Origins of Life

Early Universe, Early Earth

Class Work
1. How old is the Universe?
2. How old is the Earth?
3. In what ways is the atmosphere of the Earth different from the gaseous consistency of the early universe?
4. "We are all made of stars" may actually be a true statement. Explain how you, your classmates, and your natural surroundings are composed of once galactic matter.
5. When we refer to elements as ‘heavy’ or ‘light’ elements, how do we determine this characteristic?
6. Why is it significant for life on Earth that hydrogen and helium can attain a high velocity?
7. Why is the periodic table we use today different from the periodic table that would have existed at the dawn of the universe?
8. Where can helium still be found on Earth?
9. If the existence of planet Earth were represented by an hour on a clock, human life has existed for much less than a second. What important concept of the creation of life on Earth does this metaphor demonstrate?

Homework
10. Which is older the Earth or the Universe? By how much?
11. Considering what you know about UV radiation and the consistency of early Earth’s atmosphere, why would it be difficult for you to survive on our planet in its first billion years of existence?
12. What cosmic events triggered the release of heavier elements (elements other than hydrogen or helium) into the universe?
13. Taking into account the atomic mass of Helium and Hydrogen, explain why these gases tend to escape Earth’s atmosphere relatively well.
14. The reason we wear sunscreen today is one of the conditions that life needed to overcome on early Earth. Explain this logic.
15. Where can hydrogen still be found on Earth?
16. What is the significance of the 56,000,000 lifetimes for the relationship between human life and planet Earth?
17. If life expectancy had not reached 72 years, how would 56,000,000 lifetimes have to be adjusted for accuracy?

Water

Class Work
18. How did the cooling of the Earth influence the presence of liquid water on its surface?
19. A water molecule may be accurately compared to a magnet. Explain the properties that a water molecule and magnet share.
20. Draw a water molecule and identify the charges that exist on the molecule.
21. Hydrogen bonds are a large part of the reason that water can exist in three states on our planet. Briefly explain why this is true. (Hint: distance between atoms)
22. Explain the three properties of water (due to its polarity) that allowed life to emerge on Earth.
Homework
23. Explain the role that the larger nucleus of an oxygen atom plays in creating the polarity of a water molecule.
24. One property of water is that it has a high heat capacity. This means that it takes a lot of energy to change the temperature of water by a small amount. What role do you think hydrogen bonds may play in this property?
25. What is the difference between a hydrogen bond and a covalent bond?
27. The presence of liquid water on Earth is extremely important for its ability to moderate living conditions on the planet. Why is this ability important for life on Earth?
28. Compare and contrast cohesion and adhesion.

Organic Monomers
Class Work
29. Briefly explain the relationship between monomers and polymers.
30. Briefly explain the two theorized sources of origin of life on Earth.
31. How could the increasing thickness of the Earth’s atmosphere have allowed for the arrival of basic organic molecules from space?
32. Why was the presence of micromolecules a requirement for synthesizing organic molecules on early Earth?
33. Why was it significant that Stanley Miller’s experiment inserted specific gases into the model? What did these gases represent?
34. Stanley Miller’s model ultimately produced a collection of organic molecules. What did the synthesis of these organic molecules prove?
35. What atmospheric component was absent in early Earth’s atmosphere that is critical to our survival? Why is it important that it was absent during this time?
36. Suppose a planet in a neighboring solar system has been discovered that has all of the same characteristics of early Earth except for the presence of micromolecules. Do you predict that life could arise on this planet? Why or why not?

Homework
37. What are the individual units that comprise polymers called?
38. What is a piece of evidence that supports organic monomers coming from space?
39. Why did Miller include a condenser in his experiment? What did the condenser represent in his model?
40. Why did Stanley Miller decide to heat the water in the “primeval sea” section of his model?
41. How would an early atmosphere consisting of oxygen change the results of Stanley Miller’s experiment?
42. Suppose Miller’s model did not produce amino acids. How would this result have impacted the development of theories for the origin of life on Earth?
43. Some scientists refer to early Earth’s ocean as a ‘primordial soup.’ Explain why this metaphor may have originated.

Dehydration Synthesis, Hydrolysis
Class Work
44. What does the word synthesis mean?
45. Compare and contrast the processes of dehydration synthesis and hydrolysis. Be sure to include the role of water in these processes.
46. What role does dehydration synthesis play in the creation of advanced organic molecules?
47. What are the products of hydrolysis?
48. The following is what type of reaction: \( \text{C}_2\text{H}_5\text{OH} + \text{C}_2\text{H}_6 \rightarrow \text{C}_4\text{H}_{10} + \text{H}_2\text{O} \)
49. Suppose you were stranded on a desert island with no food or water. You are allowed to choose a machine that conducts either dehydration synthesis or hydrolysis for your utilization. Which do you choose and why?

