Astronomy 330:

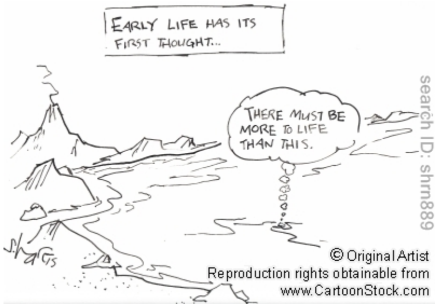
Extraterrestrial Life

This class (Lecture 18):

How Life Works

Next Class:

Origin of Life



© Original Artist
Reproduction rights obtainable from
www.CartoonStock.com

Drake Equation

That's 45.1 Life-liking systems/year

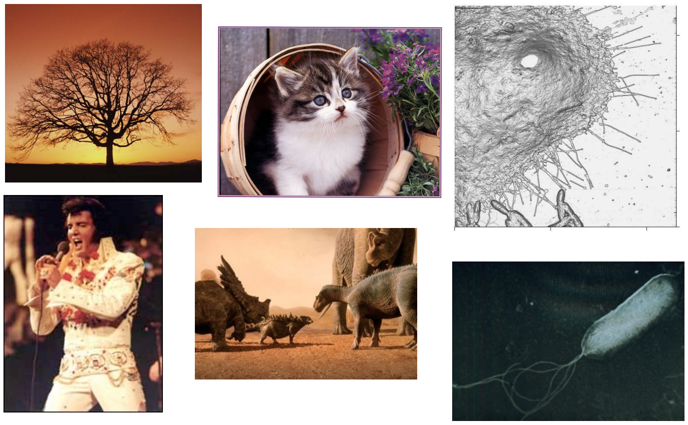
Frank Drake

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

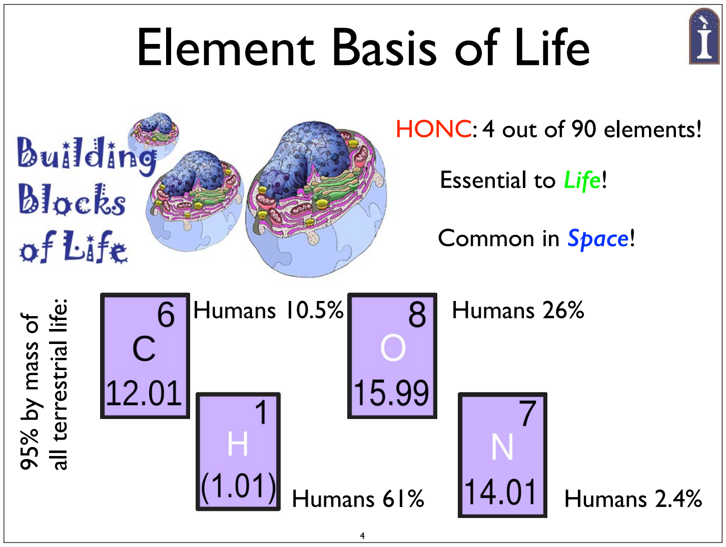
# of advanced civilizations we can contact in our Galaxy today	Star formation rate	Fraction of stars with planets	# of Earthlike planets per system	Fraction on which life arises	Fraction that evolve intelligence	Fraction that commun-icate	Lifetime of advanced civilizations
	30 stars/ yr	0.8 systems/ star	4 X 0.47 = 1.88 planets/ system	life/ planet	intel./ life	comm./ intel.	yrs/ comm.

The next term in the Drake equation is fl. Arguably the hardest term to estimate. We do not know much about the early Earth as we do not have the rock from that time period— too much processing by seismic activity. Nonetheless, we can make develop likely pathways for life, then try to draw conclusions from those arguments. One of the difficult thing here is that we will mostly be examining modern life— not early life. We are looking at the perfected machinery of life, but early life may have been very different. We skip ahead to the top of the line best designed (by evolution) car— sports car, and we do not see the first steps of develop of cars— the first car was slow, clunky, and less efficient, likely just like early life. So although modern life looks like it has too many fine-tuned parameters to have ever happened through the mechanisms we will discuss, remember we are skipping ahead to the Ferrari, by-passing the first Benz.

Same Building Blocks



They all look different, but fundamentally they are all the same. Using the same principles and the same building blocks— DNA and amino acids.



Element Basis of Life

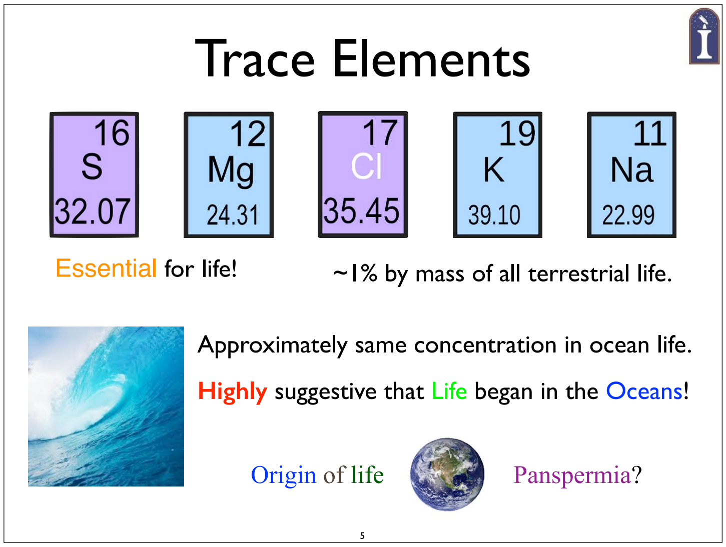
HONC: 4 out of 90 elements!

Essential to *Life*!

Common in *Space*!

95% by mass of all terrestrial life:

6 C 12.01	Humans 10.5%	
1 H (1.01)	Humans 61%	
8 O 15.99	Humans 26%	
7 N 14.01	Humans 2.4%	



Trace Elements

16 S 32.07	12 Mg 24.31	17 Cl 35.45	19 K 39.10	11 Na 22.99

Essential for life!

~1% by mass of all terrestrial life.

