Astronomy 230

Music: *Earthbound* – Darrin Drda

This class (Lecture 10):

Origins of Life
Octavio Mendoza &
Shing-Chiang Huang

Next Class:

Origins of Life
Bryan White &
Joseph Coletta

HW 4 is due Thursday

Oct 3:
Chris Johnson &
Sandor Van Wassenhove

HW #3

- **Fred Knecht & Rebecca Wright**: http://www.krysstal.com/extrlife.html
- **Chris Johnson**: http://www.bbc.co.uk/science/space/life/

Presentations

- **Octavio Mendoza**: Supernovae contributing to planet/life formation
- **Shing-Chiang Huang**: Life on Europa

Outline

- What are the monomers amino acids?
  - What are they used for?
- What are the polymers protein/enzymes?
  - What are they used for?
- The machine code for life: nucleic acids!
  - Also polymers, but made from other monomers.
- Chirality– left handed life!
- The beginning of life.

Drake Equation

Frank Drake

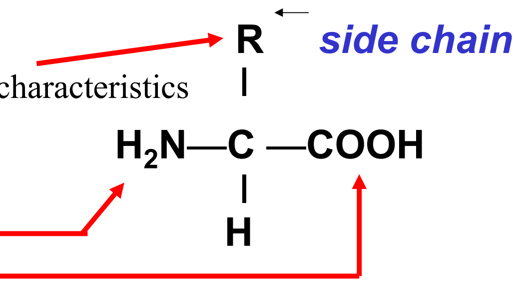
That's 2.7 Life-liking systems/year

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

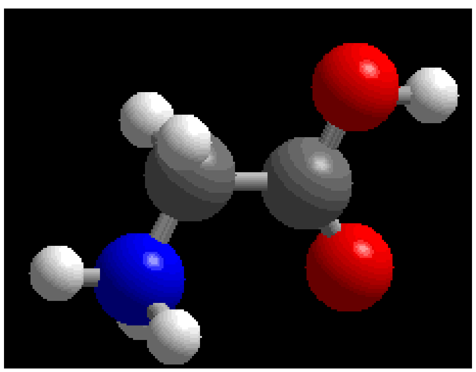
N	R_*	f_p	n_e	f_l	f_i	f_c	L
# of advanced civilizations we can contact in our Galaxy today	Star formation rate	Fraction of stars with planets	# of Earthlike planets per system	Fraction on which life arises	Fraction that evolve intelligence	Fraction that commun-icate	Lifetime of advanced civilizations
	15 stars/ yr	0.5 systems/ star	2.7 x 0.134 = 0.36 planets/ system	life/ planet	intel./ life	comm./ intel.	yrs/ comm.

Amino Acids

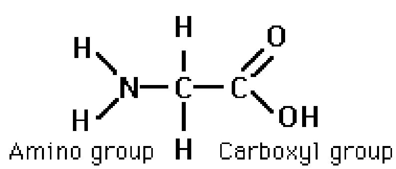
- Are the monomers from which proteins (polymers) are made– building blocks.
- Combinations of the amino acids make the proteins needed– only 20 amino acids used by life.
- Carboxylic acid group
- Amino group
- Side group R gives unique characteristics



Glycine

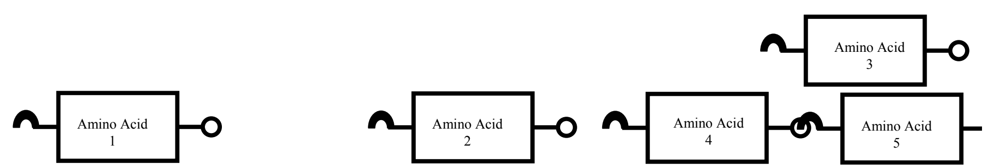


- Simplest amino acid. Just an H in the R position.
- Main ingredients are HONC– other amino acids contain Sulfur (S) as well.



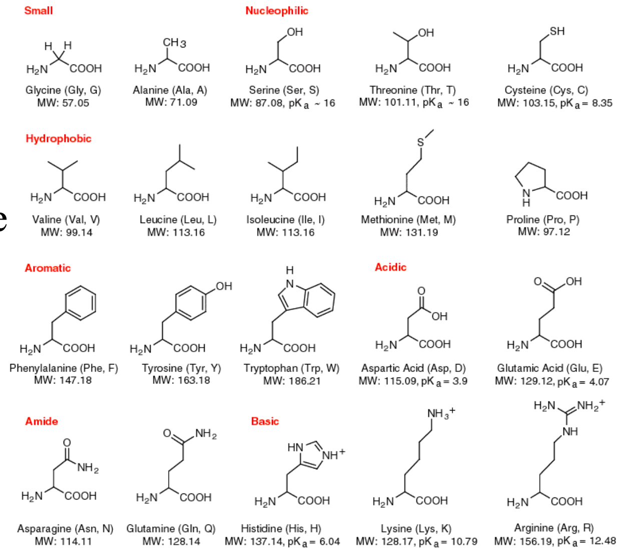
Getting Hooked Up

- Proteins are polymers, made of the monomer, amino acids.
- A number of specific amino acids "hook up" to form a specific protein.
- As a chain grows, there is always a hook (the amino group) on one end and an eye (the carboxyl group) on the other.



So?

