of carbon in interstellar chemistry. So perhaps carbon based life forms is not just Earth chauvinism.
- Study of these in space illustrates the problems of molecules getting more and more complex and not being destroyed by UV light. That's why they were not expected

Giant Molecular Clouds

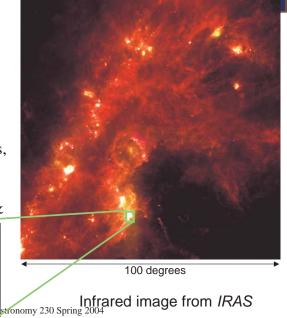
• Cool: < 100 K

• Dense: $10^2 - 10^5 \, \text{H}_2$ molecules/cm³ (still less dense than our best vacuum)

• Huge: 10 - 100 pc across, $10^5 - 10^6$ solar masses

• CO molecular emission & dust emission

structure



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Drake Equation

Frank Drake



















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

of advanced civilizations we can contact

Rate of formation of Sunlike stars

Fraction of stars with planets

of Earthlike planets per system

Fraction Fraction on which that evolve life arises intelligence

Fraction that commun-

Lifetime of advanced civilizations

Estimate of R_{*}:The Rate of formation of Sun-like stars

- We are about to start the topic of star formation and planet formation, but really the field is not well developed to estimate R_* .
- Instead take the total number of stars in the galaxy and divide by how long it took those stars to form.

$$R_* = \frac{10^{11} stars}{10^{10} years} = 10 \frac{stars}{year}$$

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Drake Equation

Frank Drake



















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

of advanced civilizations we can contact

Rate of formation of Sun-like stars

Fraction of stars with planets # of Earthlike planets per system

Fraction Fraction on which that evolve life arises intelligence

Fraction that communicate

Lifetime of advanced civilizations

~10

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