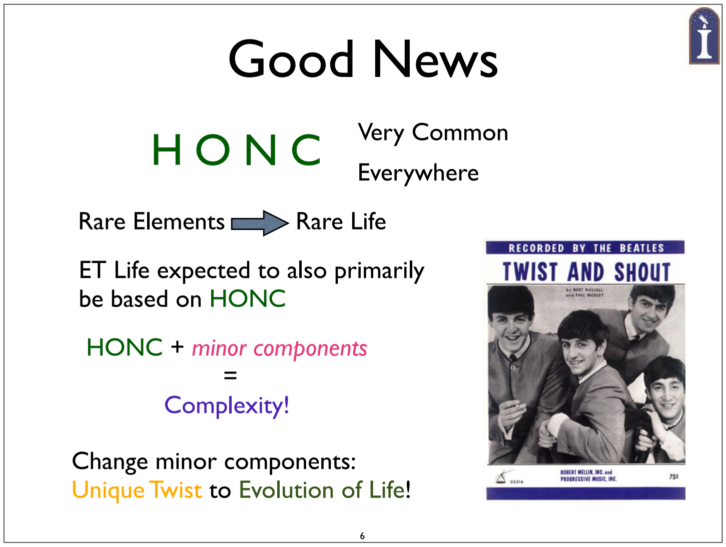
Approximately same concentration in ocean life.

Highly suggestive that Life began in the Oceans!

Origin of life

Panspermia?

SInce the trace elements in life are similar to the trace elements in sea water, it is very highly suggestive that life started on this planet, and puts doubts that life started elsewhere and came to Earth. The latter idea is called Panspermia, and we will talk about that more later.



Good News

HONC

Very Common

Everywhere

Rare Elements → Rare Life

ET Life expected to also primarily be based on HONC

HONC + *minor components*

=

Complexity!

Change minor components:
Unique Twist to Evolution of Life!

H,O,N,C is very common in universe; everywhere as far as we can tell. If Earth life were based totally on rare elements, we might expect its occurrence to be extremely rare…So, we expect ET life to be based primarily on HONC. The four primary chemical elements of life with some other simple components can produce staggering complexity. But, we expect that each planet will feature its own environment of trace elements giving each planet's life a unique twist to the standard HONC chemistry

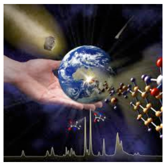
Dr. Truth, PI

Nature's Complexity: Biological Molecules

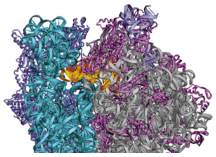
Operations are amazing!

How did they evolve?

H O N C Why?



From these four elements to the molecules of Life?



The workings of biological molecules are an absolute marvel. How did this complexity develop? How did it evolve? Remember we are looking at the positive results of life— bad evolutionary stages were unsuccessful and are not around today. We are examining the winners of the origin of life— not the losers.

As complex and mysterious as life on Earth may be, we can begin to understand it. Start with the basics:
Why are H,O,N,C the basis for living organisms? How do the molecules formed by these (and other elements) work to make DNA, proteins, life?

You R Special :-)

H O N C Not the most abundant elements

H O N C necessity for the chemistry of life?

life is Carbon-based = Carbon is the chemical-backbone.

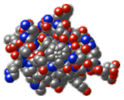
Good News?

Why is Earth life based on H,O,N,C instead of the more abundant elements found on Earth? Suggests that the formation of life is not able to be formed just out of anything lying around. The selection of H,O,N,C seems to be a necessity of the chemistry of life. In general, Earth life is a carbon based life. Carbon is the main backbone of the chemistry.

Is this good news?

Why Carbon?

Insulin $C_{254}H_{377}N_{65}O_{76}S_6$

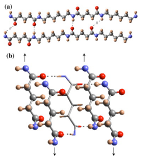


The electronic properties of Carbon allow the formation of long chains.

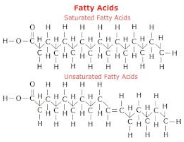
Complexity

Chains of atoms

Chains of molecules

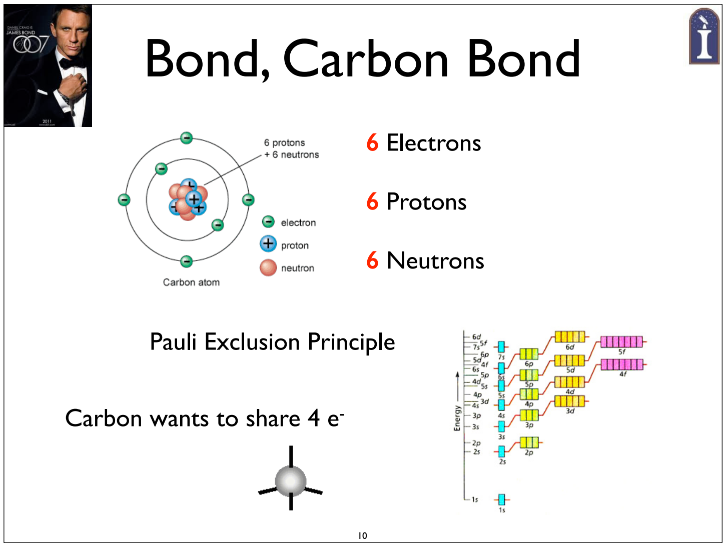


Carbon bonds are stable but breakable at temperatures where water is in liquid form.



Carbon-based Chemistry: ***Organic Chemistry***

Carbon's electronic structure allows it to form long chains. Chains of atoms and chains of molecules– complexity. Life needs bonds to be stable but breakable. Good for us, at temperatures at which water is liquid, carbon bonds are stable but breakable Organic chemistry is the special branch devoted to carbon chemistry.



Bond, Carbon Bond

6 Electrons

6 Protons

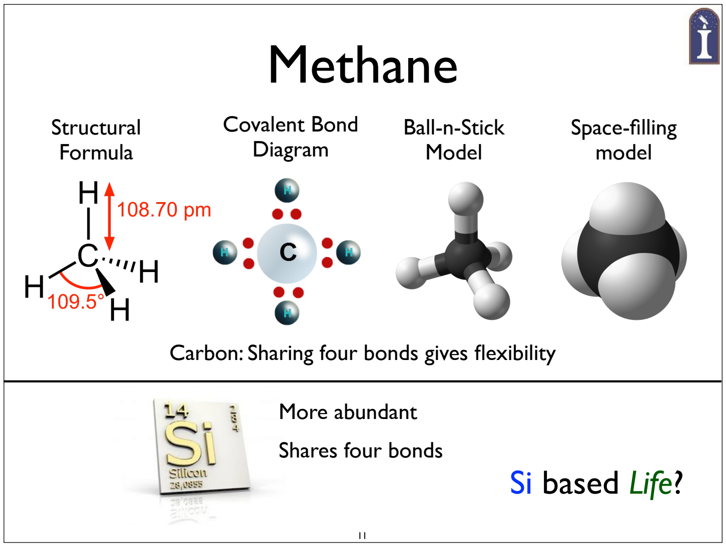
6 Neutrons

Pauli Exclusion Principle

Carbon wants to share 4 e^-

Carbon has 6 protons, 6 neutrons, and 6 electrons. Electrons distribute themselves in “shells”. Pauli exclusion principle. 1st (inner-most) shell wants to be filled by 2 electrons. 2nd shell wants to be filled with 8 electrons. BUT, Carbon only has 6 electrons! So, Carbon has 2 electrons in inner shell and 4 in 2nd shell. It likes to bond: to “fill” second shell by sharing with four other electrons