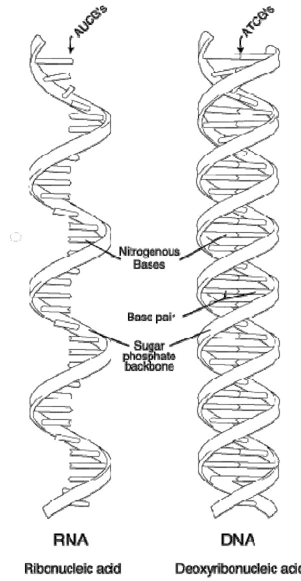
- Amino acids are essential for life– building blocks.
- But who orchestrates or writes the message (the special proteins) that the amino acids make up?
- Need something to teach them how to spell.



http://www.neb.com/neb/tech/tech_resource/miscellaneous/amino_acid.html

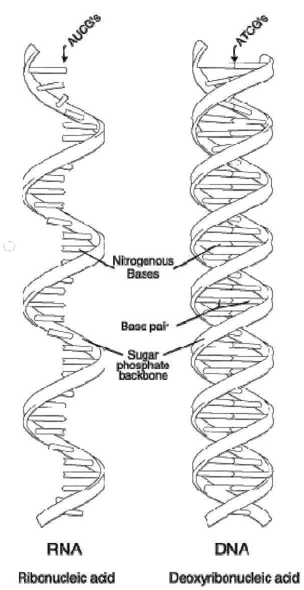
Nucleic Acid: DNA and RNA

- Two types of nucleic acid.
- A polymer built up from monomers we'll come back to which ones.
- RNA (RiboNucleic Acid) is usually a long strand
- DNA (DeoxyriboNucleic Acid) is the double helix– visualize as a spiral ladder.



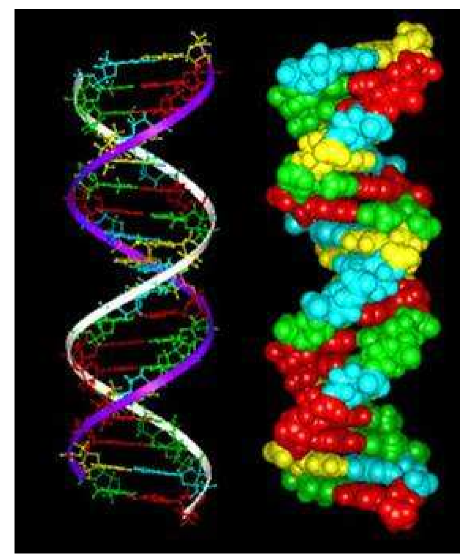
Nucleic Acid: DNA and RNA

- These molecules carry the genetic information of the organism– the message that gets coded into the amino acid chain.
- It is very much like computer code in many ways– and teaches how to spell useful word (proteins) out of the letters of the available amino acids.

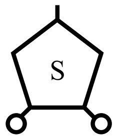


DNA / RNA

- The origins of DNA and RNA are mysterious and amazing
- DNA/RNA are complex: Built from three basic types of monomers
  1. Sugar (deoxyribose or ribose)
  2. A phosphate PO_4
  3. One of four "nitrogenous bases"
     - Adenine (A)
     - Guanine (G)
     - Cytosine (C)
     - Thymine (T) in DNA / Uracil (U) in RNA
       – ***These four monomers are collectively called "nucleotides"***



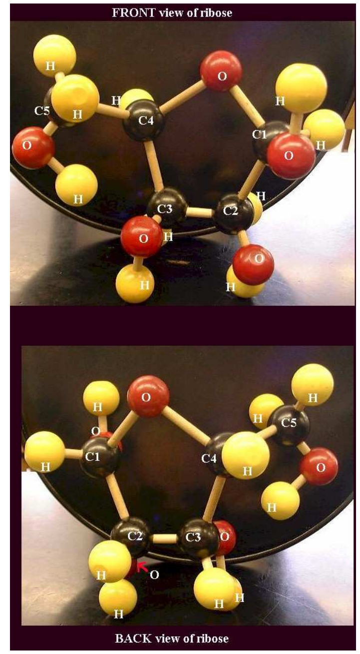
Sugars: Ribose or Deoxyribose

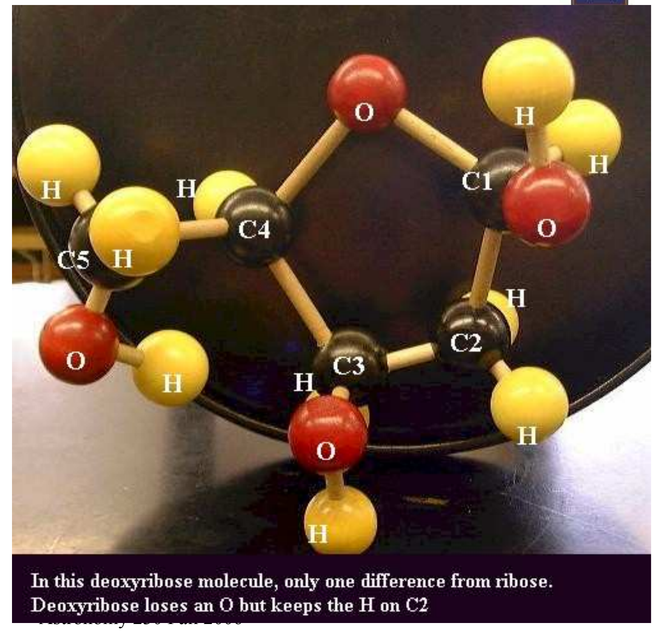


We will represent the sugar molecule (either ribose or deoxyribose) as a pentagon with two eyes.

http://www.dscc.edu/bwilliams/Biology/biology1molemodels.htm

Sugars: Ribose or Deoxyribose

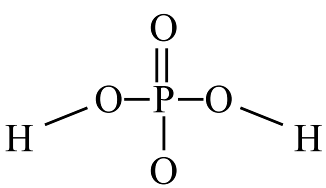


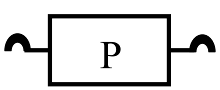


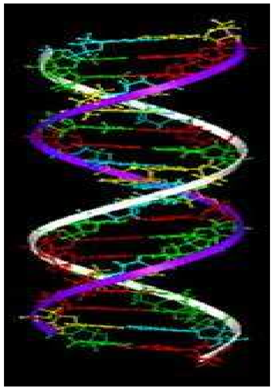
http://www.dscc.edu/bwilliams/Biology/biology1molemodels.htm

Phosphates

- Is often referred to as phosphoric acid.
- Makes five bonds with oxygen.