Homework

50. What does the word lysis mean?
51. Would you use hydrolysis or dehydration synthesis to break a larger molecule into two smaller molecules? Support your answer.
52. Polymers can be broken down into two new molecules through what process?
53. What are the reactants in a hydrolysis reaction?
54. The following is what type of reaction: \( \text{C}_6\text{H}_{14} + \text{H}_2\text{O} \rightarrow \text{C}_5\text{H}_{11}\text{OH} + \text{CH}_4 \)

**Phospholipids**

Class Work

55. What does hydrophobic mean?
56. When in the presence of water, how does a phospholipid orient itself? What property of water initiates this reaction?
57. Phospholipid arrangements on early Earth are most accurately comparable to which of the following:
   a. Battery
   b. Tunnel
   c. Bubble
   Briefly explain your answer.
58. What relationship exists between phospholipids and cell membranes?
59. Compare a phospholipid bilayer to a beaker in chemistry class. What role to these two objects have in common, though obviously at a different scale.
60. Within early cells, what more complex molecules were able to form?
61. In baseball terminology, a “5-tool player” is a player who can execute 5 skills extremely well. RNA may be described as a “3-tool” molecule. Explain this comparison and identify the “3 tools.”
62. Why is it significant that RNA can accomplish the three specific tasks you identified in the previous question?

Homework

63. What does hydrophilic mean?
64. What characteristic of phospholipids causes them to always orient themselves in the same direction?
65. The special alignment of phospholipids in an aqueous environment led to the formation of what?
66. What role do phospholipids play in the creation of protobionts?
67. Briefly explain why the emergence of phospholipids may have allowed for the creation of more advanced organic polymers.
68. Why is the development of molecules such as nucleic acids, carbohydrates and lipids important for the development of life on Earth?
69. Suppose RNA had not developed at the time it had on Earth. How may have this influenced the further development of life? Support your answer.
70. How have DNA, ATP and proteins replaced RNA in more complex biological systems?

**LUCA, Characteristics of Life**

**Class Work**
71. The letter ‘U’ in “LUCA” represents the word ‘universal.’ Explain the significance of this word when analyzing the meaning of this term.
72. Why does all life on Earth share much of the same metabolic processes?
73. Humans, trees and insects all share the same mRNA, phospholipid bilayer structure, molecular energy and genetic code. Briefly justify how we use the “LUCA” principle to explain these commonalities.
74. Would a “LUCA” more closely resemble a bacterial cell or a eukaryotic cell? Why?
75. List the seven properties that we use to define “life.”
76. The cheetah is a species that has developed small ears, large nostrils, non-retractable claws and a long, sturdy tail over many generations. Which characteristic of living organisms does the development of these characteristics satisfy?
77. Homoeostasis is the maintenance of stable internal conditions regardless of the external environment. Provide an example of how a seal demonstrates homeostasis considering its environmental features.
78. A planarian moving towards a light source (phototaxis) is an example what characteristic of living organisms?
79. Suppose you are a NASA scientist, and a space probe returns with an object of unknown origin. Describe two tests you would use to help determine if the object could be considered living.

**Homework**
80. Explain, in terms of statistics, why shared metabolic processes throughout the domains of life support the theory of a common ancestry.
81. Explain the relationship between the three major domains of life (Archaea, Bacteria, Eucaryota) and LUCA.
82. Why is it highly unlikely that the existing branches of life evolved from multiple origins?
83. Why is it important for scientists to establish characteristics of living organisms?
84. A bacterium budding (binary fission) and a pine tree producing pollen are both examples of what process that is part of the criteria of life?
85. How would plants conducting photosynthesis represent a characteristic of life?
86. Explain how you as a human being meet all the criteria for life.
Free Response

1. Dry air from Earth’s atmosphere contains 78.08% nitrogen, 20.95% oxygen, 0.93% argon, and 0.038% carbon dioxide, but only traces of hydrogen and helium gases.
   a. The formula for kinetic energy is KE = 1/2mv^2. Explain, based upon this, why hydrogen and helium gases have escaped the Earth’s atmosphere, but nitrogen and carbon dioxide gases remain.
   b. Hydrogen gas is used to fuel rockets, and helium is used to fill balloons. How do scientists and manufacturers obtain these gases?