---



Methane

Structural Formula

Covalent Bond Diagram

Ball-n-Stick Model

Space-filling model

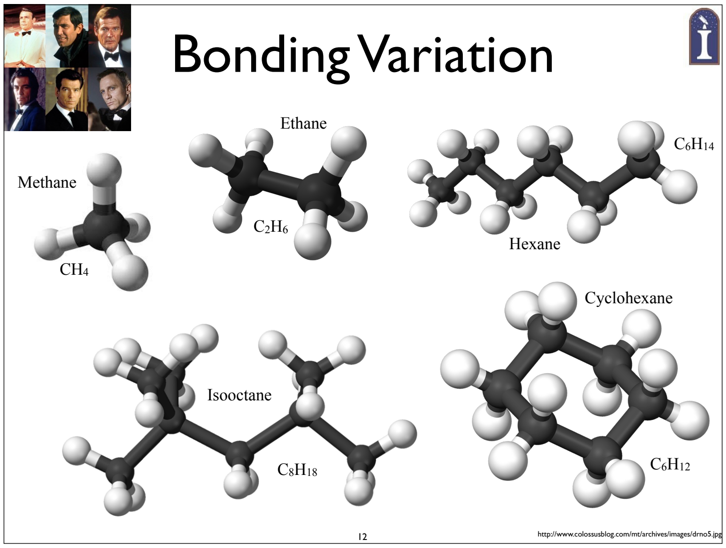
Carbon: Sharing four bonds gives flexibility

More abundant

Shares four bonds

Si based *Life*?

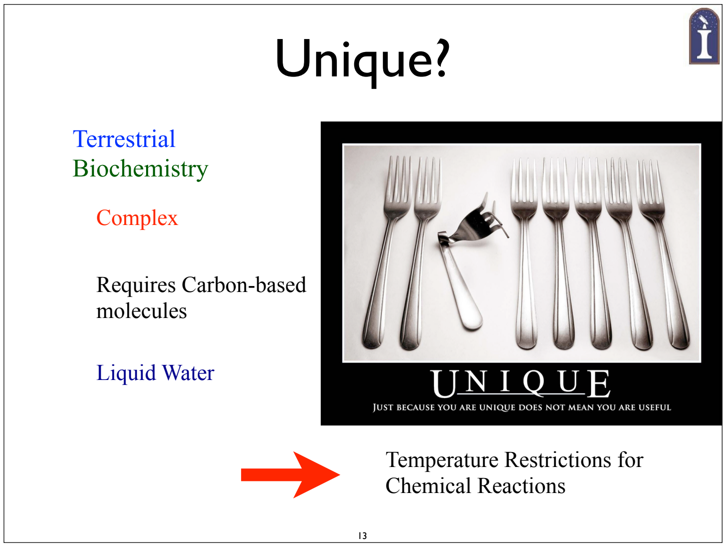
Not many other elements can share 4 bonds. Silicon, which is much more abundant, can. Silicon based life? More on Si life later.



Bonding Variation

http://www.colossusblog.com/mt/archives/images/drno5.jpg

Diversity is amazing!



Unique?

Terrestrial
Biochemistry

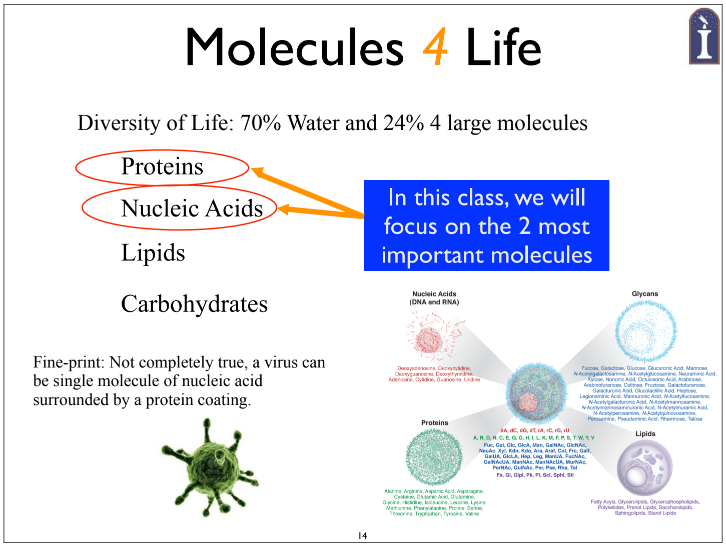
Complex

Requires Carbon-based molecules

Liquid Water

Temperature Restrictions for Chemical Reactions

As far as we know, the complexity of terrestrial biochemistry can **only** be achieved with carbon-based molecules. Especially considering the need for liquid water, which puts restrictions on the temperature in which the chemical reactions occur.



Molecules 4 Life

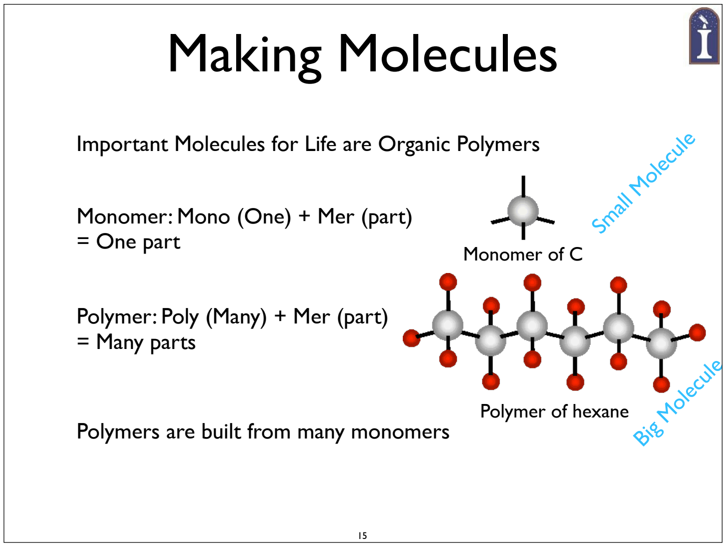
Diversity of Life: 70% Water and 24% 4 large molecules