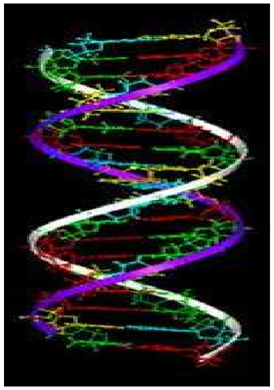


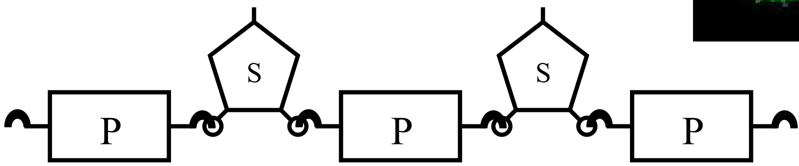




Phosphates and Sugars

- Make the sides of the twisted DNA ladder structure.
- Sugars and phosphates connect up in alternating bonds. P-S-P-S-P-S-P
- These are phosphodiester bonds.





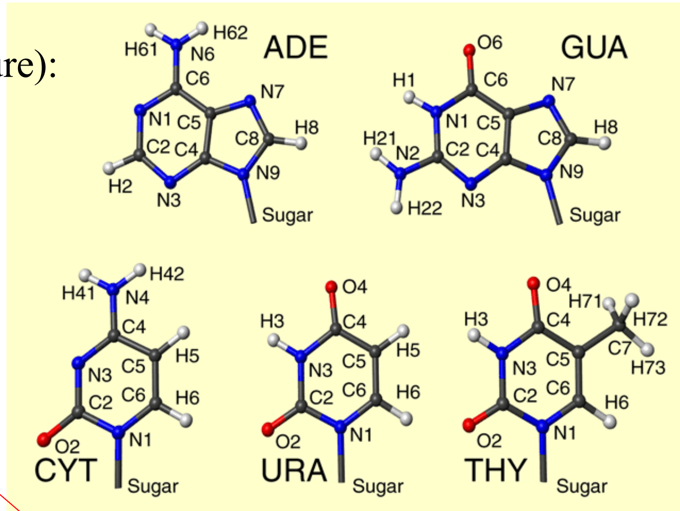
And the Bases

5 types in 2 groups (based on structure):

- Purines:
  - Adenine
  - Guanine
- Pyrimidines:
  - Cytosine
  - Uracil
  - Thymine

For DNA

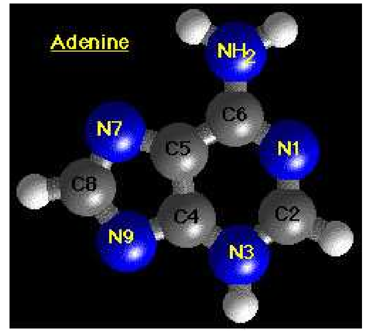
For RNA

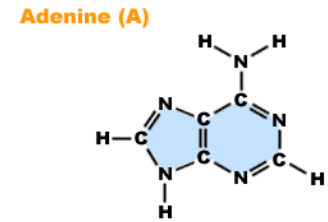


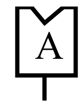
http://www.bmrb.wisc.edu/referenc/nomenclature/figures/bases.gif

Purines: Adenine

- 5-sided ring built on the side of a 6-sided ring.







Adenine

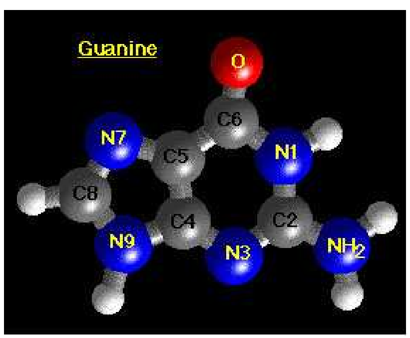
$H_5C_5N_5$

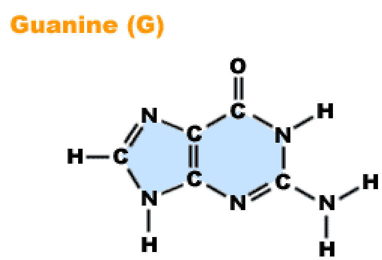
http://resources.emb.gov.hk/biology/english/inherit/genetics.html

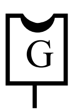
http://dlm.tmu.edu.tw/phase2/glossary/image/adenine.gif

Purines: Guanine

- 5-sided ring built on the side of a 6-sided ring.







Guanine

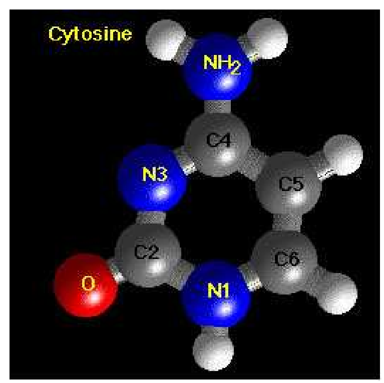
$H_5C_5N_5O$

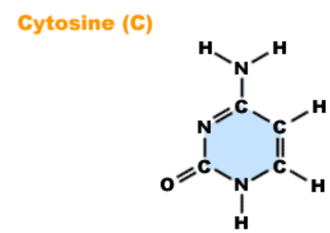
http://resources.emb.gov.hk/biology/english/inherit/genetics.html

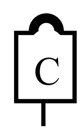
http://dlm.tmu.edu.tw/phase2/glossary/image/adenine.gif

Pyrimidines: Cytosine

- 6 sided rings (without a 5 sided ring)







Cytosine

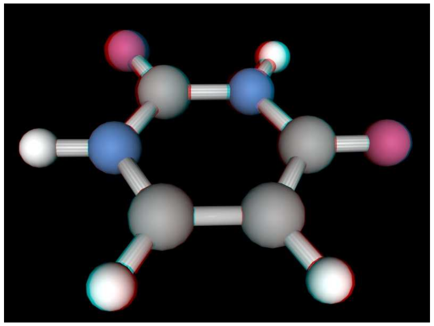
$H_5C_4N_3O$

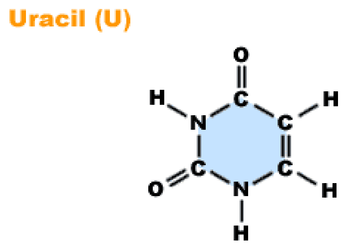
http://resources.emb.gov.hk/biology/english/inherit/genetics.html