2. Scientists, such as Stanley Miller, have conducted important experiments to determine the origins of life on Earth.
   a. Describe the setup of Miller’s experiment and the results.
   b. What was the significance of his results?

3. Chemical reactions are important for the synthesis and recycling the organic matter. Explain each of the following types of reactions and give an example.
   a. dehydration synthesis
   b. hydrolysis

4. The concept of a LUCA reflects a theory about the ancestry of life on earth that is supported by vast amounts of evidence throughout time.
   a. What does LUCA stand for?
   b. What is the main idea of LUCA?
   c. Provide at least 5 pieces of evidence supporting the existence of LUCA.

5. Production of phospholipid molecules is considered to be one of the critical steps toward the development of life.
   a. Describe the structure of phospholipid molecules.
   b. Explain how the structure of individual phospholipid molecules results in membranes.
   c. Why is the development of membranes considered an important step in the emergence of life on earth?

6. In very early cells, RNA played distinct roles that allowed for the key processes of life.
   a. Describe two of these roles.
   b. Name the macromolecule that currently performs this function.
Origins of Life
Answer Key

1. 14 billion years old
2. 4.6 billion years old
3. Hydrogen & Helium escaped long ago, and there was no Oxygen present in early Earth atmosphere either
4. No new elements have been created since Earth was formed, so all matter on Earth has been created from recycling the original elements
5. By the atomic mass of the element
6. By escaping as gases, Hydrogen and Helium allow the Earth’s atmosphere to be much more compatible for sustaining life.
7. The periodic table at the dawn of the universe would not have included all of the heavier elements that exist on Earth today.
8. On Earth the majority of helium found comes from radioactive decay.
9. This demonstrates that the Earth has been here for an extremely long time, and life has taken an extremely long time to develop to the point it is today. The amount of time that the human race has been in existence is infinitesimally short when considered in these terms.
10. The universe is older by 10 billion years
11. Earth’s early atmosphere was much more volatile than it is today. It was also subject to much higher levels of UV radiation, which is hazardous and can be a mutagen. These conditions would make it much more difficult for complex life as we know it to exist.
12. The explosion of stars, or supernovae, expelled heavier elements into the universe.
13. The lower the mass, the higher the velocity. Hydrogen and Helium have the lowest masses (Atomic mass 1 and 2, respectively), and thus can attain a high enough velocity to escape Earth’s atmosphere.
14. We wear sunscreen to protect our skin from ultraviolet radiation, which can damage our cells and promote mutations of DNA. For the first few billion years on Earth, the levels of ultraviolet radiation were much higher than they are today, and would have been inhibitive for the creation of life.
15. On Earth, hydrogen is found in combination with other elements such as carbon (hydrocarbons), oxygen (water) and nitrogen (ammonia).
16. 56 million lifetimes, with a life expectancy of 72 years, is the length of time that life has been developing on Earth.
17. The number would have to be increased, because it would require more lifetimes to equal the amount of time life had been developing.
18. The cooling of Earth caused some of the water vapor in the atmosphere to condense into liquid water.
19. Due to its polarity, a water molecule has charges on opposite ends, just as a magnet does.
20. Water molecule – should have polarity/electronegativity noted
21. The presence of hydrogen bonds between molecules of water pushes the molecules further apart, which ultimately decreases the density of water as it reaches its freezing point. Water as a gas has little, if any hydrogen bonds formed, as the molecules move freely and are not condensed. The presence or absence of hydrogen bonds has a large impact on the state of water.
22. Ability to moderate temperature, versatility as a solvent, and cohesive behavior.
23. The larger nucleus of oxygen exerts a stronger pull on the shared electrons in a water molecule, creating the partial negative charge on the oxygen atom and partial positive on the hydrogen atoms, resulting in the polarity.
24. In order to change the temperature of water, bonds must be formed or broken. The substantial energy input required to form or break these bonds results in the high heat capacity.
25. A hydrogen bond is a weak attraction between atoms as a result of slight charges, a covalent bond is the actual sharing of electrons between atoms.
26. Not in this case. Hydrogen bonds exist because of the partial charges that are created through polarity.
27. The presence of liquid water on Earth prevents massive temperature swings and allows organisms to adapt to relatively stable living conditions.
28. Adhesion is the joining of unlike particles such as water and your body. Cohesion is the joining of like particles such as water and water.
29. Monomers are the building blocks of polymers. Multiple monomers are bonded to create a polymer.
30. 1. Organic monomers arrived on meteorites from space
    2. Chemical processes on Earth created organic monomers
31. The thickness of the Earth’s atmosphere could have slowed the meteorites as they arrived in the atmosphere, allowing organic molecules they carried to land on Earth without being destroyed.
32. Micromolecules provided the raw material from which organic molecules eventually arose.
33. The gases (NH3, CH4, H2O, CO2, N2, H2) Miller included were the gases that are believed to have been present in the Earth’s atmosphere at the time. Again, Miller is trying to replicate the conditions of early Earth as best he can.
34. The creation of these organic molecules proved that the conditions on early Earth could have potentially spontaneously generated more complex organic molecules, which would become the precursors for life on Earth.
35. Oxygen was absent in early Earth’s atmosphere. Oxygen tends to break molecular bonds, and thus would have prevented the creation of organic molecules had it existed in the quantity it does today.
36. Highly unlikely. Micromolecules are the raw materials necessary for the development of higher level organic molecules. Without them, the
generation of polymers and eventually living organisms would be impossible.

