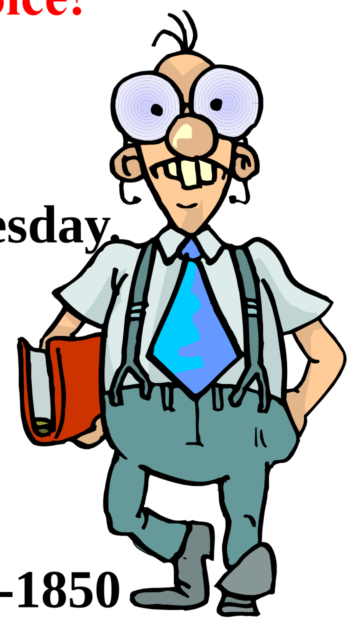
Welcome to Physics 498Bio

Understanding biology using "simple" ideas from physics.

with an emphasis on single-molecule biophysics

You've (hopefully) made a good choice!



Your host:

Professor Paul Selvin; Office: 365 Loomis

Office Hr: after class or 10:30-11:30 am Tuesday

(Can anyone NOT make it?)

selvin@uiuc.edu: 244-3371

Your co-host:

Marco Tjioe, 3rd year Biophysics student

Office: tjioe2@gmail.com: 364 Loomis: 333-1850

Office Hrs: Either Sunday 3-4pm OR Tuesday 1- 2pm.

[Depending on whether HW due on Mon. or Wed.]

HW due 1 week from date of assignment

Course Info: M, W, 10:30-12 pm;

Rm 322 LLP (not here!)

http://people.physics.illinois.edu/Selvin/indexSP12.html

Or:

http://physics.illinois.edu/courses/

then:

498Bio (undergraduates) or 498BIP (graduates)

We will get to the stuff we need to take in the course, grading, homeworks, etc.
but for now…**the most amazing story ever…**

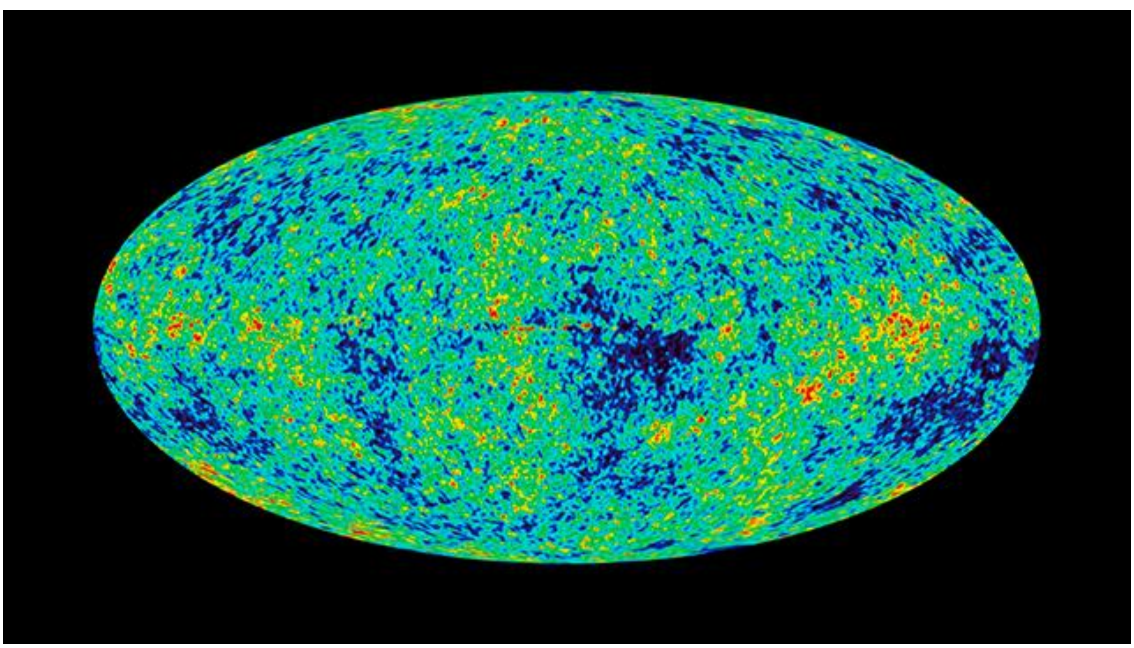
How old are you?

