Lec 8 – Origin and Evolution of Life

What is life?

Actually hard to define – I found two almost identical:

Life = a self-sustaining chemical system capable of Darwinian evolution

Life is a self-sustaining chemical system capable of evolving 9replicating, mutating, undergoing natural selection).

Attributes of a living organism:
-self-sustaining
-metabolism
-growth
-reproduction
-mutation

What is metabolism? "the chemical and physical reactions that take place in order to maintain growth and normal functioning"; "the ways cells build food stuffs and break them down" – in other words processes like fermentation and photosynthesis – which convert building materials and energy into useful stuff like hormones.

Cell – "fundamental units of biological organization"

A prokaryotic cell is the smallest (typically 1 to 5 microns across) and simplest form of life

It has the minimum stuff needed for a living organism, including

A body
 -boundary (cell membrane)
 -interior cytoplasm
Identity – a single strand of DNA
Machinery for metabolism and reproduction – ribosomes (the little dots in the image)
Way to store and transfer energy – ATP

We'll talk about all of these, but first we need to discuss some of the components that these are composed of

So what is a MONOMER?

According to one of many definitions that I found, it is “a single molecule that has the ability to combine with identical or similar molecules” via a process known as polymerization. The key point is that these are simple repeating units that combine to make longer molecules

A good example of a monomer is the sugar GLUCOSE

A POLYMER is a large organic molecule which is constructed from combining lots of monomers – “Any of numerous natural and synthetic compounds of usually high molecular weight consisting of up to millions of repeated linked units, each a relatively light and simple molecule. “

There are basically four major groups of MONOMERS and their corresponding POLYMERS that you need to remember

MONOMER	POLYMER
Sugars (such as glucose, ribose, fructose)	Carbohydrates (such as starch, cellulose) – used for cell walls and energy
Fatty acids – chains of carbon with a carboxyl group at one end	Lipids (such as fats and many hormones, including cholesterol, testosterone, and estrogen) – used for energy storage and cell membranes
Amino acids – next slide	Proteins – structural materials, enzymes, some hormones
Nucleotides (made up of one of four bases, one of two sugars, and a phosphate)	Nucleic Acids (such as DNA and RNA) – stores and transmits genetic information

Amino acids:

consist of

a) a carboxyl group COOH

b) an amino group NH_3
c) a side chain that is unique for each amino acid and distinguishes it from the rest

Diagram to the right shows the 20 amino acids used by life

Not symmetric molecules, can come in right and left handed varieties. All life on Earth uses left handed amino acids

So back to our cell

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Cell membranes are boundaries through which cells absorb nutrients from surrounding environment and expel waste products and the products manufactured by the cell, such as proteins, hormones, etc.

Cell membranes are made of double layers of lipids, and are best discussed in biology.

Cytoplasm – the stuff that fills up the interior of the cell. I looked this up in my "intro to biology book" and got the following definition:

"a dynamic aqueous solution that contains the raw materials required for growth, self-maintenance and reproduction" (in other words, a liquid that contains things such as amino acids, fatty acids, sugars, etc.)

I was wondering what the word "dynamic" referred to and found the next two slides, which makes me think this is a topic for a biology class.

- the cytoplasm is the material between the plasma membrane (cell membrane) and the nuclear envelope

(melinda adds that this is for a eukaryotic cell)

- fibrous proteins that occur in the cytoplasm, referred to as the cytoskeleton maintain the shape of the cell as well as anchoring organelles, moving the cell and controlling internal movement of structures

- microtubules function in cell division and serve as a "temporary scaffolding" for other organelles

- actin filaments are thin threads that function in cell division and cell motility with intermediate filaments between the size of the microtubules and the actin filaments

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Mendel's law is composed of five points:
1. In each organism, a character (for example seed shape) is composed of two alternative states (for example, *wrinkled* or *round*). These alternative states are called alleles.
2. Only one of the alleles is passed on to the offspring. Since an offspring gets an allele from each parent, it also has two alleles.
3. Each allele has an equal chance of being passed on to the offspring.
4. The two alleles do not blend, but remain distinct.
5. There is a dominant/recessive relationship between the alleles. that is, if the two alleles are different, one will be expressed and the other will not.

