Prologue:
The Origin of Life

Vocabulary
Click on each word below to go to the definition.

- adhesion
- asexual
- cell
- cohesion
- dehydration synthesis
- homeostasis
- hydrolysis
- hydrophillic
- hydrophobic
- last universal common ancestor

- membrane
- monomer
- organic
- phospholipid
- polar
- polymer
- sexual
- solute
- solution
- solvent
The Origin of Life Unit Topics

- Early Universe, Early Earth
- Water
- Organic Monomers
- Dehydration Synthesis, Hydrolysis
- Phospholipids
- LUCA, Characteristics of Life

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Early Universe, Early Earth

Earth formed about 9.5 billion years after the start of the universe, about 4.6 billion years ago.

In those 9.5 billion years, many generations of stars were born and died.
Heavier Elements

The early universe was almost completely made of hydrogen and helium. Elements heavier than helium didn't exist at the dawn of the universe.

When the early stars died explosively (novae and supernovae), those heavier elements were scattered into space.

Periodic Table of the Early Universe

About 14 BYA

Elements and Earth

When Earth, and its solar system, formed, it was in a cloud of matter which included all the naturally occurring elements in the periodic table.

No new elements have been created since Earth formed.

This means that all the atoms in you and your world, other than hydrogen and helium, were once inside a star, long ago.
Periodic Table when Earth formed
About 4.6 BYA

Elemental hydrogen and helium escaped Earth's atmosphere long ago.

The lighter the gas atom or molecule, the higher it's velocity.

That's because all atoms and molecules in a gas mixture have the same average kinetic energy, since they have the same temperature, and temperature is a measure of a gas's average kinetic energy.

$$\text{KE}_{avg} = \frac{3}{2}nRT$$

Early Earth's Atmosphere

Velocity and Earth

Remember, the lower the mass, the higher the velocity.

$$\text{KE} = \frac{1}{2}mv^2$$

H₂ and He molecules can easily exceed Earth's escape velocity, so they escaped long ago.
Hydrogen and Helium on Earth

As a result, $H_2$ and He are absent from our atmosphere.

He is a noble gas, it doesn't form compounds, so it is only found trapped under Earth's surface.

Hydrogen is found in compounds.

Hydrogen on Earth

Where do you think most hydrogen is found on Earth?

Click here to watch "Where does Earth's Water Come From?"

1. How many billions of years old is the universe?
1. How many billions of years old is the universe?

   Answer: 14 Billion

2. How many billions of years old is Earth?

   Answer: 4.6 Billion
3 Nitrogen was created by the fusion of 3 helium atoms and one hydrogen atom. Where did this occur?

- A the sun
- B stars that we see at night
- C stars that exploded long ago
- D the other planets

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**Early Earth's Compounds**

Studies of volcanos suggest the early atmosphere of Earth was composed of a mix of chemical compounds.

The most prevalent were:
- water vapor (H₂O),
- carbon dioxide (CO₂),
- nitrogen (N₂),
- hydrogen sulfide (H₂S),
- methane (CH₄), and
- ammonia (NH₃).
Earth was also subject to intense lightning and ultraviolet radiation.

*It is ironic that life arose under conditions that included bombardment by UV radiation.*

*Today, depletion of the ozone layer that protects us from this radiation is a major environmental concern!*
Scientists hypothesize that Earth's early atmosphere contained substances such as:

- A oxygen, carbon dioxide and hydrogen gas
- B nitrogen, oxygen, and water vapor
- C water vapor, methane, and oxygen
- D ammonia, water vapor, and hydrogen gas

Which of the following was probably not present in the atmosphere of the primitive Earth?

- A methane (CH₄)
- B oxygen (O₂)
- C water (H₂O)
- D carbon dioxide (CO₂)
- E ammonia (NH₃)
5 Which of the following was probably not present in the atmosphere of the primitive Earth?

- A methane (CH₄)
- B oxygen (O₂)
- C water (H₂O)
- D carbon dioxide (CO₂)
- E ammonia (NH₃)

Answer: B

Time is critical for life to have developed from simple chemicals to the complex world we see around us today. The scale of time and space in the universe is almost incomprehensible to all of us. Metaphors help, but you really have to struggle to imagine Deep Time.