How old are the atoms in you?

Physics says your atoms are billions of years old!

13.7 Billion years ago, Big Bang (BB) happened.

(Based on NASA's Wilkinson Microwave Anisotropy Probe (WMAP) released in February 2003—Nobel Prize, 2006)



http://map.gsfc.nasa.gov/media/030653/index.html

Cosmic Microwave Background—*nearly* constant background, formed about 400,000 years after BB. Universe expanded and been cooling ever since. Now about 2.73 ˚K.

Formation of atoms

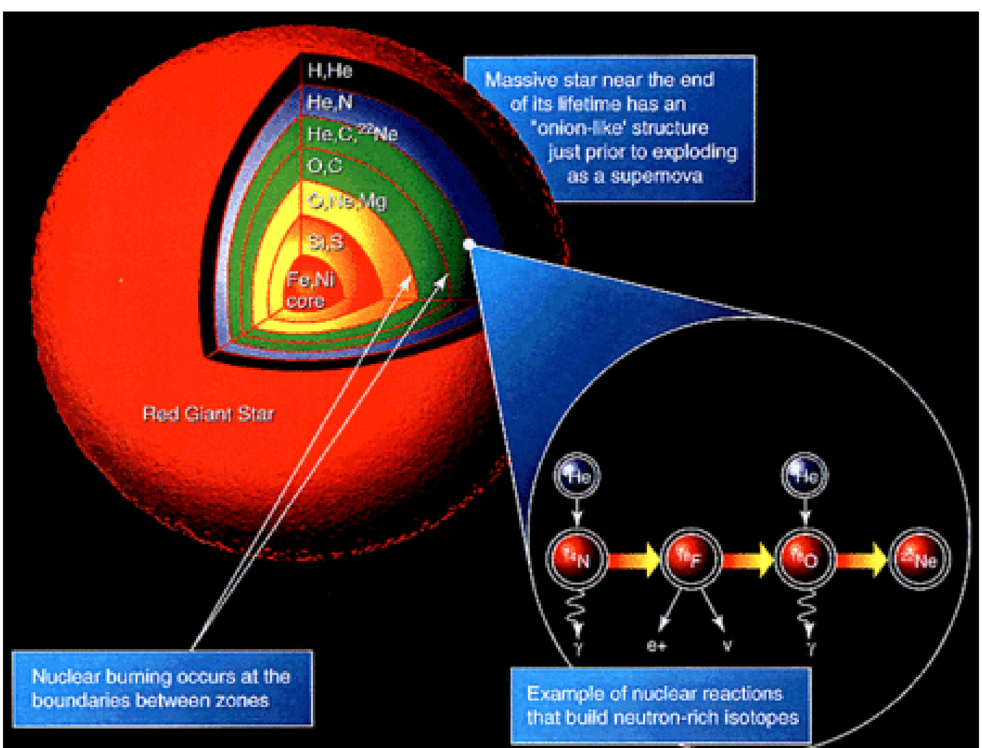
In Big Bang, Hydrogen was formed; within 3-20 minutes, during the rapid “expansion” of the universe, the smallest elements formed (by fusion because of super hot temp.), H, He, Li (and some radioactive Beryllium): Big Bang Nucleosynthesis.

Within 100-200 million years, density fluctuations caused the first stars formed.
(Also dark matter appeared to form—no idea what this is, although it is 90% of the gravitational mass of everything.)