So people defined:

Gene
portion of the hereditary material that codes for a characteristic (for example, seed shape).

Another definition of gene: a discrete unit of inheritable information

Alleles
the alternative forms for each gene responsible for the form the character may take (for exam
ple, for the gene for seed shape there is a wrinkled allele and a round allele).

But where were they?

In the 20th century, cells were discovered, and it turned out that most cells (eukaryotic ones) had a nucleus. During cell division, threadlike structures called chromosomes become visible. Each species has a specific number of chromosomes – humans have 46, horses have 64 (note they come in pairs).

It was later discovered that chromosomes were coiled stands of DNA. Genes are specific segments of DNA that code for information.

The nucleic acids (DNA and RNA) consist of a "backbone" of phosphate and sugar (either deoxyribose or ribose) connected to "rungs" of bases – this MONOMER unit (above) is called a NUCLEOTIDE. DNA uses the four bases adenine, guanine, cytosine, and thymine. RNA uses uracil instead of thymine.

The DNA molecule has paired "backbones" and "rungs". The RNA molecule just has one half of the "ladder". The major functions of both are to store genetic information in coded form and to participate in the conversion of this information into protein structure, and to pass on the information from generation to generation.

DNA is duplicated by unzipping its double helix and adding on the correct building blocks to create two new halves – sometimes there are "copying errors" – mutations.

Nucleic Acids:

DNA – stores genetic information

mRNA – messenger RNA carries information from DNA to ribosomes

tRNA – transfer RNA carries amino acids (available in cytoplasm) to ribosomes. There are specific tRNA molecules for each of the 20 amino acids used by life

rRNA-ribosomal RNA – essential component of ribosomes

Okay, what are these ribosomes I keep talking about?

Machinery for metabolism and reproduction – ribosomes (the little dots in the image)

Ribosomes are the cellular factories that manufacture proteins. mRNA copies (or transcribes) the DNA code and carries it to the ribosome. Remember there are 20 types of tRNA (one for each amino acid). The ribosome "reads" the mRNA and selects the appropriate tRNA/amino acid to match the code from the mRNA (translation). The ribosome attaches amino acid to the next amino acid, according to the instructions (code from the mRNA), building a protein which is made of a sequence of amino acids. Want to know more? Take biology.

All of this requires ENERGY

Way to store and transfer energy – ATP

Cells store and transfer energy using a molecule called adenosine triphosphate (ATP)

What is the difference between the two molecules on this page?

One is a nucleotide of RNA, the other is ATP – it differs from the RNA nucleotide by having two extra phosphate units.

ADP (two phosphates) vs. ATP (three phosphates). It requires energy to add the third phosphate – reaction is ADP + phosphate + energy -> ATP + water. The energy is stored in the molecular bond. To release the energy – break the bond (add water): water + ATP -> ADP + phosphate + energy

In prokaryotes, ATP is produced on the cell membrane. In more complicated cells, ATP is produced by special organelles (little organs), such as chloroplasts in plant cells that do photosynthesis (and store solar energy).

All life on Earth uses ATP for energy. Other molecules should be as useful. Evidence that all life on Earth from one common ancestor.

The more complicated cell is called a EUKARYOTIC cell

Eukaryotes are much larger (typically 5-60 microns across) and more complex cells than prokaryotic cells.
Eukaryotes have numerous organelles. The cell's numerous strands of DNA are segregated into a NUCLEUS that has its own membrane.
Organelles such as chloroplasts and mitochondria have their own membranes, DNA, mRNA, tRNA, and ribosomes.

Every organism that we've ever examined on Earth manufactures proteins at ribosomes. Ribosomes are made mostly of ribonucleic acids (RNAs), which
consist of phosphates, sugars, and a coded string of 4 bases. Over time, mutations alter the sequence of the four bases. We can tell how closely related two organisms are by looking at their ribosomal RNA and seeing how similar the sequence of bases is between the two organisms.