Deep Time Put to Scale

Earth is 4.6 billion years old; the chemical processes we're describing have proceeded for more than 4 billion years: 400 x 10⁷ years. Given an average human life span of 72 years, how many humans lifetimes is that?
Earth is 4.6 billion years old; the chemical processes we’re describing have proceeded for more than 4 billion years: $400 \times 10^7$ years. Given an average human life span of 72 years, how many humans lifetimes is that?

\[
\frac{400 \times 10^7 \text{ years}}{72 \text{ years}} = 5.6 \times 10^7 = 56 \text{ million lifetimes}
\]

56 Million Lifetimes

No wonder it’s so hard to imagine the evolution of life. Our first records from human history are about 10,000 years old, about 140 lifetimes ago.

The process of developing life started about a million times further back in time than that.

The unimaginably distant past.

Deep Time

*Let's put this into perspective...Imagine our planet having existed in the universe for the span of one year...*

Prokaryotes (bacteria) evolved at some point during the middle of MARCH

Eukaryotes (cells with a nucleus) came on the scene in SEPTEMBER

Dinosaurs were in their prime around the middle of DECEMBER

Human life as we know it happened during the last half-second before the beginning of the next year is celebrated on NEW YEARS EVE.

Click here for a video of our world in the making
What is the most critical thing for the development of life on Earth?

- A oxygen
- B carbon dioxide
- C time
- D land

Answer: C
As Earth's crust cooled and solidified, water vapor condensed to create oceans.

For many years, it was theorized that water had been initially brought to Earth by comets in the early solar system. A paper published in September 2014 changed that idea.

A reexamination of lunar samples taken during the Apollo missions of the 1960s and 70s have shown that the water found on soil particles on the moon actually came from components of solar wind.

The hydrogen atoms which arrive on the wind from the sun can convert to water or OH ions when interacting with rocks. This discovery alters previously held ideas about how Earth became the blue marble we now recognize.
Three-quarters of Earth’s surface is submerged in water.

The abundance of water is the main reason Earth is habitable.

**Water Molecules**

A water molecule consists of two hydrogen atoms covalently bonded to one oxygen atom.

The more electronegative oxygen atom pulls the electrons from the hydrogen atoms toward it, resulting in an uneven distribution of charge.

Since a water molecule has a positive end and a negative end it is called a **polar** molecule.

This property of water causes it to act like a magnet, attracting other molecules that have positive and negative poles.
Properties of Water

The polarity of water gives it several important properties that allowed life to emerge on Earth:

- Ability to moderate temperature
- Versatility as a solvent
- Cohesive behavior

Moderate Temperature

Water has a very high specific heat, it takes a lot of energy to raise the temperature of water even a few degrees. This means that temperature on Earth’s surface can undergo extreme variations - between night and day, or between seasons - without its water freezing or boiling away.

*Why is this important in the development of life on Earth?*

Universal Solvent

A solution is a homogeneous mixture of substances.

An aqueous solution has water as the solvent. Water is sometimes referred to as the *universal solvent* because of its ability to dissolve most compounds.

Life’s chemical reactions need to occur in solution. In water, nutrients can dissolve and chemical reactions occur.
Cohesive Behavior

The polarity of water molecules causes them to be attracted to each other. Weak hydrogen bonds form between the hydrogens on one water molecule and the oxygen atoms on another to form liquid water.

Attraction between water molecules is called **cohesion**. Attraction between a water and a non-water molecule is called **adhesion**.

Among other things, this property allows:

- plants to pull water up through their roots
- small insects to walk on water
- and most importantly, water to bend carbon (**organic**) molecules into 3-D shapes.