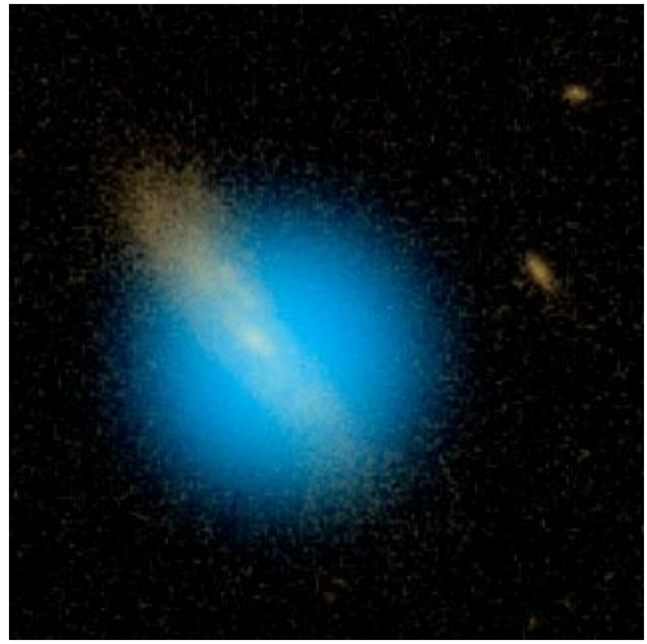
Formation of atoms up till Iron

In Sun, form He.
In more massive stars, form Carbon up to Oxygen.
Therefore we are derived from a long-dead star which exploded and reformed to make us (& sun, earth…)
***Big stars: Elements up to Iron formed*.**

(≈ 1 billion years passed and galaxies proliferated.
CMB ≈19˚ K a billion years after the BB)
(Darkness to light.)



Supernova



A type II supernova, or stellar explosion, occurs when a star of at least eight times our sun's mass runs out of nuclear fuel at its core.

(Stars that are more than 250 times more massive than the sun do not explode at the end of their lives; instead they collapse into similarly massive black holes.

All atoms > Iron come from Supernova!

What are we made of?

- About 20–25% of the 92 elements are essential to life
- Carbon, hydrogen, oxygen, and nitrogen make up 96% of living matter
- Most of the remaining 4% consists of calcium, phosphorus, potassium, and sulfur
- **Trace elements** are those required by an organism in minute quantities (e.g. iron)

Table 2.1

Table 2.1 Elements in the Human Body

Element	Symbol	Percentage of Body Mass (including water)	
Oxygen	O	65.0%	96.3%
Carbon	C	18.5%	
Hydrogen	H	9.5%	
Nitrogen	N	3.3%	
Calcium	Ca	1.5%	3.7%
Phosphorus	P	1.0%	
Potassium	K	0.4%	
Sulfur	S	0.3%	
Sodium	Na	0.2%	
Chlorine	Cl	0.2%	
Magnesium	Mg	0.1%	

Trace elements (less than 0.01% of mass): Boron (B), chromium (Cr), cobalt (Co), copper (Cu), fluorine (F), iodine (I), iron (Fe), manganese (Mn), molybdenum (Mo), selenium (Se), silicon (Si), tin (Sn), vanadium (V), zinc (Zn)

We are mostly made of water (H_2O): ≈75%

Then:

C —very versatile: everything made of: proteins, fats, nucleic acids…

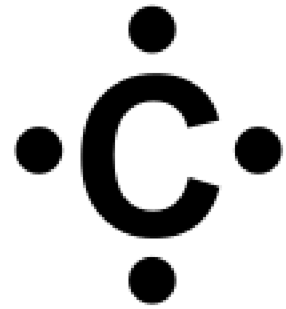
O —bonding, proteins, fats, nucleic acids

N — proteins, genetic material

Ca, P — bones

What’s so special about Carbon?

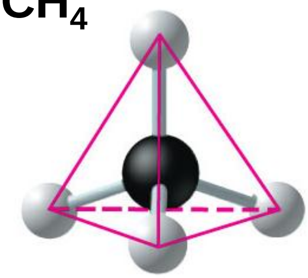
Carbon is backbone of life



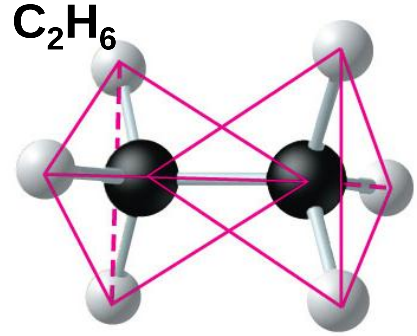
- Carbon, along with Oxygen, Hydrogen, Nitrogen, (and Phosphorous) make up “life”.
- C is abundant (on earth).
- C has 4 valence electrons.
- C can make up huge array of C-containing polymers.
- C is water-soluble.
- C is small size and intermediate energy levels (so enzymes can manipulate).