- Proteins
- Nucleic Acids
- Lipids
- Carbohydrates

In this class, we will focus on the 2 most important molecules

Fine-print: Not completely true, a virus can be single molecule of nucleic acid surrounded by a protein coating.

http://ucsdnews.ucsd.edu/newsrel/health/09-0868Molecules.asp



Making Molecules

Important Molecules for Life are Organic Polymers

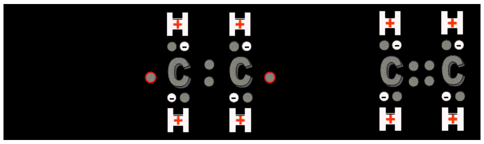
Monomer: Mono (One) + Mer (part)
= One part

Polymer: Poly (Many) + Mer (part)
= Many parts

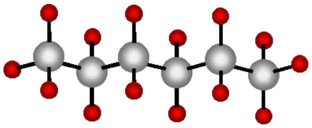
Polymers are built from many monomers

All of the fundamental chemicals of life are organic polymers. A monomer is a small molecule (like carbon bonds we have seen). A polymer is a number of monomers joined together to form larger, more complex molecules. Polymers are nice for life, as they can form complex and repetitive sequences

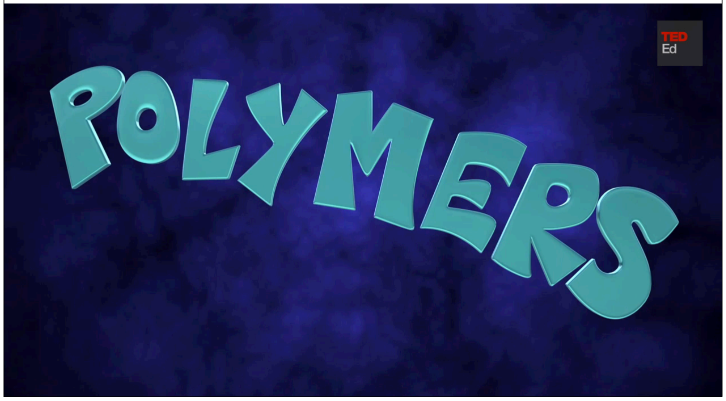
Making A Polymer




Monomer of C


Polymer of hexane

The Diverse World of Polymers



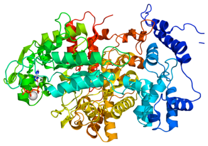
Polymers of Life

Proteins & Nucleic Acids

Proteins:

1) Structural Elements

2) Provide Catalytic Reactions (Enzymes)

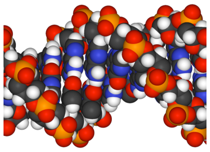


Nucleic Acids: Carry genetic information

Replication of Nucleic Acid

↓

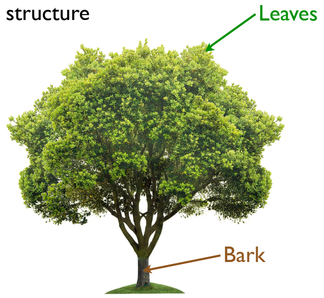
Reproduction of Organism



Proteins are either structural elements or provide catalytic reactions (enzymes). Nucleic acids carry the genetic information– Replication of nucleic acid is crucial to reproduction of organism. They are the polymers of life!

Relevance for Life?

Living things have structure



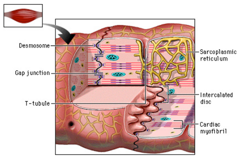
Question: How do these structures relate to complex organic polymers and nucleic acids?

DNA Based Life

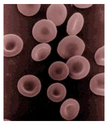
DNA exists in cells.

Except viruses, which are basically just DNA.

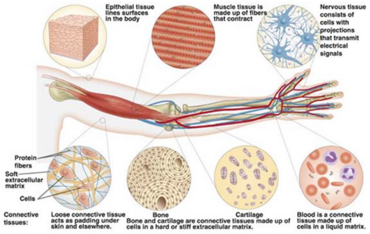
Different cell types handle different functions.

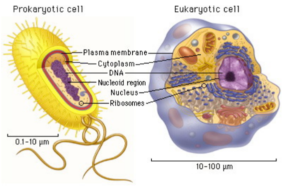


Cardiac Muscle Cell



Red Blood Cell





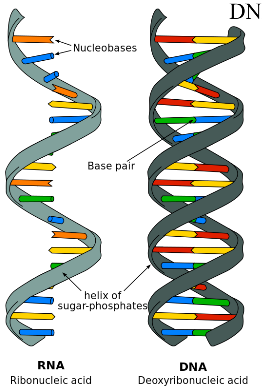
The cell function directly relates to a different organic polymer:

Proteins: They form the structural components of the cell or form enzymes that do all the real chemical work inside the cell. Polymers of amino acid monomers.

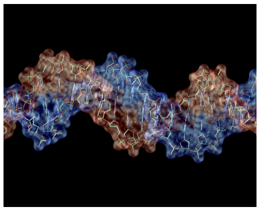
DNA: The genetic coding molecules that control enzyme and cell reproduction. Polymers of a sugar, phosphate, and nucleotides monomers.

DNA Based Life

All terrestrial life is based on DNA/RNA - a complex molecule



What does this mean?



Responsible for encoding the reproduction of all living organisms

All life is based on DNA/RNA. What does this mean?

The basic reproducible unit of all living organisms is centered around the complex DNA molecule. DNA lives in cells. Except in viruses, which are basically pure DNA. Cells of different types form different parts of each organism. Heart cells different from blood cells. Leaf cells different from root cells.

All cells, and all life on Earth uses more or less the same encoding, which means a universality of life on Earth.

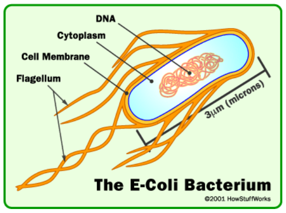
Bacteria Cells

Simplest cell in existence.

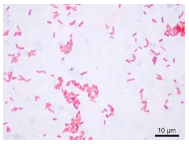
Self-contained organism.

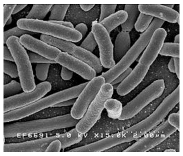
Human cells much more complex.

~ 1 trillion cells in typical human, each around 10 microns in diameter.



Escherichia coli





Found in lower intestine of warm-blooded organisms.