37. Monomers
38. Meteorites; Fossils; Comets; Soil
39. The condenser cooled the water vapor and other molecules and caused them to precipitate into the collection area at the bottom of the model. This represented rain.
40. Miller was attempting to replicate the conditions of primeval Earth as best he could, which involved a much warmer, volatile ocean than exists today.
41. This presents the hypothesis that perhaps the ingredients necessary for life were brought from outer space.
42. The experiment would have to be modified or the theory would have to be discarded. The results would not have supported the hypothesis that life could have originated from spontaneous chemical reactions on early Earth.
43. As chemical processes continued in the atmosphere and organic monomers fell into the ocean, they would react and combine with other monomers and compounds, resulting in a solution full of a variety of organic and inorganic monomers and polymers, similar to the contents of a bowl of soup.
44. The combination of ideas to form a theory or system.
45. Dehydration synthesis is the creation of a polymer from two monomers joining and subsequently releasing a water molecule. Hydrolysis is the breaking of a polymer into two monomers in the presence of water.
46. Dehydration synthesis bonds two simpler molecules together to produce H2O and a more complex organic molecule.
47. Glucose and Fructose
48. Combustion
49. Dehydration synthesis would benefit you because one of the products of the reaction is water molecules.
50. The disintegration of a cell by rupture of the cell wall or membrane.
51. Hydrolysis. Hydrolysis breaks bonds, synthesis creates bonds.
52. Hydrolysis
53. Water and a polymer
54. Hydrolysis Reaction
55. Water fearing
56. The polar end of a phospholipid is polar, and will thus always be oriented towards the water molecules. The polarity of water is what causes this reaction.
57. C, Bubble. The nature of phospholipids causes them to always orient in the same direction, in some cases creating a sphere, very similar in structure to a bubble.
58. Cell membranes are created by arrangements of phospholipids.
59. A phospholipid bilayer creates an isolated internal environment in which reactions can occur without interference from the environment, just as a beaker provides an area where chemicals are mixed to initiate and observe reactions.

60. Carbon

61. RNA is a molecule with multiple functions including: replication, metabolism, catalyzation

62. Hydrophilic means that something has a tendency to dissolve in or mix with water.

63. Phospholipids have hydrophobic (non-polar) tails and hydrophilic (polar) heads, which causes them to always align consistently in the presence of water.

64. LUCA, Characteristics of life.

65. Phospholipids created a secluded environment which protected organic molecules from potentially corrosive surroundings, and may have allowed for further chemical reactions to occur, creating more advanced molecules and leading to the chemical processes that characterize life.

66. The phospholipids provide the secure environment in which reactions could occur that led to the creation of more advanced organic polymers.

67. These molecules are identified as the molecules that are necessary for the processes of life, as we know it.

68. This could have theoretically delayed the development of life until another molecule (or molecules) developed that could accomplish the tasks that RNA did.

69. Each of these molecules accomplishes a specific task more efficiently than RNA, though RNA is capable of accomplishing these tasks.

DNA-Replication
ATP-Metabolism
Proteins-Catalyzation

70. “Last Universal Common Ancestor”. The word universal implies that all life on Earth originated from this first living thing. Regardless of how simple or complex, all organisms can be traced back to this first ancestor.