Si is alternative, but larger, more stable, tends tends to form crystals.

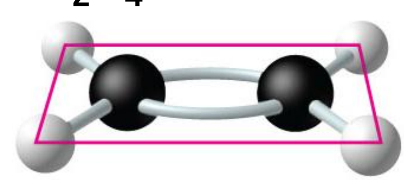
CH_4



C_2H_6



C_2H_4



Astrobiology: life elsewhere is probably C-based: carbon chauvinism.

http://en.wikipedia.org/wiki/Carbon-based_life

Should you be here?

Yes, if you want to know about the physics of biology (medicine), single molecules.

<u>Prerequisites</u>

Physics 111, 112 (or equivalent)

Some Statistical Mechanics

Some elementary calculus

Boltzmann's Constant, k_B

(relationship between energy and temperature)

Boltzmann Factor: $\exp(-E_i/k_B T)$

(α of being in some state with energy i given that it's at temperature T)

Remember in useful units:

$k_B T = 4$ pN-nm at RT;

ATP ~ 25 $k_B T$ ~80-100 pN-nm

Ex: molecular motor pulling a load.

How far, how much force?

Gibb's Free Energy, $\Delta G = \Delta H - T\Delta S; \approx \Delta E - T\Delta S$

If ΔG negative, reaction will go there spontaneously;

If ΔG is positive, takes some "push".

<u>No previous biology assumed. I teach it in course.</u>

Required Reading

Campbell's Biology, 9th edition: by Campbell & Reese

It's free this semester including
web (quizzes) supplement!

Excellent introduction to biology.

Hope: You can learn basic biology from text;
Learn biophysics in class (& assigned readings)

Need to know biology in order to do biophysics!
Using physics to understand biology!
Not biology to understand physics!

Course Information Physics 498Bio

Better title:

Introduction to the physics of quantitative biology with an emphasis on single molecule biophysics

Major concepts of physics inherent to biological systems. Basics of biology, including protein and DNA structure and their organization into cells are discussed, with a focus on single molecule biophysics. Major techniques including x-ray diffraction, optical and magnetic traps, and fluorescence microscopy, including "new" super-resolution techniques. Applications to cytoplasmic and nuclear molecular motors, bacterial motion, nerves, and vision.

It’s only been last 10-20 years that single molecule measurements have been possible!

Single: molecules, cells, species (men vs. women), planets… very hot, very cold, only if you look

In singulo Biophysics

In singulo Biophysics

Single: molecules, cells, species, planets…
Heterogeneity (in space, time) is the norm

People: Men vs. women: height, sex organs
Important to understand
(prostate cancer, ovarian cancer)

Planets: T_{ave} = ?? °
--Some are really cold (Uranus -223°C; -370 °F)
And some are really hot (Venus 449 °C; 850 °F)
Some have huge variability…
[Mercury from 465°C (870 °F) to -184 °C (-300 ° F)!]

Only one (or few) where life is possible: Earth 7.2 ° C; [Mars 36° C : -140 to +20° C)]

Course Syllabus Physics 498Bio

DNA, RNA & Proteins

1. Jan 18: Introduction to Biophysics: The Earth's Temperature, King Kong and Bacteria
2. Jan 23: The Language of Life: DNA, Proteins, Carbohydrate, Lipids: How you eat!
3. Jan 25: DNA and Boltzmann Factor
4. Jan 30: RNA (and Proteins)
5. Feb 1: Protein Folding
6. Feb 6: ATP & ATP Synthase
7. Feb 8: Ribosome
8. Feb 13: Protein Folding in Silico: Visual Molecular Dynamics (VMD): Klaus Schulten

Magnetic Tweezers; X-ray Crystallography

9. Feb 15: Magnetic Tweezers Bends & Twists DNA
10. Feb. 20: Magnetic Tweezers, Part II
11. Feb 22: X-ray Crystallography- Imaging vs. Diffraction
12. Feb 27: **No class**
13. Feb 29: X-ray Crystallography: Analysis of Watson & Crick's DNA; Proteins
14. ***March 5: Mid-term Exam*** *(Lec. 1-13)*