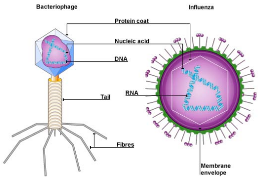
Model organism: heavily studied

Human cells much more complex. In humans, we have about 1 trillion cells and each around 10 microns in diameter, which is more than 3 times larger than typical bacteria cells..

Virus

Straddles divide between living and non-living (Parasitic)

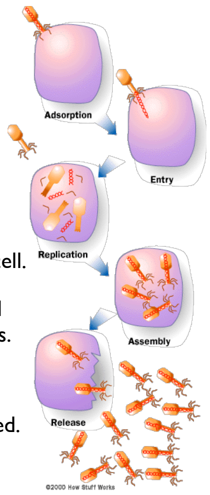
Protein shell protects virus in the wild.



Nucleic acid is released into host cell.

Host cell is hijacked into replicating virus.

New viruses are released.



Straddles between the living and non-living. The protein protects the virus until it enters a living cell, where the nucleic acid is released. Using the cell's machinery, the nucleic acid reproduces itself. They are all parasites, so thought to be from free-living organisms and not descendents of early life. We will ignore them for the rest of the discussion on life.

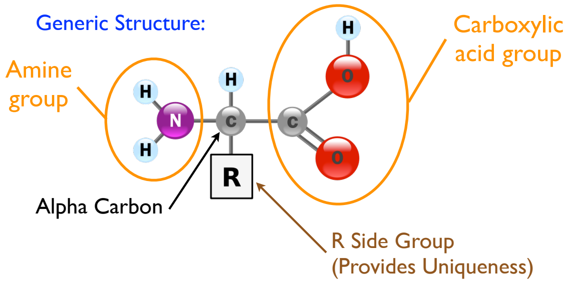
General Protein Types

Type	Example
Structural	tendons, cartilage, hair, nails
Contractile	muscles
Transport	hemoglobin
Storage	milk
Hormonal	insulin, growth hormone
Enzyme	catalyze reactions in cells
Protection	immune response

What makes up

$H_2NCHRCOOH$

Amino Acids



Generic Structure:

Amine group

Carboxylic acid group

Alpha Carbon

R Side Group (Provides Uniqueness)

Monomers for building proteins.

Only 20 standard amino acids used by *life*.

H O N C

+ other trace elements like sulfur

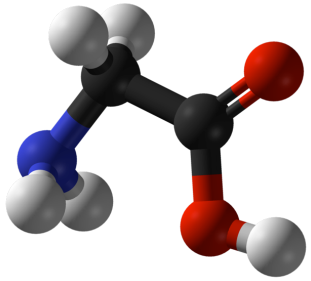
Amino Acids are the monomers from which proteins (polymers) are made- the building blocks. Combinations of the amino acids make the proteins needed- only 20 amino acids used by life.

Carboxylic acid group and amino group.

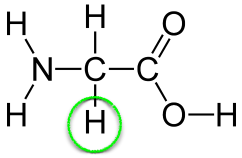
Side group R gives unique characteristics

Glycine

Simplest amino acid



Hydrogen is the R side chain



H O N C

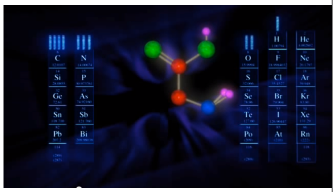
Found in meteorites and now comet dust!

Hooking Up

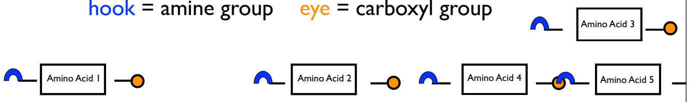
Short chains of amino acids are called peptides.

Long chains of amino acids are called polypeptides or proteins.

Specific amino acids ‘hook-up’ to form a specific protein.



hook = amine group eye = carboxyl group



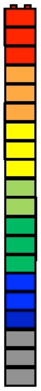
Proteins are polymers, made of the monomer, amino acids. A number of specific amino acids “hook up” to form a specific protein. As a chain grows, there is always a hook (the amino group) on one end and an eye (the carboxyl group) on the other.

Amino Acids

What if each of the 20 standard amino acids was a different lego block?

Can combine them together to build different towers, like different proteins

Different block combinations give different types of towers.



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.

Question

If we think of a protein as a stack of Legos, then what are the blocks?

a) Amino acids

b) Ribonucleic Acids

c) Proteins

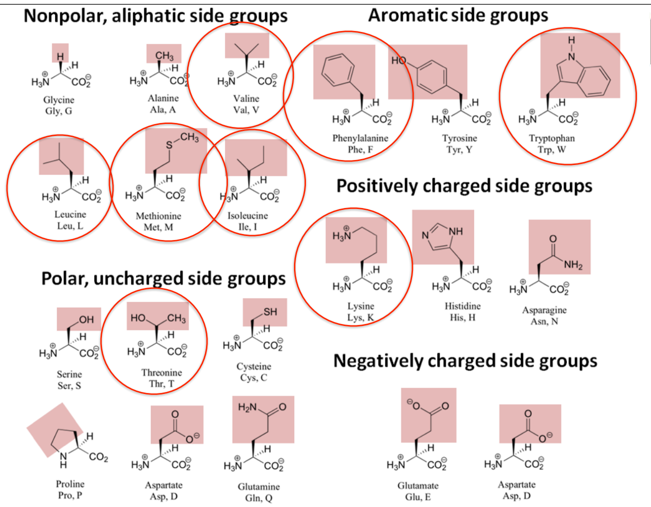
d) Deoxyribonucleic Acids

e) Enzymes

iClicker

A

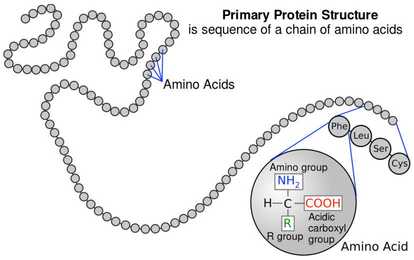
The 20 standard Amino Acids



Encoded in the universal genetic code

Amino acids are critical to life, and have many functions in metabolism. One particularly important function is to serve as the building blocks of proteins. Amino acids can be linked together in varying sequences to form a vast variety of proteins. Twenty-two amino acids are naturally incorporated into polypeptides. Of these, 20 are encoded by the universal genetic code. Eight standard amino acids are called “essential” because they cannot be created from other compounds, and so must be taken in as food. Due to their central role in biochemistry, amino acids are important in nutrition.