7 What is now believed to have been the source of water for Earth?

- A nuclear fission
- B chemical reactions on Earth
- C comets
- D Solar Wind
7. What is now believed to have been the source of water for Earth?
   - A: Nuclear fission
   - B: Chemical reactions on Earth
   - C: Comets
   - D: Solar Wind

   Answer: D

8. In a water molecule hydrogen and oxygen are bonded together by ___________.
   - A: Ionic bonds
   - B: Covalent bonds
   - C: Hydrogen bonds
   - D: Van der waals forces

   Answer: B
9. Which of the following best describes a hydrogen bond?

- **A** formed through an electrostatic attraction between two oppositely charged ions
- **B** formed by the equal sharing of electrons between to atoms
- **C** the attractive force between neutral molecules
- **D** the attractive force between the hydrogen attached to an electronegative atom of one molecule and an electronegative atom of a different molecule

10. Which property of water accounts for the others?

- **A** cohesion
- **B** adhesion
- **C** polarity
- **D** high specific heat
10. Which property of water accounts for the others?
   - A. cohesion
   - B. adhesion
   - C. polarity
   - D. high specific heat

   Answer: C

11. Trees must pull water up their trunks from the roots. What property of water allows trees to pull against gravity?
   - A. cohesion
   - B. universal solvency
   - C. high specific heat
   - D. all of the above

   Answer: A
12 Oceans do not freeze in winter due to which property of water?

- A cohesion
- B universal solvency
- C high specific heat
- D all of the above

Answer: C
Monomers and Polymers

Use the picture below to define monomer and polymer in your groups.

- **Monomer**
- **Polymer**

How life may have emerged

1. Organic **monomers** formed
2. Monomers combined to form **polymers**
3. **Phospholipids** formed, creating membranes
4. Membranes created isolated **early cells**
5. Early cells replicated and performed simple metabolism (energy processing)
6. RNA developed inside the early cells, marking the transition to life.

Organic Monomers Formed

There are two theories for the source of organic monomers

- Arrival on Earth from space
- Creation on Earth through chemical reaction
Theory 1: Organic Monomers from Space

The dust in the solar system, from which Earth formed, was rich in organic chemicals.

Meteorites striking Earth would have hit with lower velocity since the atmosphere was thicker; the monomers would have survived.

Click for a video of comets and early Earth

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We find organic chemicals in old meteorites discovered even today, such as this one.

Also, it's estimated that several million kg* (5,000,000 pounds) of organic chemicals fall as cosmic dust to Earth each year.

*The Story of Life, Richard Stockton, 2003, p. 11

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Theory 2: Organic Monomers from reactions

Two scientists (Oparin and Haldane), in the 1920's, proposed that organic chemistry could have evolved in the early Earth's atmosphere because it contained no oxygen.

The oxygen-rich atmosphere of today is corrosive and breaks molecular bonds.
In 1953, Stanley Miller used Oparin and Haldane’s original idea and tested a hypothesis involving an artificial mixture of inorganic molecules while simulating the conditions thought to be found on primitive Earth.

Within days, the experiment produced some of the 20 amino acids presently found in organisms, as well as other organic molecules.

Click here for an explanation of Stanley Miller's experiment

The primeval sea: flask of warmed water
Stanley Miller’s Experiment

The early atmosphere - a mixture of:
- water vapor
- H₂
- CH₄
- and NH₃

The “ocean” is sampled and its composition analyzed.

Sparks simulate lightning.

Early weather conditions: electrodes discharging sparks into the gas mixture.

The “ocean” is sampled and its composition analyzed.

Rain: a condenser cooling and collecting water vapor and dissolved chemicals.
Stanley Miller's Experiment

Miller's Experiment Moving Forward

Recent experiments, improving on Miller’s, have produced most of the naturally occurring organic molecules including:

- amino acids
- sugars
- lipids
- nucleotides

These experiments have also shown there are 4 conditions required for chemicals to evolve.