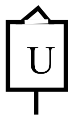
http://dlm.tmu.edu.tw/phase2/glossary/image/adenine.gif

Pyrimidines: Uracil

- 6 sided rings (without a 5 sided ring)







$H_4C_4N_2O_2$

For RNA

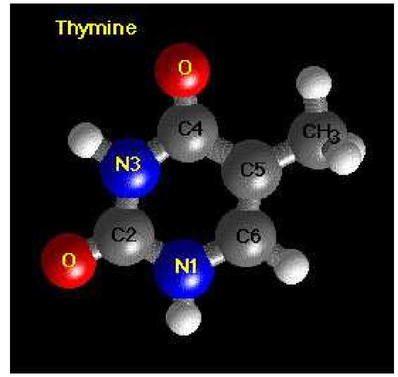
Uracil

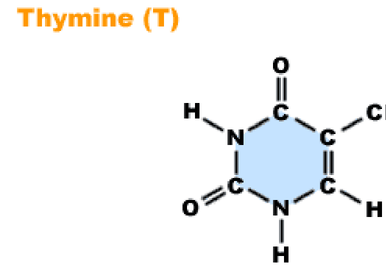
http://nautilus.fis.uc.pt/molecularium/stereo/

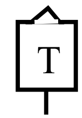
http://dlm.tmu.edu.tw/phase2/glossary/image/adenine.gif

Pyrimidines: Thymine

- 6 sided rings (without a 5 sided ring)







$H_6C_5N_3O_2$

For DNA

Thymine

http://resources.emb.gov.hk/biology/english/inherit/genetics.html

http://dlm.tmu.edu.tw/phase2/glossary/image/adenine.gif

Monomers and Polymers

Monomer:

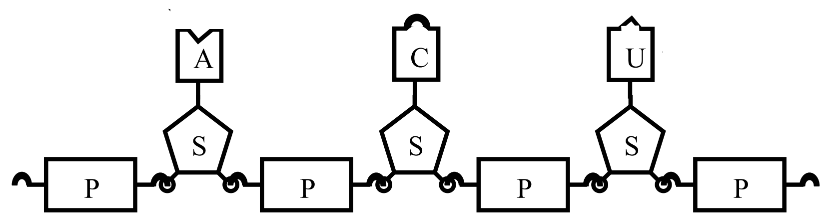
1. Amino acids
2. Sugar
   phosphate
   nitrogenous bases

Polymer:

1. Proteins
2. Nucleic acids

Making RNA Mean Something

- Schematic of an RNA molecule.
- This segment can be read from left to right as ACU– called a codon (a three letter word, so to speak)
- Can be translated to a specific amino acid (**the code!**) – this corresponds to the amino acid Threonine. GGU is gylcine.
- By building up these amino acid codons, we can spell out (and thus construct) a protein.



Meaning in Mystery

FIRST LETTER	SECOND LETTER U	SECOND LETTER C	SECOND LETTER A	SECOND LETTER G	THIRD LETTER
U	Phenylalanine	Serine	Tyrosine	Cysteine	U
U	Phenylalanine	Serine	Tyrosine	Cysteine	C
U	Leucine	Serine	Stop	Stop	A
U	Leucine	Serine	Stop	Tryptophan	G
C	Leucine	Proline	Histidine	Arginine	U
C	Leucine	Proline	Histidine	Arginine	C
C	Leucine	Proline	Glutamine	Arginine	A
C	Leucine	Proline	Glutamine	Arginine	G
A	Isoleucine	Threonine	Asparagine	Serine	U
A	Isoleucine	Threonine	Asparagine	Serine	C
A	Isoleucine	Threonine	Lysine	Arginine	A
A	(Start) Methionine	Threonine	Lysine	Arginine	G
G	Valine	Alanine	Aspartate	Glycine	U
G	Valine	Alanine	Aspartate	Glycine	C
G	Valine	Alanine	Glutamate	Glycine	A
G	Valine	Alanine	Glutamate	Glycine	G

For DNA replace U with T

http://library.thinkquest.org/C004535/PF_amino_acids.html

Overconstrained

- 4 options for each letter in the Codon
- 4 x 4 x 4 = 64 options (can think if it as bits)
- But only 20 amino acids ⇒ over constrained
- 4 x 4 = 16 wouldn't work.
- Life picked the next highest number and copes with redundancy.

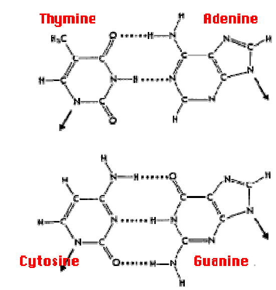
FIRST LETTER	SECOND LETTER U	SECOND LETTER C	SECOND LETTER A	SECOND LETTER G	THIRD LETTER
U	Phenylalanine	Serine	Tyrosine	Cysteine	U
U	Phenylalanine	Serine	Tyrosine	Cysteine	C
U	Leucine	Serine	Stop	Stop	A
U	Leucine	Serine	Stop	Tryptophan	G
C	Leucine	Proline	Histidine	Arginine	U
C	Leucine	Proline	Histidine	Arginine	C
C	Leucine	Proline	Glutamine	Arginine	A
C	Leucine	Proline	Glutamine	Arginine	G
A	Isoleucine	Threonine	Asparagine	Serine	U
A	Isoleucine	Threonine	Asparagine	Serine	C
A	Isoleucine	Threonine	Lysine	Arginine	A
A	(Start) Methionine	Threonine	Lysine	Arginine	G
G	Valine	Alanine	Aspartate	Glycine	U
G	Valine	Alanine	Aspartate	Glycine	C
G	Valine	Alanine	Glutamate	Glycine	A
G	Valine	Alanine	Glutamate	Glycine	G