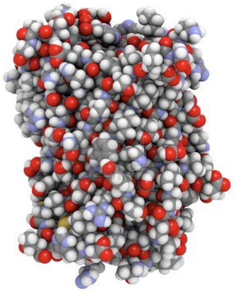
Focus on Proteins



Proteins:

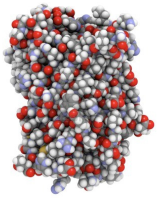
Large,
Very Complex,
Very Numerous

All made from combinations of
20 different types of amino acids.



Green Fluorescent Protein molecule (GFP)

Focus on Proteins



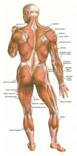
Proteins composed of hundreds to thousands of ONLY these 20 amino acids.

Each with a particular shape and sequence of amino acid monomers.

20^{100+} possible combinations!

But *life* only uses around 10,000 proteins.

Note, about 20% protein.



How many 100 character sequence can you form from the alphabet?

Proteins are large, very complex, and very numerous. Polymer made out of amino acids monomers Yet, all proteins in living organisms are made from combinations of 20 types of amino acids (about 100 available though).

Life on Earth typically uses about 10,000 proteins

Protein Desert

20^{100+} possible combinations!

Only 10,000 used.

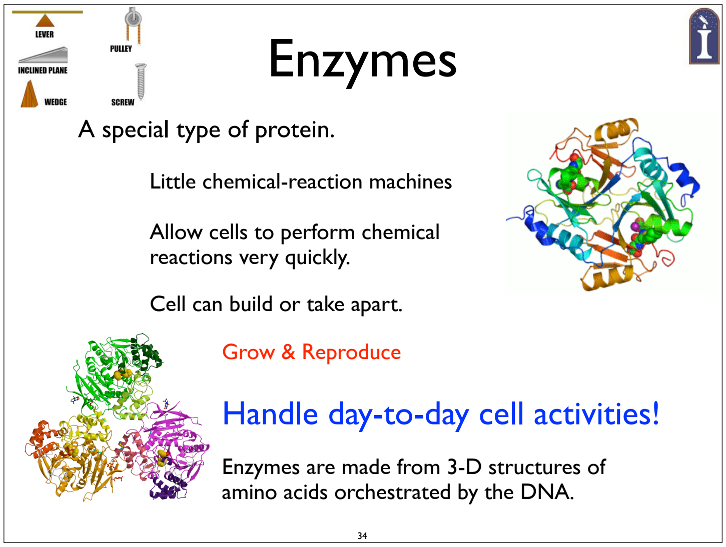
Why?

Is *Life* picky?

Do only certain combinations work?

ET life use the same permutations, or different ones?

Does this depend on environment?



Enzymes

A special type of protein.

Little chemical-reaction machines

Allow cells to perform chemical reactions very quickly.

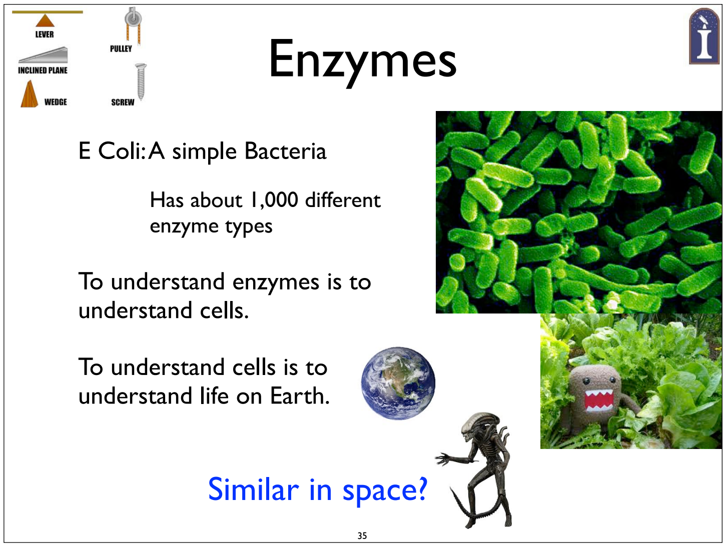
Cell can build or take apart.

Grow & Reproduce

Handle day-to-day cell activities!

Enzymes are made from 3-D structures of amino acids orchestrated by the DNA.

All of the day-to-day work of life is being done by enzymes. Enzymes are little chemical-reaction machines. The purpose of an enzyme is to allow the cell to carry out chemical reactions very quickly. These reactions allow the cell to build things or take things apart as needed- grow and reproduce.



Enzymes

E Coli: A simple Bacteria

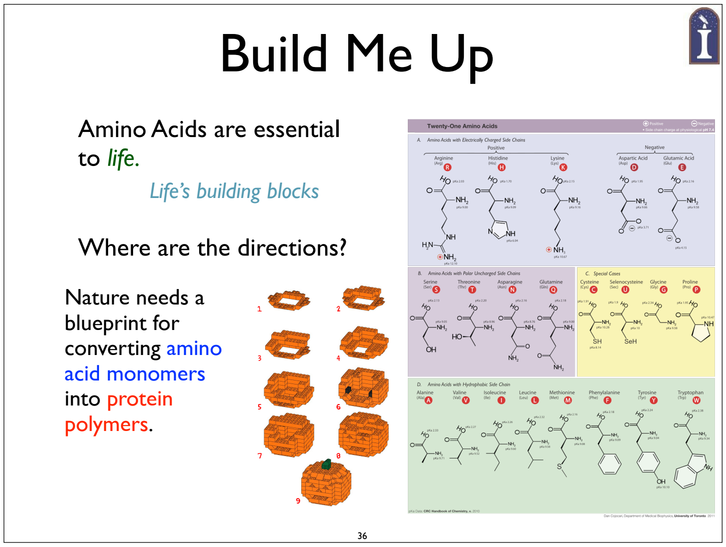
Has about 1,000 different enzyme types

To understand enzymes is to understand cells.

To understand cells is to understand life on Earth.

Similar in space?

E. coli has about 1,000 different types of enzymes floating around in it at any given time. To understand enzymes is to understand cells. To
understand cells is to understand life on Earth. Maybe similar to life in space? Enzymes are made from 3-D structures of amino acids orchestrated by the DNA.



Build Me Up

Amino Acids are essential to *life.*

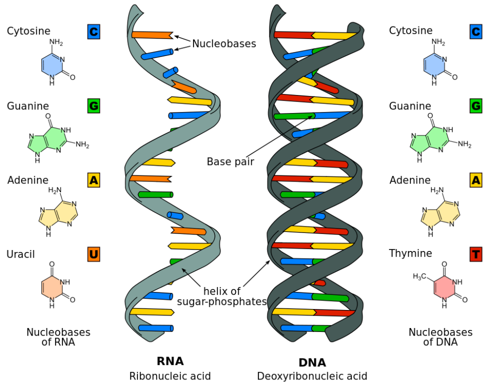
Life's building blocks

Where are the directions?