Four Conditions Required for Chemical Evolution

Click to reveal

- Absence of oxygen in the atmosphere
- High-energy input from the sun
- Micromolecules - the gas in the chamber had to be in the atmosphere and prime the ocean
- Time - a long time was needed to get the molecules in a form to react and reproduce
13 Miller and other scientists have shown that:

- A simple cells can be produced in a laboratory
- B amino acids and sugars could be produced from inorganic molecules
- C cells survived in the primitive atmosphere
- D life on early Earth required material from space

Answer: B

14 Which of the following is not a condition for the formation of organic molecules?

- A a long period of time
- B inorganic micromolecules in the system
- C presence of oxygen in the atmosphere
- D high energy input
14. Which of the following is not a condition for the formation of organic molecules?
   - A. a long period of time
   - B. inorganic micromolecules in the system
   - C. presence of oxygen in the atmosphere
   - D. high energy input

   Answer: C

15. Which of the following was Stanley Miller able to produce in his 1953 experiment?
   - A. proteins
   - B. prokaryotes
   - C. amino acids
   - D. lipids

   Answer: C
16 Water vapor travels through the tube in which labelled section?

A
D
B
C

17 Sparks simulate lightning in which labelled section?

A
D
C
B
17. Sparks simulate lightning in which labelled section?

A

B

C

D

Answer: B

18. Organic compounds are found in which section?

A

B

C

D

Answer: D
Dehydration Synthesis

Polymers are formed through a process called dehydration synthesis.

<table>
<thead>
<tr>
<th>Word Breakdown</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Dehydration</strong></td>
</tr>
<tr>
<td><strong>Synthesis</strong></td>
</tr>
</tbody>
</table>

Dehydration Synthesis

removal of water molecule (dehydration)

molecule 1 + molecule 2

new molecule is formed (synthesis)
Part of the process of chemical evolution was that molecules had to react together and then form new molecules.

Reacting together also involved breaking molecules apart.

This process is called **Hydrolysis**.

Hydro (water)

Lysis (splitting)

**Hydrolysis**

Addition of water molecule splits into 2 new molecules

Dehydration Synthesis & Hydrolysis

**Dehydration Synthesis**

Monomer + Monomer → Polymer + Water

**Hydrolysis**

Polymer + Water → Monomer + Monomer
19. The following equation is an example of:

- A. dehydration synthesis
- B. hydrolysis

\[ C_5H_{12} + H_2O \rightarrow C_3H_7OH + C_2H_6 \]

20. The following equation is an example of:

- A. dehydration synthesis
- B. hydrolysis

\[ C_8H_{12} + C_3H_7OH \rightarrow C_8H_{16} + H_2O \]
20 The following equation is an example of:

- A dehydration synthesis
- B hydrolysis

\[ C_8H_{18} + C_3H_7OH \rightarrow C_8H_{12} + H_2O \]

Answer: A

21 Which is true about dehydration synthesis?

- A one monomer loses a hydrogen atom, the other loses a hydroxyl group
- B electrons are shared between the joined monomers
- C water is formed when monomers join
- D covalent bonds are formed between monomers
- E all of the above are true

Answer: E
22 The results of dehydration synthesis can be reversed by:

- A condensation
- B hydrolysis
- C polymerization
- D adding an amino group

23 The products of dehydration synthesis are:

- A two monomers
- B a polymer and water
- C two polymers
- D a hydroxyl group and a H atom
23 The products of dehydration synthesis are:

- A two monomers
- B a polymer and water
- C two polymers
- D a hydroxyl group

**Answer:** B

24 The products of hydrolysis are:

- A two monomers
- B a polymer and water
- C two polymers
- D a hydroxyl group and a H atom

**Answer:** A
**Phospholipids, RNA**

**Phospholipids** are molecules whose opposite ends are very different:

- One end is polar and can form hydrogen bonds with water
- The other end is non-polar and cannot form hydrogen bonds

As a result, the polar end is **hydrophilic** (attracted to water) and the non-polar end is **hydrophobic** (repelled by water).

When phospholipids are placed in water, they move so that their hydrophilic ends are in contact with water and their hydrophobic ends are isolated from the water.
Phospholipids Created Membranes

Lipids formed, naturally creating membranes which led to primitive cells: isolated chemical environments

Click for an animation of phospholipid membrane

Primitive Cells

Membranes

The result is that phospholipids naturally form membrane surfaces that enclose a volume of space

Membranes are an arrangement of phospholipids that gather together and make a closed shape.