DNA

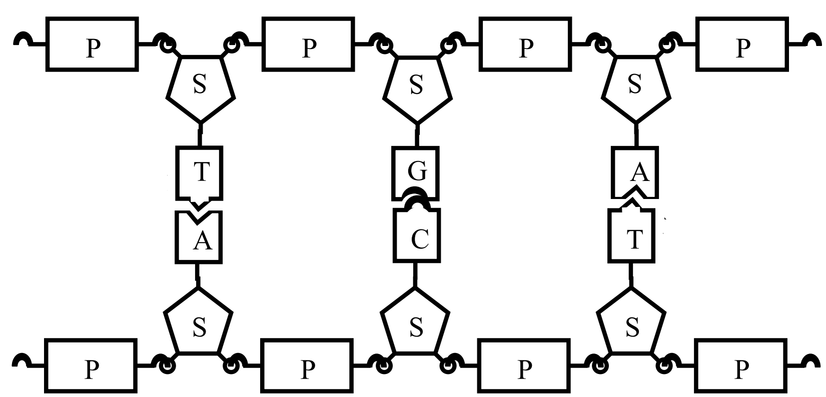
- For life more complicated than viruses, the genetic code is stored in DNA.
- Differs from RNA in a few ways: uses deoxyribose sugar rather than ribose sugar and uses thymine instead of uracil.
- Forms the double strand where two complementary bonds are held together with weaker hydrogen bonding– allowing easier separation.
- In that case, bases form unique pairs:
  - AT, TA, GC, CG

http://mbsu.sus.mcgill.ca/POST_MIDTERM PICS/DNA is my life.jpg

DNA

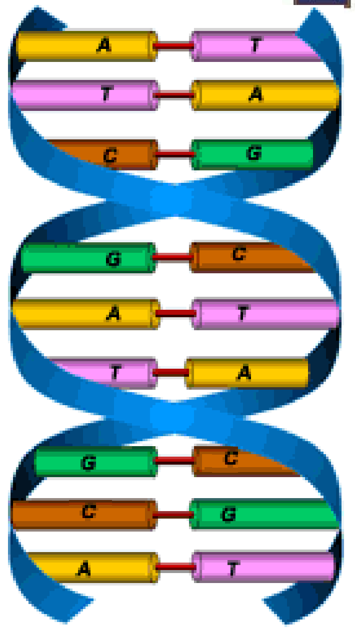


- A codon of DNA: AT, CG, TA
  - purine to pyrimidine connections



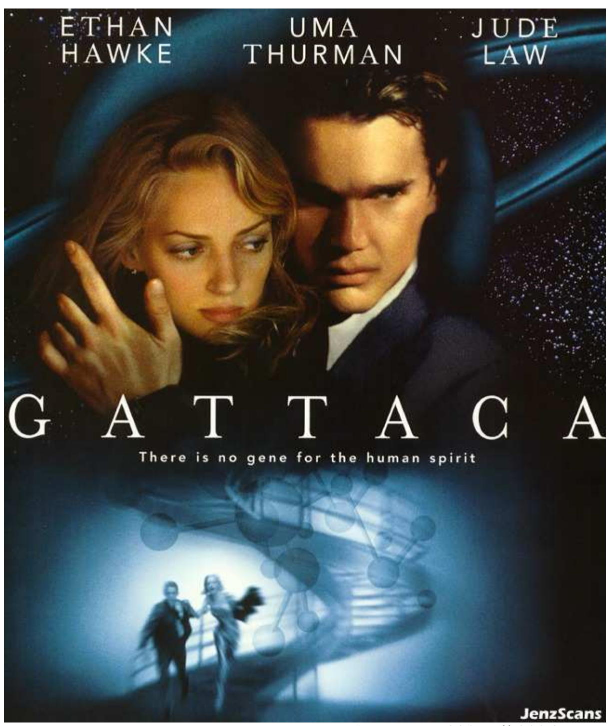
The Double Helix

- Resembles a twisted ladder
- The sides of the DNA ladder are made of the sugar and phosphate.
- The steps or rungs of the ladder are composed of one of the 4 nitrogenous base pairs.
  - AT, TA, GC, CG
- In other words, if you know the sequence on one side, you can deduce the sequence on the other side.



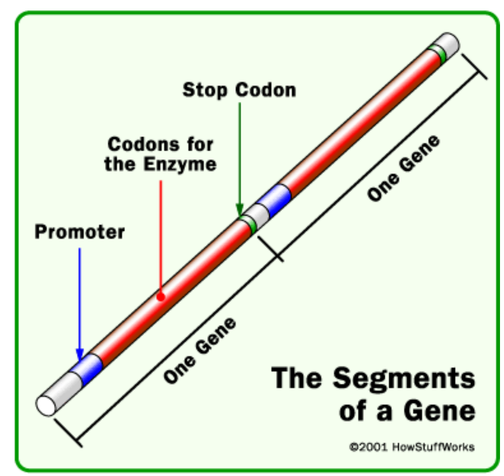
The Double Helix

- The ladder is twisted into the helix shape since the hydrogen bonds are at an angle.
- 3 pairs make up a codon, like RNA (4x4x4 = 64)
- Each codon is info on the amino acid, but only 20 of those– again over constrained.



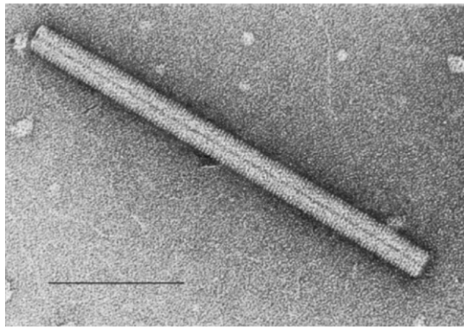
Genes

- Each codon specifies an amino acid, and a sequence of condons specifies a protein or enzyme.
- E. coli bacterium has about 4,000 genes, and at any time those genes specify about 1,000 enzymes. Many genes are duplicates.