Nature needs a blueprint for converting amino acid monomers into protein polymers.

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.

Two types of Nucleic Acids



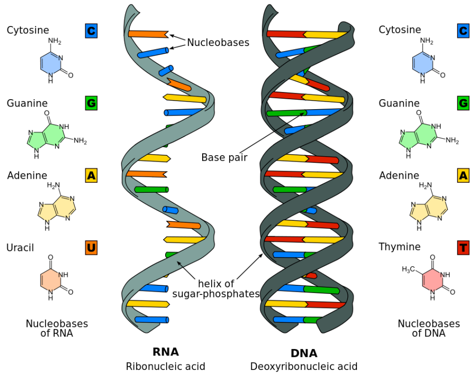
Two types of nucleic acid can store this information. A polymer built up from monomers. The origins of DNA and RNA are mysterious and amazing
DNA/RNA are complex.
1. RNA (RiboNucleic Acid) is usually a long strand
2. DNA (DeoxyriboNucleic Acid) is the double helix- visualize as a spiral ladder.

They are made up of three basic types of monomers
1. Sugar (deoxyribose or ribose)
2. A phosphate PO4
3. One of four “nitrogenous bases”
    i. Adenine (A)
    ii. Guanine (G)
    iii. Cytosine (C)
    iv. Thymine (T) in DNA / Uracil (U) in RNA

Nucleic Acid

DNA & RNA encode the genetic information of the organism

A code to turn amino acids (letters) into proteins (words)

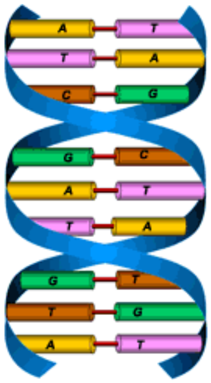


Encoded in these molecules are the genetic information of the organism- the message of what amino acids make up a protein. It is very much like computer code in many ways- and it teaches life how to spell useful word (proteins) out of the letters of the available amino acids.

For DNA: molecule 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. (This is how reproduction works. The ladder is twisted into the helix shape since the hydrogen bonds are at an angle.

Meaning in Mystery

Codon Code



Groups of three nitrogenous bases are encoded into a amino acid.

We call this code, the Codon Code.

The nitrogenous bases are encoded into amino acids using the codon code. Note that in DNA, there is extra redundancy in the double helix. If you know

Meaning in Mystery

Codon Code

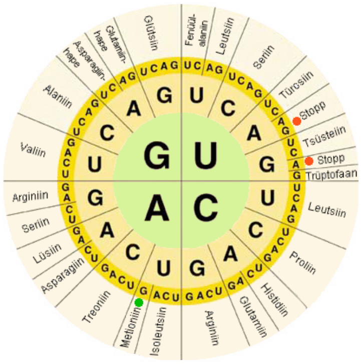
FIRST LETTER	SECOND LETTER U	C	A	G	THIRD LETTER
U	Phenylalanine	Serine	Tyrosine	Cysteine	U
	Phenylalanine	Serine	Tyrosine	Cysteine	C
	Leucine	Serine	Stop	Stop	A
	Leucine	Serine	Stop	Tryptophan	G
C	Leucine	Proline	Histidine	Arginine	U
	Leucine	Proline	Histidine	Arginine	C
	Leucine	Proline	Glutamine	Arginine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

For DNA replace U with T

The nitrogenous bases are encoded into amino acids using the codon code. Each group of three bases correspond to a specific amino acid.

Meaning in Mystery

Codon Code



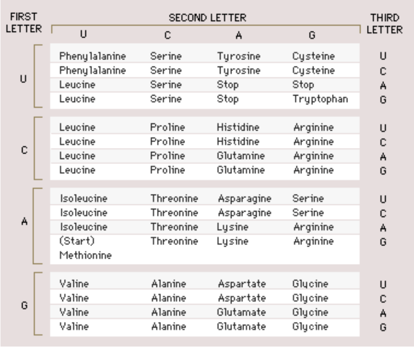
For DNA replace U with T

Amino Acid Codons can be combined to construct a Protein

Nearly universal for terrestrial life!

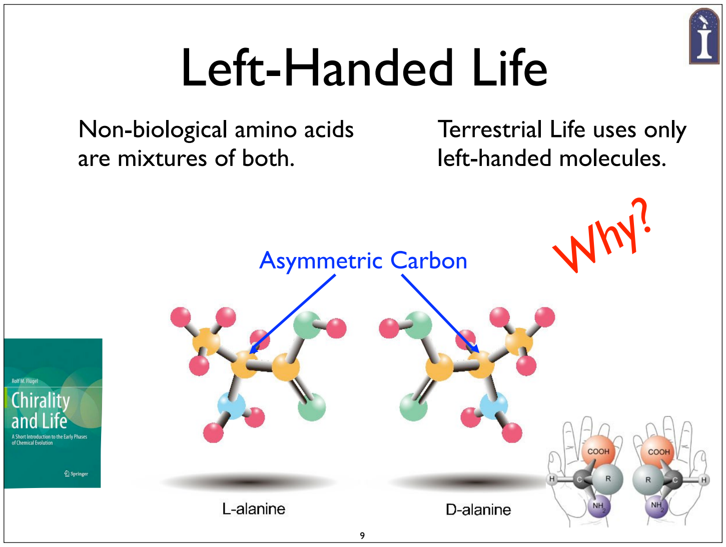
Over-Constrained

- 4 bases, so 4 options for each Codon letter
- 4 x 4 x 4 = 64 options
- 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	C	A	G	THIRD LETTER
U	Phenylalanine	Serine	Tyrosine	Cysteine	U
	Phenylalanine	Serine	Tyrosine	Cysteine	C
	Leucine	Serine	Stop	Stop	A
	Leucine	Serine	Stop	Tryptophan	G
C	Leucine	Proline	Histidine	Arginine	U
	Leucine	Proline	Histidine	Arginine	C
	Leucine	Proline	Glutamine	Arginine	A
	Leucine	Proline	Glutamine	Arginine	G
A	Isoleucine	Threonine	Asparagine	Serine	U
	Isoleucine	Threonine	Asparagine	Serine	C
	Isoleucine	Threonine	Lysine	Arginine	A
	(Start) Methionine	Threonine	Lysine	Arginine	G
G	Valine	Alanine	Aspartate	Glycine	U
	Valine	Alanine	Aspartate	Glycine	C
	Valine	Alanine	Glutamate	Glycine	A
	Valine	Alanine	Glutamate	Glycine	G

This is why some DNA damage could not make any difference and some damage (1 change in a single base) makes a huge difference. We'll come back to this. This over-constraint means that life is not so fine tuned as we often think,



Left-Handed Life

Non-biological amino acids are mixtures of both.