Membranes act as a wall or a barrier separating the outside and the inside of the closed shape.
Macromolecules

Within the enclosed environment, the processes of chemistry would create even more complex molecules such as:

- Proteins
- Carbohydrates
- Lipids
- Nucleic Acids

25 Phospholipids contain both a _______ head and a _______ tail section.

- A hydrophobic, hydrophilic
- B hydrophilic, hydrophobic
- C hydrophobic, hydrophobic
- D hydrophilic, hydrophilic

Answer: B
26 Liposomes and micelles can both occur naturally when phospholipids interact with water. Distinguish between these two structures.

- A In liposomes, phospholipid tails are on the outer surface of the structure.
- B In micelles, the phospholipids form a single layer.
- C Micelles contain an aqueous interior.
- D Liposomes are formed by a monolayer.

27 The creation of membranes from phospholipids provided an enclosed space in which chemical reactions could occur. Which of the did not occur within these primitive cells?

- A RNA synthesis
- B Replication
- C Creation of new elements
- D Production of proteins
27 The creation of membranes from phospholipids provided an enclosed space in which chemical reactions could occur. Which of the did not occur within these primitive cells?

- A RNA synthesis
- B Replication
- C Creation of new elements
- D Production of proteins

Answer: C

The chemical reactions in these cells would eventually create sugars, and then Ribonucleic Acid (RNA). RNA is capable of some of the key functions enabling life:

- **Replication**: making identical copies of itself
- **Metabolism**: storing energy for chemical reactions
- **Catalyzation**: dramatically speeding up favored chemical reactions

Once these three functions were developed, evolution accelerated.

**RNA in Later Cells**

In more advanced biological systems, RNA's functions have been taken over by more specific chemical processes

- **Replication**: DNA is more effective at storage of genetic information
- **Metabolism**: ATP now stores energy in our cells
- **Catalyzation**: Proteins now catalyze reactions

*RNA's role as the predecessor of these has only recently been discovered.*
28 Metabolism is a very important characteristic of life. What molecule replaced RNA as the energy storage molecule in most living organisms?

- DNA
- ATP
- Proteins
- Sugars

29 Which molecule is currently responsible for lowering the activation energy of most biochemical reactions?

- DNA
- RNA
- ATP
- Proteins
29 Which molecule is currently responsible for lowering the activation energy of most biochemical reactions?

- DNA
- RNA
- ATP
- Proteins

Answer: D

30 Discuss at your table:

How does the development of replication, metabolism, and catalyzation accelerate the evolution of different forms of life?

LUCA, Characteristics of Life
Cells became ever more complex until they included all the large biological molecules, including both RNA and DNA and the enzymes needed to maintain and use them. This led to what is called Last Universal Common Ancestor (LUCA), the organism from which all life on Earth descended.

The common features of life on Earth are so profound that all life must have evolved from a single ancestor.

"A universal common ancestor is at least $10^{2860}$ times more probable than having multiple ancestors…“

Saey, Tina (5 June 2010). "Life has common ancestral source". Science News 177 (12): 12. doi:10.1038/465168a

Some of the common features of all life on Earth that make a universal ancestor a logical necessity.

ALL LIFE on Earth uses the IDENTICAL:

- Universal Genetic code
- ATP as the "currency" of energy
- Bases for DNA and RNA
- Lipid bilayer cell membranes
- Amino acids for proteins
- Cellular division
- DNA and RNA polymerases
- ATP Synthase
- mRNA
- Sodium and Potassium ion pumps
- tRNA
- L-isomers of amino acids
- Ribosomes
- Glucose as an energy source

AND MUCH MORE.....
ALL LIFE, from the smallest amoeba, to the largest redwood tree, share the features listed on the prior slide.

None of these features of life on Earth had to be exactly this way. There were alternative ways to solve each problem.

The only reasonable explanation that ALL LIFE uses the exact same molecular features is that those features were in place before life branched out.

They would not have been shared if they were developed independently at a later time.