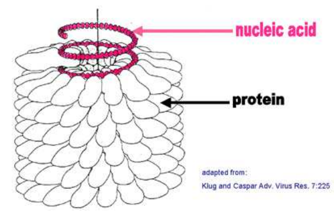


Backy

- Different organisms have different number of genes.
- Tobacco mosaic virus has 4 genes.
- A small bacterium has about 1000 genes– average sized bacterium has 4000 genes.



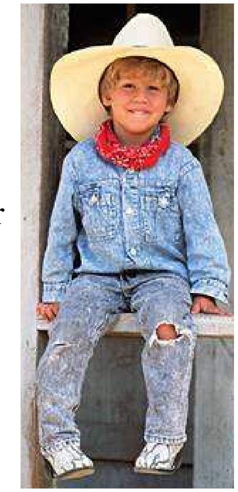
TOBACCO MOSAIC VIRUS



http://pathmicro.med.sc.edu/mhunt/intro-vir.htm

My Old Blue Genes

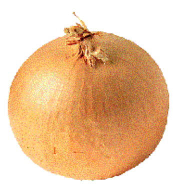
- The Human Genome Project found 30,000 genes
- If you took all of the nucleic acid in one human cell and stretched out the long sequence, it would be more than a meter long!
- Human cells have 3 x 10^9 base pairs, but 98% of it has no obvious function, and 99.9% is the same for all humans.



http://images.encarta.msn.com/xrefmedia/sharemed/targets/images/pho/t373/T373681A.jpg

Which requires the most genes?

1. Onion
2. Mosquito
3. Carp
4. Human

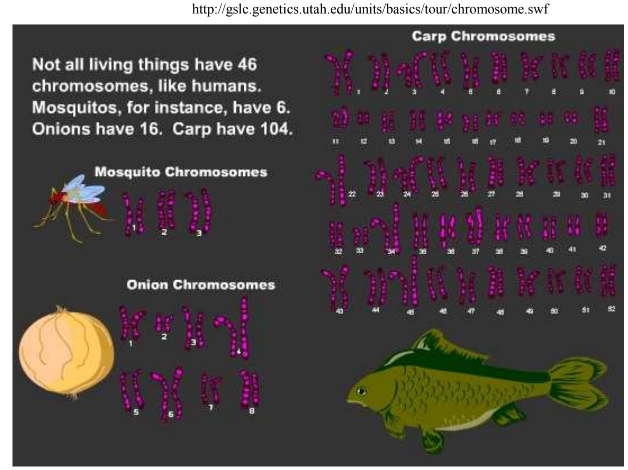


http://www.thefishermom.com/images/071804small.htm
http://www.themoderatevoice.com/files/joe-mosquito.jpg
http://www.freewebs.com/flyingonion/Onion.gif

Chromosomes

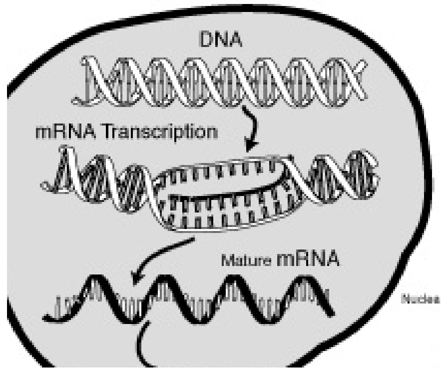
- Best way to package DNA is in chromosomes– DNA wrapped around proteins,
- Humans have 23 sets of chromosomes (total of 46).
- Each ranges from 50 million to 250 million base pairs
- For each set, you got half from each parent.

http://gslc.genetics.utah.edu/units/basics/tour/chromosome.swf



DNA: Message in a Cell

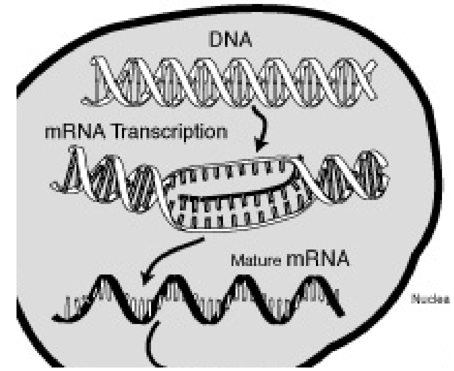
- A cell is informed it needs a enzyme– call it Z.
- Other enzymes in nucleus unravel and separate the easily broken DNA at the site where the gene for making that enzyme in encoded.



http://www.accessexcellence.org/AB/GG/mRNA.html

DNA: Message in a Cell

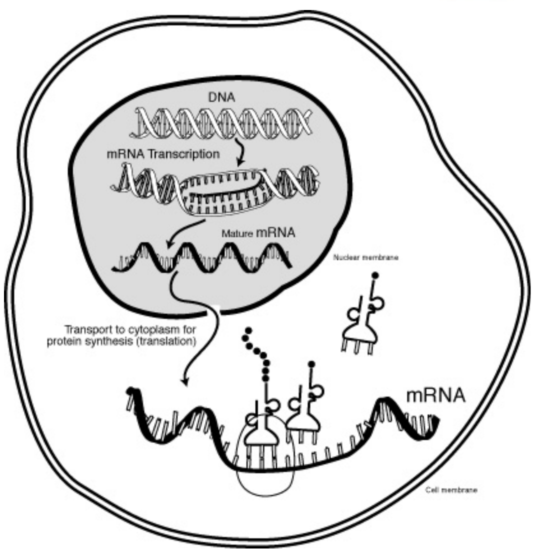
- Transcription of the gene is made via complementary bases and are assembled in a messenger RNA or mRNA.
- DNA zips itself back together.
- The mRNA (a series of codons) moves from the nucleus to the cytoplasm.



http://www.accessexcellence.org/AB/GG/mRNA.html

DNA: Message in a Cell

- Translation is the next step.
- A ribosome (the site of the protein synthesis) recognizes the mRNA by a special base sequence that attaches.
- The amino acids are built up from transfer RNA (tRNA) that move along the mRNA.
- The tRNAs have anticodon and carry amino acids.
- The chain of amino acids grows until the stop codon signals the completion of enzyme Z.