Terrestrial Life uses only left-handed molecules.

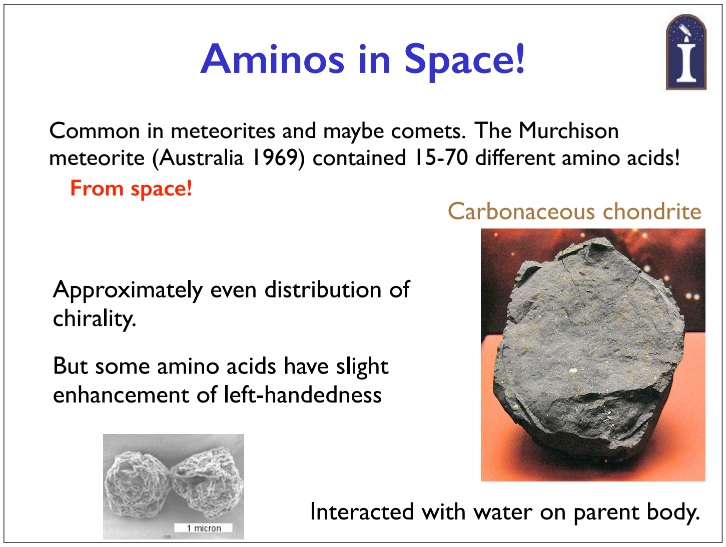
Why?

Asymmetric Carbon

Amino acids in non-biological situations are mixtures of both, but in life only left-handed molecules are used.
Why? We don't know. Some models suggest early Earth had a preference for left handed life. Once life started with one type, it continued— too late to change.

To match, 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 process (i.e. eat) our food. Bummer.



Aminos in Space!

Common in meteorites and maybe comets. The Murchison meteorite (Australia 1969) contained 15-70 different amino acids!

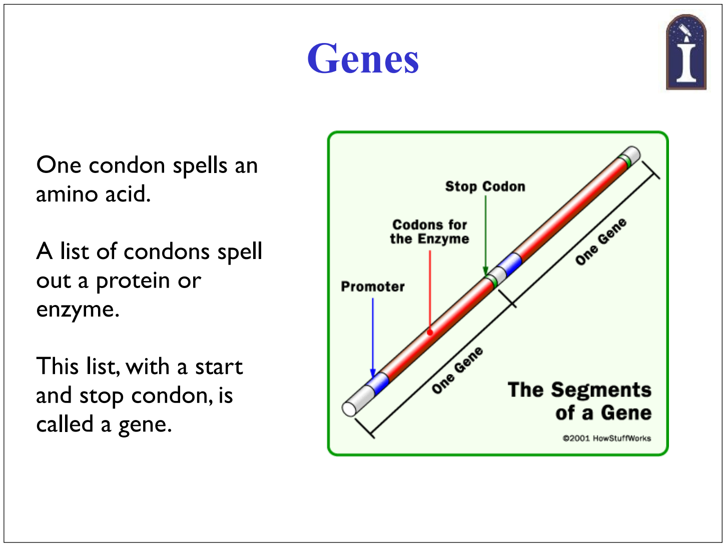
From space!

Carbonaceous chondrite

Approximately even distribution of chirality.

But some amino acids have slight enhancement of left-handedness

Interacted with water on parent body.



Genes

One condon spells an amino acid.

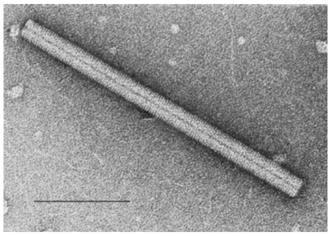
A list of condons spell out a protein or enzyme.

This list, with a start and stop condon, is called a gene.

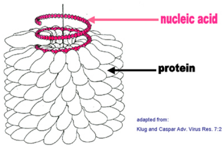
Each codon specifies an amino acid, and a sequence of condons specifies a protein or enzyme. E. coli bacterium has about 4,000 genes, and at any time those genes specify about 1,000 enzymes. Many genes are duplicates.

Ta-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



adapted from:
Klug and Caspar Adv. Virus Res. 7:225

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 3×10^9 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

---

My Old Blue Genes

98% is often called "junk" DNA (also called "Dark Matter"), but unclear to function

Likely controls the early development from embryo to adult.

May be as important as the protein encoding portion, but we don't know.

There is evidence that there is evolutionary conservation of "junk" DNA, which implies importance.

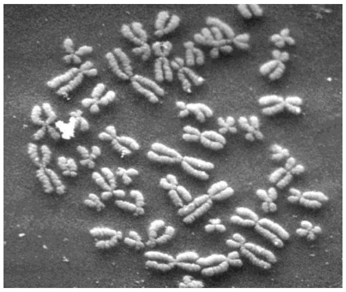
http://images.encarta.msn.com/xrefmedia/sharemed/targets/images/pho/t373/T373681A.jpg

Chromosomes

Humans have 23 pairs of chromosomes (total of 46).

Range from
50 million to
250 million base pairs

For each set, you got half from each parent.



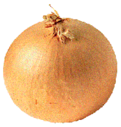
http://folding.stanford.edu/education/GAH/gene.html

Best way to package DNA is in chromosomes– DNA wrapped around proteins,

---

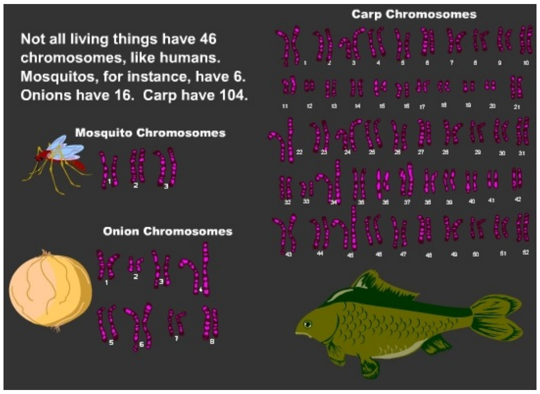
Which requires the most genes?

a) Onion
b) Mosquito
c) Carp
d) Human



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

Chromosomes



Not all living things have 46 chromosomes, like humans. Mosquitos, for instance, have 6. Onions have 16. Carp have 104.

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