71. Because all life on Earth developed from one common ancestor that had developed these metabolic processes.

72. All these organisms share these molecules because they arose from the same ancestor billions of years ago.

73. A prokaryotic cell. Prokaryotes are much more primitive and more closely resemble the first living cells


75. These characteristics demonstrate adaptations that have been developed by this species over time.
76. A seal, being warm blooded, must maintain a stable internal body temperature regardless of the external environment. Its blubber, hair, lack of external ears, control of heart rate and other characteristics allow it to maintain suitable body temperature, thus exhibiting homeostasis.

77. Stimulus response.

78. Multiple answers may be suitable here. The tests should demonstrate whether the object demonstrates the characteristics defined as those exhibited by living organisms. For example, the ability to move should not be tested.

79. It is statistically improbable (basically impossible) that the metabolic processes that exist in all forms of life would have arisen in so many different places at different times. Statistically, it is exponentially more likely that these processes evolved at one time, and were then carried through different branches of evolution.

80. Each of these major groups of life has developed from the same common ancestor.

81. The statistical probability of the metabolic processes shared by all living organisms developing through different ancestors, at different times is almost impossibly low.

82. Guidelines for living organisms are necessary for scientists to study how life itself evolved, how to categorize life, and for us to understand the universe and each organism’s place in it.

83. Reproduction.

84. Photosynthesis is the chemical reaction through which light energy is converted into chemical energy. This is an example of metabolism, and the subsequent conversion of the chemical energy into ATP is the basic metabolic process of most life on Earth.

85. Human life has all seven characteristics of life. We have order because we are made of cells. We reproduce, we develop into adults, we respond to our environment. We process energy when we eat and we use this energy to regulate our internal environments but keeping set temperature, pH, etc. As a species we adapt to our environments.

Free Response: Answer Key

1. The kinetic energy of the gases is the same as the temperature. Because the temperature was the same for all of the gases, their KE was the same. This means that the equation can be changed to reflect velocity, \( v = \sqrt{2KE/m} \). Therefore, the lighter the atoms/molecules (less mass) the higher the velocity. Very light gases such as helium and hydrogen were able to escape the earth’s gravity due to their extremely high velocity.
   a. Hydrogen gas is obtained from the splitting water molecules.
   Helium is obtained from underground stores.

2. Stanley Miller’s experiment sought to replicate the environment of early Earth by replicating the primeval sea, lightning, Earth’s early atmosphere,
and rain. His experiment produced some of the 20 amino acids that exist today as well as other organic molecules.

a. The results support the idea that the organic molecules on Earth could have been derived from chemical reactions on early Earth.

3. Dehydration synthesis is the joining of two monomers to form a water molecule and a polymer. In the process of dehydration synthesis, one monomer loses a hydroxyl group and the other loses a hydrogen atom.

Ex. CH₄ + CH₃OH → C₂H₆ + H₂O (answers will vary)

a. Hydrolysis is the breaking down of a monomer to form two polymers through the addition of a water molecule. C₂H₆ + H₂O → CH₄ + CH₃OH (answers will vary)

4. The acronym LUCA stands for “last universal common ancestor”.

a. The main idea of LUCA is that there is one common ancestor that existed upon which all subsequent life developed.

b. Pieces of evidence: Universal genetic code, ATP, DNA and RNA, lipid bilayer cell membranes, amino acids, cellular division, DNA and RNA polymerases, ATP synthase, mRNA, sodium/potassium ion pumps, tRNA, L-isomers of amino acids, ribosomes, and glucose for energy (answers will vary)

5. Phospholipid molecules consist of a phosphate “head” and lipid “tail”. The phosphate is hydrophilic, which means to can exist in a water environment (attracted to water). The lipid tails of these molecules are hydrophobic (repelled by water).

a. Because of a hydrophilic head and a hydrophobic tail, phospholipid molecules tend to orient themselves either in a single layer (with their heads towards a water environment and their tails towards a non-water environment) or in a bilayer (two layers). In a bilayer the heads of the double molecules oriented “out” while the tails orient “in”. This produces two environments: one inside (internal) and one outside (external).

b. Membranes are important because they allow for a situation where there can be a managed internal environment, separate from an external environment. Chemical reactions can take place inside a membrane, which can lead to changes over time.

6. Metabolism: RNA stored energy for chemical reactions; reproduction: RNA allowed for making identical copies; catalyzation: RNA greatly increased the speed of chemical reactions (answers will vary)

a. Metabolism: ATP; reproduction: DNA; catalyzation: proteins