http://www.accessexcellence.org/AB/GG/mRNA.html

Reproduction

- DNA unzips itself, with appropriate enzyme.
- Each strand acts like a template for making a new strand.
- As each side is complementary, the molecule is successfully reproduced into 2 copies.

http://xupacabras.weblog.com.pt/arquivo/zipper.jpg

Reproduction

- For dividing cells, a copy goes to each daughter cell.
- Really, the process includes many special enzymes, so sometimes errors can occur.
- Still, very efficient
- DNA is the stuff from which all life is made.
- Probably not the method of the first life– too complicated.

http://xupacabras.weblog.com.pt/arquivo/zipper.jpg

Molecular Basis of Life

1. Atoms needed are H,O,N, and C with small amounts of P and S.
2. 2 basic molecules are essential for life: proteins and nucleic acids
3. Both are polymers– made of simpler monomers that make up the “alphabet” or code of life. These direct the transcription and translation of the proteins from the code.
4. Proteins and nucleic acids are closely linked at a fundamental level. Communicating through the genetic code that must have originated very early. In most cases, the same code is used by different messages for chicken or shark or human.

Molecular Basis of Life

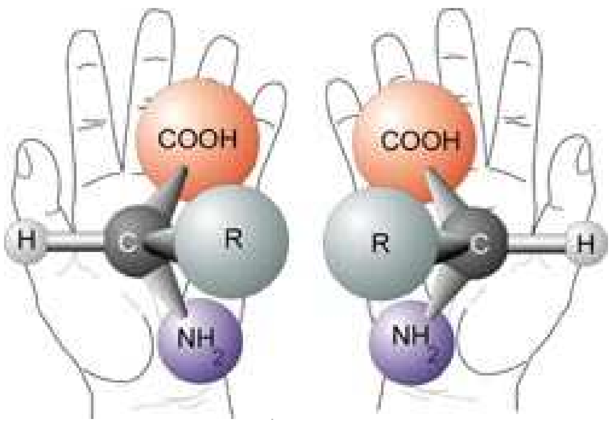
5. #4 rises an important question.
   - Proteins synthesis must be directed by nucleic acids, but nucleic acid transcription requires enzymes (proteins).
   - Chicken or the egg problem?
   - Did proteins arise on Earth first and give rise to nucleic acids, or vice versa?

Molecular Basis of Life

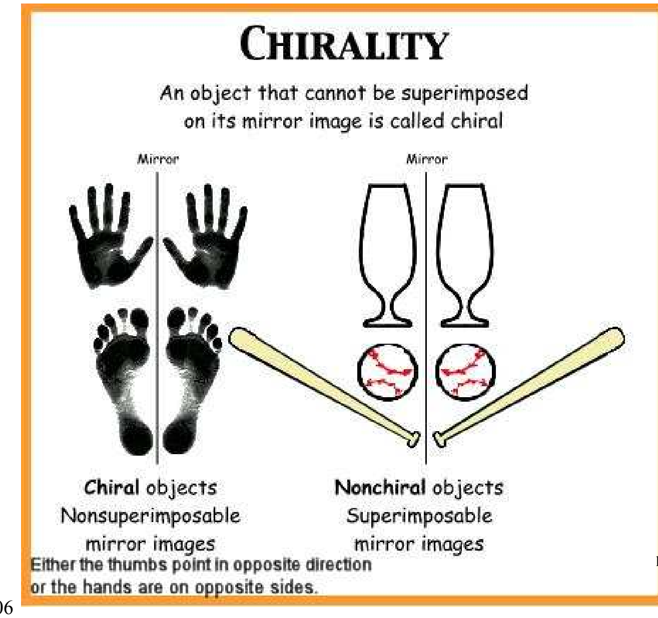
6. Careful to distinguish DNA from RNA. RNA probably developed first. Still, a related question is how did the connection between RNA/DNA and the connection with Life’s genetic code originate?
7. Also, there are some instances of a few organisms where there are small differences in the code of life. The code has evolved, albeit very slightly, since the last common ancestor of all life.
8. This leads us to consider the chemical basis of life, implying a tendency toward greater complexity.

Chirality

Handedness: Some molecules exist in two versions based on the position of the bonds. One molecule is the mirror image of the other, but they are not similar.



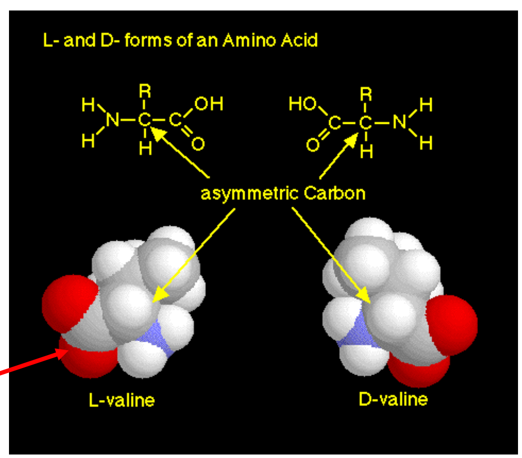
Chirality



http://universe-review.ca/I15-32-chirality.jpg

We are Left-Handed Based

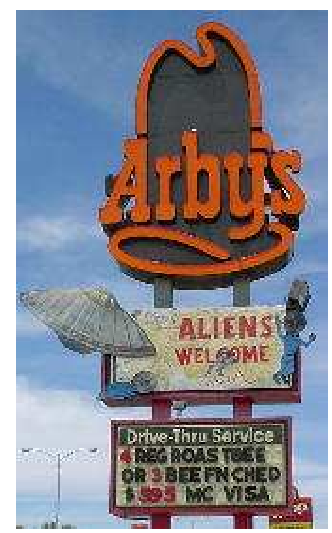
- Amino acids in non-biological situations are mixtures of both, but in life only left-handed molecules are used.
- Why? We don't know.



http://www.sp.uconn.edu/~bi107vc/fa02/terry/proteins.html

We are Left-Handed Based

- Sugars in life are right-handed
- Suggests a common ancestor for life.
- The opposite should have worked just as well, and this arrangement probably arose out of chance. Once a preponderance of one chirality occurred it was replicated
- An ET organism may be made of the same stuff, but if they are made of right-handed amino acids, they couldn't eat our food. Bummer.