What we find, based on RNA is that all life on Earth today is related, and evolved from a common ancestor. As far as we know, that common ancestor went extinct, as none of the organisms alive today are genetically close enough to each other to be close to the "common ancestor. However, it is clear that the "common ancestor" was a simple, rather than complex cell.

We also find that organisms alive today that are closest to the “common ancestor” are thermophilic bacteria and archea, typically found at hot springs and hydrothermal vents at mid-ocean ridges.

Back to metabolism: “the chemical and physical reactions that take place in order to maintain growth and normal functioning”
In order to stay alive (and to reproduce), organisms need to have building materials (roughly 22 elements, but mostly C H O N) and energy to build with.

Metabolism is the process by which organisms acquire C H O N and energy.

Only two categories of metabolism have been invented by life on Earth. All the various metabolic processes are simply variants on of the these two types of metabolism

Autotrophs: self feeders – these organisms take in simple nutrients, usually carbon dioxide, water, nitrate and phosphate. Energy can come from light (photoautotroph) or chemical reactions (chemoautotroph).

Heterotrophs: other feeders – these organisms get their C H O N, etc. from food they consume (something that was once alive) and energy from the chemical bonds in that food

The only metabolism present in all forms of life on Earth is glycolysis, which is a type of fermentation (heterotrophy). A glucose molecule is broken down and energy released. That energy is then used by a cell to form 2 ATP molecules.

Requires glucose (why glucose?). Glucose is the least susceptible of all six-carbon sugars to break down due to changes in temperature and acidity, so most likely to be available to early organisms.

Glucose gives a primitive cell a source of C H and O, What about other elements, particularly N? On the early Earth there must have been small amounts of ammonia (NH3) available (and essentially no oxygen in the atmosphere). Anaerobic heterotrophs thrive if fed glucose and ammonia (by fermentation). But what happens if your environment runs out of sugar or ammonia?

You starve? No, you figure out how to create glucose (by becoming an autotroph- photosynthesis or chemosynthesis) and find another source of nitrogen. Most of the Earth's atmosphere is nitrogen (N_2) and probably always was. Most "early evolved" bacteria and archea can "fix" atmospheric nitrogen (combine nitrogen from atmosphere with hydrogen to make ammonia). The process requires a lot of energy, so would not have evolved if not absolutely necessary. Also, requires the absence of oxygen.

Photosynthesis:
$H_2O + CO_2 \rightarrow$ "CH_2O" $+ O_2$
$H_2S + CO_2 \rightarrow$ "CH_2O" $+ S$

photosynthesis can give off sulfur rather than oxygen as a byproduct

Okay, so we've discussed the components associated with life

How Did Life Arise?

We don't know…
But we can speculate

Look at the simplest forms of life

Simplest metabolism: glycolysis – requires glucose + ADPs + phosphate + enzymes (proteins which are made of amino acids)

Simplest cell has a cell membrane, a strand of DNA and ribosomes (to manufacture proteins).

So we need glucose, cell membranes (lipids), enzymes (proteins), and either RNA or DNA and we have to package it all together

So the question of how life arises can be broken into pieces:

1) how do monomers form
2) how do monomers combine to form polymers
3) if we need RNA to create proteins and we need enzymes (which are proteins) to use RNA, how did this process get going
4) how do cell membranes form
5) how do you put it all together (and where?)

How do Monomers Form:

Phosphate is easy – weathering of rocks

The Miller-Urey experiment 1953 **–** used sparks and a “simple atmosphere”

Produced formaldehyde, ATP, hydrogen cyanide, alanine, glycine, aspartic acid, etc.

Has been repeated for a variety of C H O N rich atmospheres and energy sources (intense heat, UV radiation, etc.)

Get a lot of organic molecules – 2 most common ar hydrogen cyanide and formaldehyde, both identified in interstellar space

When asymmetric molecules (such as amino acids) are formed by these experiments, we get racemic mixtures (roughly 50/50 left and right handed versions).