Life on Earth

LUCA (3.5 - 3.8 BYA)
31. Evidence for a last universal common ancestor among life on Earth is:
   - A. they all have the same synthesis pattern
   - B. they share the same underlying molecular biology
   - C. they all look the same
   - D. they all breathe oxygen

   Answer: B

32. According to the cladogram of life on Earth, LUCA arose ________ billion years ago and is most closely related to ________________
   - A. 3.6; eukaryotes
   - B. 3.6; bacteria
   - C. 4.6; bacteria
   - D. 4.6; archaea
32. According to the cladogram of life on Earth, LUCA arose ______ billion years ago and is most closely related to _______.

- A 3.6; eukaryotes
- B 3.6; bacteria
- C 4.6; bacteria
- D 4.6; archaea

Answer: B

Characteristics of Life

It's important to have a definition for what is "life" and what is not. These are the properties used to define something as being alive.

- Organization/Order
- Adaptations
- Response to the environment
- Regulation
- Energy processing
- Growth and Development
- Reproduction

Order

All life is organized into fundamental units called **Cells**

Cell:
- a membrane bound structure containing organic molecules.
- They are microscopic in size.

Cells are the smallest unit that can be considered a life form, therefore they are referred to as "the building blocks of life"
Adaptation

All living organisms must be able to adapt to their changing environment.

It is not an individual organism that adapts. It is the passing of naturally selected traits to offspring that drives this change.

33 The smallest unit which can be considered life is called _________.
   - A a prokaryote
   - B a LUCA
   - C a cell
   - D a phospholipid

Answer: C
**Response to the Environment**

Living organisms must be able to recognize their surroundings and respond to them.

For instance, moving away from something hot.

Or moving towards something that is nutritious.

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**Regulation**

Living organisms must be able to regulate their internal conditions. This is called maintaining homeostasis.

They must be able to keep their internal systems separate and different from the external environment.

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**Homeostasis in Humans**

Humans must maintain certain constant conditions inside their bodies even when things change in their environment.

- Body Temp $= 37 \, ^\circ C$
- Blood Ph $= 7.4$
- Blood Pressure $= 100 \, mmHg$
- Blood Sugar $= 0.1\%$
- Water Content $= 40 \, liters$
34 Quickly pulling your hand off a hot stove is considered a
   - A Regulation
   - B Response to the environment
   - C Homeostasis
   - D any of these are correct

   Answer: B

35 Which is true regarding fever in humans?
   - A The sick individual is failing to maintain homeostasis
   - B The body is regulating it's internal conditions
   - C The individual is responding to its external environment
   - D The sick individual is temporarily lacking a characteristic of life
35 Which is true regarding fever in humans?

- A The sick individual is failing to maintain homeostasis
- B The body is regulating its internal conditions
- C The individual is responding to its external environment
- D The sick individual is temporarily lacking a characteristic of life

Answer: B

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**Energy Processing**

All living things require energy to carry out the functions of life. They must be able to obtain energy and process it to be used in their biological functions.

Animals process food (chemical energy) and convert it into matter and work (mechanical energy). Some bacteria and all plants can convert light energy into chemical energy.

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**Growth and Development**

A living organism is born from a parent generation and eventually develops into a mature form.

At maturity, organisms are capable of producing their own offspring. A life cycle is a series of stages through which an organism passes.
Reproduction

Living things must be able to pass on their traits to future generations of organisms.

This creation of offspring can be asexual (single organisms reproducing on their own) or sexual (requiring the mixing of genetic material).

36 A living organism must be able to pass on traits to future generations.

☐ True
☐ False

36 A living organism must be able to pass on traits to future generations.

Answer: TRUE
37 Homeostasis is the regulation of which environment of an organism?
- A external
- B internal

Answer: B

38 Asexual reproduction refers to
- A puberty
- B sexual maturity
- C an organism reproducing on its own
- D genetic recombination between two different organisms
38 Asexual reproduction refers to
A puberty
B sexual maturity
C an organism reproducing on its own
D genetic recombination between two different organisms.
Answer: C

39 All organisms can convert energy from the sun into chemical energy.
True
False

Slide 119 (Answer) / 120
Answer: FALSE