From Space?

- The Murchison meteorite (Australia 1969) contained approximately even amount of left and right amino acids
- 70 different amino acids were found in it, but only 6 are used in living organisms.
- New results show that 4 of the amino acids had a slight excess of left-handed types.

First Life

- We currently think that life appeared on Earth around 3.8 billion years ago, or only 700 million years after the formation of the Earth.
- That is about the same time as the heavy bombardment ended. So, that means life was fast– perhaps only a few 10-100 million years from sterile planet to party town.

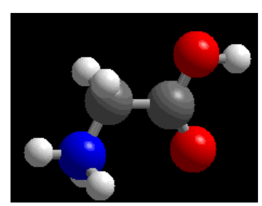
http://youconnect.canon-europe.com/swedish/2003-10/images/earth/love_parade.gif

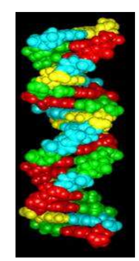
Life

- The most crucial monomers required for life are:
  - Amino acids (20 flavors) for **<u>proteins</u>**
  - The nucleotides: sugar, phosphates, and nitrogenous bases for **<u>DNA/RNA</u>**.
- How did they occur in a useful configuration so **fast** on the early Earth?
  - Remember the early Earth is not a fun place.
    - Poisonous gas atmosphere, hot, lots of meteorites, and cable TV is still 3.8 billion years away.

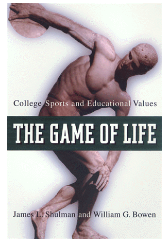
Chemical Evolution

- Chemical basis of life obviously crucial.
- Apparently evolution of life is a continuation of tendencies toward greater complexity
- Chemical evolution has 3 steps:
  - Synthesis of monomers
  - Synthesis of polymers from the monomers
  - Transition to life.





Synthesis of Monomers



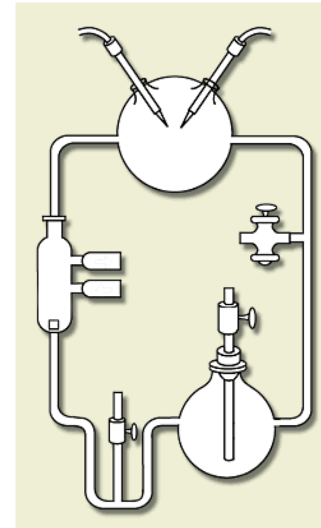
Life arose under the following conditions

- Liquid water
- Some dry land
- A neutral or slightly reducing atmosphere (somewhat new). Remember no OXYGEN, mostly methane (CH_4) and CO_2.
  - Reducing has elements that *give up* electrons, e.g. hydrogen. A good example is the atmosphere of Jupiter: CH_4, NH_3.
  - Oxidizing has elements that *take* electrons, e.g. oxygen. A good example is the atmosphere of Mars or modern Earth.
  - Neutral is neither.
- Energy sources, including UV light, lightning, geothermal.

http://www.pupress.princeton.edu/titles/6903.html
http://origins.jpl.nasa.gov/habitable-planets/images/ra6-early-earth-th.jpg

Miller and Urey Experiment

- In 1953, Miller and Urey (UC) tried to duplicate conditions that they believed existed on the Early Earth– a heavily reducing atmosphere.
- They Mixed CH_4, H_2, and NH_3 gases in a flask for the atmosphere, and connected that to a flask with water for the oceans. A spark was used in the atmosphere flask to simulate lightning.
- They found interesting organic molecules in the "ocean".



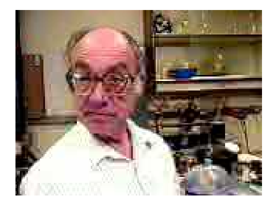
http://www.vobs.at/bio/evol/e05-millerurey.htm

Miller and Urey Experiment

- 4 amino acids were made: glycine, alanine, aspartic acid, and glutamic acid. Also some nucleotide bases and acetic acid.
- It has been shown that ALL 20 amino acids needed for life can form in this way.
- http://www.ucsd.tv/miller-urey/
- Does not produce directly all monomers of nucleic acids, but intermediates were produced.

http://physicalsciences.ucsd.edu/news_articles/miller-urey-resurrected051903.htm

Miller and Urey Experiment



http://www.ucsd.tv/miller-urey

Early Monomers

- The Miller-Urey experiment legitimized the scientific study of life. The production of amino acids under the presumed conditions of the early Earth was exciting.
- But the assumptions of the experiment have been questioned.
  - Early notions of methane-rich reducing atmosphere are wrong; Earth's early atmosphere was more likely CO_2, N_2, and H_2O vapor.
  - We still don't know early atmospheric composition well enough to make stronger case
  - We still don't know how this leads to DNA, the basis of all terrestrial life
- Recently, a group in Japan has showed that with enough energy, you can still get significant yields of amino acids in a mildly reducing environment.

Early Monomers

- We do not have a detailed theory of how all the monomers arose on the early Earth.
- General conclusion is that many of the monomers needed for life can be produced in a strongly reducing atmosphere, but that different environments are needed to get specific monomers.
- Don't forget that after the monomers are formed they MUST come together to form the polymers of life.

Other places

- Maybe if we require (still not sure) a strongly reducing environment, we have to look elsewhere.
  - Area around undersea hot vents, some of which have CH_4, NH_3, and other energy-rich molecules like hydrogen sulfide.
  - Interstellar space.

http://www.noaanews.noaa.gov/magazine/stories/mag114.htm
http://www.chl.chalmers.se/~numa/photo/keyhole-small.jpg