Overall, monomers don’t seem difficult to produces, although there are issues about concentrations, particularly about ribose

How do we create polymers?
By dehydration condensaiton – we need to remove water

But if you’re trying to start life in water?

Because of their crystal structure, clay minerals have weak negative electrical charges on the outside of the grain.

Experiments with monomers and clays have produced short segments of “not-quite polymers”, suggesting clays may have played a role in creating polymers.

How do monomers form – this seems to be relatively easy
How do monomers combine to form polymers – not so easy – we’re not there yet – but maybe need clays
If we need RNA to create proteins and we need enzymes (which are proteins) to use RNA, how did this process get going

Past my level of knowledge **–** but I do know in 1980s a special kind of RNA called ribozymes discovered – they house information (via 4 bases), but also do enzyme-like functions (cut molecules apart and/or splice them together; some are self-splicers).

Idea of “RNA world” – some RNA can evolve outside of a cell inside a test tube – so maybe some ribozyme-like polymer formed and began to evolve. Eventually got into a cell and evolved DNA

Okay, what about cells – experiments by Jack Szostak

Under certain conditions, some substances like soap (amphiphilic molecules) will form spheres (here referred to as vesicles) with the water-loving sides facing outwards. Szostak discovered that vesicles formed on a particular clay incorporated that clay inside the vesicle.

It is not a cell, but it is a cell-like structure with a clay template upon which you might be able to make RNA, proteins,etc

Despite the fact that we can’t create life in a lab, we know that life formed, because we’re here.

Oldest rock sample on Earth - 3.96 by old Acasta Gneiss - also a few zircons aged 4-4.4 by old in later originally sedimentary rocks.

Zircons and Acasta Gneiss derived from granitoid precursors

Evidence for Archean Life:

Indirect evidence in heavily metamorphosed rocks (~3.8 by old), in the form of kerogen (a tar-like substance) that has 13C/12C isotopic ratios similar to present-day life, and unlike non-biologic material.

- **Carbon has two stable isotopes:**
  C12 = 6 protons, 6 neutrons
  C13 = 6 protons, 7 neutrons

- **Abiotic systems typically have a ratio of**
  C13 / C12   = 1/89

- **Life favors C12 because it is slightly lighter and reacts faster.**

- **So… if the ratio of C13/C12 in a fossil sample does not equal 1/89 , there is evidence that life was present!**

Stromatolites are present in
greenstone belts as early as
3.5 by ago. They are dome- or conical-shaped layered mounds of sediments. Modern stromatolites are created by microorganisms, including cyanobacteria

We see oxygen going up starting about 2.5 by ago – no doubt we have photosynthesizing organisms by that time.

How and when did we go from prokaryotes to eukaryotes?
Not sure – maybe as long ago as 1.4-1.8 billion years ago?
Bad case of indigestion?

How do you get to multicellular life? Probably started with colonial organisms where cells all the same and then some cells began to specialize

Volvox is a tiny freshwater colony of thousands of flagellated cells, each of which resembles the aga Chlamydomonas. Each cell has an "eye spot" sensitive to light and nourishes itself by photosynthesis. Cells connected by thin cytoplasmic strands and arranged in a single layer around a jellylike mass. Cells on one side have larger eye spots and primarily direct mvoement – other side responsible for reproduction – offspring colonies can be seen embedded among cells of parent colony

Sponges are among the simplest form of multicellular life – they are literally a collection of cells that have whip-like flagellum and secrete a shared porous skeleton – epithelial cells form outer covering, pore cells form passages for water intake, contractile cells control flow of water, mesenchyme cells help with digestion and support – no sense organs, nerve cells, muscles or other organ systems – all activiteis carried out at cellular level.

With corals you get "tissue-level" organization

2 layers of outer cells with jelly-like material between layers

Aggregates of cells serve as organs such as ovaries and testes

But no controlling group of nerves or brain

That's as far as I got – Cambrian EXPLOSION