Imaging and Microscopy—Seeing small things

15. March 7: Basics of Fluorescence and Optical Microscopes
16. March 12: Basics of Fluorescence: In vivo labeling & FIONA
17. March 14: Fluorescence: Super Accuracy & Super Resolution

Spring Break

March 26: Fluorescence: 1 & 2-photon; Confocal and STED Microscopy
March 28: Fluorescence: HMM, a bit on PALM; SHRIMP
April 2: Fluorescence: FRET
April 4: Optical Traps: seeing Angstrom and Nanometer distances and Forces
April 9: Optical Traps II

Diffusion

April 11: Diffusion: Inertia doesn't mean anything
April 16: Diffusion and Bacteria Moving

Ion Channels and Vision

April 18: Ion Channels
April 23: Ion Channels II
April 25: Vision

Student lectures (given over 2 or 3 nights)

April 30: ***Student Talks***
May 2: ***Student Talks***

Extraneous: Most Genes are few in Number—some surprising results

Studying Gene Activity in Individual Cells
Studying Gene Activity in Individual Cells II

Grading

(may be modified slightly if changes to course)

<u>Grading</u>

25%: written Homework : (about 9 total; drop lowest 1):

(You CANNOT drop the last homework!)

Work together, but turn in separately.

Hand in at start of class– in class! (Do not be late.)

10% on-line assignments (covering Campbell reading) or in-class Quizzes (on extra-reading)

25%: Written Project & Oral Project– Same topic

-- 12.5% on written report: 10 pg report.

-- 12.5% on oral report: 8-12 min plus 4 min for questions.

15% on midterm exam

15% on final exam

--5 min quizzes making sure that you've read readings

10% on classroom participation /class evaluation

Plagiarism

Not allowed! You will flunk the course.

In written project…

Something has always been written…
(unless you have truly come up with something new.)

Usually what's written will be clearer than you can write it.

But you want to independently understand it.
And show me that you independently understand it.

So…

Read book/article, then close it,
Then write your own version. This way you know you understand it, and can explain it in your own words.

Also, when you "steal" a picture from somewhere, write in your paper where you got it from. A picture is worth a thousand words, but give credit where due.

Yes, you get to evaluate class!

Three (or 4) questions:

1. What was the most interesting thing you learned in class today?
2. What are you confused about?
3. Related to today's subject, what would you like to know more about?
4. Any helpful comments.

Answer, and turn in at the end of class.

(I'll give you ~5 minutes.)

I'll typically start class with some of your questions.

Get to know your neighbors

You will have to report to the whole class immediately afterwards –so listen carefully!

With a partner (who you don't know)…

In 2 min (or less), tell your

1) Name

2) Your year (undergrad, vs. grad.)

3) What you want to be when you "grow up".

4) Why you're taking class.

5) Tell one thing that's surprising about yourself.

This is Paul. I'm very old. When I grow up (in the next stage of my life), I want to be a downhill ski instructor. …and start a company doing medical diagnostics

Something surprising about myself:

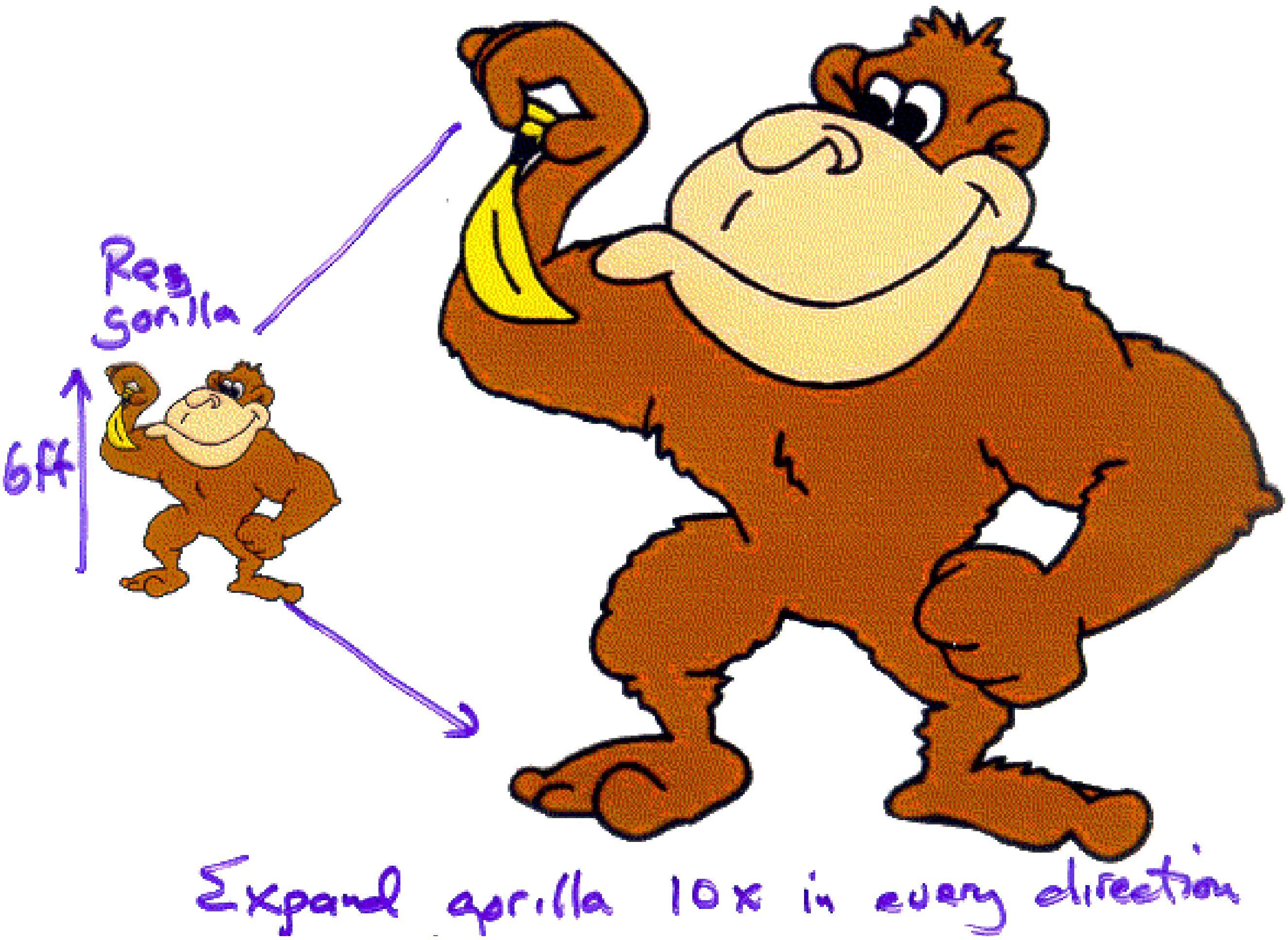
9 years ago, in San Diego, I had an unfortunate incident: I hit a car head-on while riding my bicycle. After months of hospitalization and rehab, I can do most things, but have trouble with my leg and arm.

What determines size of you?

Example of Physical constraints & Scaling Laws.

Could King Kong have existed?

Why gymnasts are small; why ants are so strong.



Mass? (density is the same): $10 \times 10 \times 10 = 10^3$

Strength? α Cross-sectional area (rope): $10 \times 10 = 10^2$.

Strength/Mass ratio? 1/10… 1/dimension

King Kong is proportionally speaking is 10x weaker than regular gorilla!

Regular gorilla with 10 gorilla's on him—couldn't walk.

Example Strength & area

Bones of the deer-family

Bison & deer roughly same shape, but bison bigger.

Gazelle

Bison

Gymnasts…Elephants.

Whales? If really thick bones…

In water– held up by buoyant force.
Bones do not need to support weight
If have to, have super big bones– would sink.

If whale stranded on the beach?

Bones break; also overheat (because warm-blooded and water is going at conducting away heat, whereas air is not.)

Homework

Due by:
beginning of class on Monday, Jan 23rd

Read

1. Chpt 1-3 (60 pages) of Campbell

2. Do web-site homework on reading, Chpt 1-3

Evaluate class

1. What was the most interesting thing you learned in class today?
2. What are you confused about?
3. Related to today's subject, what would you like to know more about?
4. Any helpful comments.

Put your name in upper right-corner.

Then tear off your name before turning in.
(That way you can be brutally honest!)

Answer, and turn in at the end of class.

(I'll give you ~5 minutes.)