Study Questions for
Creating Life in the Lab, by Fazale Rana, PhD

Chapter 1:

1. Do scientists have a clear definition of what life is? p. 14
   No

2. What is biochemistry? How would you describe the work of biochemists? p. 14
   The study of the structural and transformational qualities of molecules (proteins, DNA, RNA, carbohydrates, and fats) essential to life, how they undergo change when reacting with each other, and how they chemically react to higher-order biological structures and processes

3. What are Dr. Rana’s “big three” questions about biological life? p. 14
   What is life?
   How does life operate at its most fundamental level?
   How did life begin?

4. Which of Dr. Rana’s questions have been mostly answered, and which ones remain unanswered? p. 15
   “How does life operate at its most fundamental level?” has been answered, for the most part.
   “What is life” and “How did life begin” remain substantially unanswered.

5. What are the three main approaches scientists pursue to identify pathways that could lead to life’s origin? p. 17
   1. Bottom-up strategy: uses lab techniques to identify pathways that could lead to the formation of biologically important compounds from materials present on early Earth
   2. Top-down approach: starts with life as it exists today and works backward to determine what first life must have been like long ago
   3. Constructing life “from scratch” in the lab

6. What is the main objective of most origin-of-life efforts? pp. 17-18
   To shed light onto the pathways that led to life’s origin. Most scientists’ expressed hope is to provide validation that life can emerge from nonlife [by natural processes alone].

7. It is simply “good science” to look for natural causes wherever possible?
   Scientists continue to make progress in finding natural causes.

8. Do you think that “natural” causes require an explanation for their existence?

9. Do you think that “natural” causes are sufficient to explain life, or does the evidence indicate the necessity of creative, intelligent, intentional power beyond “natural” causes?

10. If intelligent scientists must carefully plan their designs for creating life in the lab, what do you think this fact implies for the origin of life in nature?
Chapter 2:

1. Typing *the miracle of life* into a search engine produces over 1,000 results. Why do you think this topic holds such wide interest?

2. How does the existence of information-rich systems such as DNA, protein creation, and cell division impact the debate between naturalists and those who believe in divine design?
   
The answer depends critically on how the argument for design is presented. Too often ID proponents misstate or misrepresent the core argument. So handle with care!

3. What three tenets apply to all living entities? pp. 25-26
   1. Life is made up of atoms combined to form molecules.
   2. Life is made up of cells.
   3. Life obeys the laws of chemistry and physics.

   1. Life is organized.
   2. Life is chemically distinct from its environment.
   3. Life is homeostatic (staying the same—maintaining its chemical distinction).
   4. Life takes energy and matter from the environment and transforms them.
   5. Life responds to stimuli from the environment.
   6. Life reproduces.
   7. Life is adapted to its environment.
   8. Life evolves.

5. By what mechanism can organisms evolve [change with respect to time]? p. 29
   Through mutations in their genetic material

6. Are mutations that create new biochemical and biological traits common or rare? p. 29
   Rare

7. Are new traits that are *beneficial* to the organism common or rare? p. 29
   Rare

8. What terms are used to identify different kinds of evolutionary change? pp. 29-30
   In a single cell organism such as viruses, bacteria, archaea, and single-celled eukaryotes: *microbial evolution*
   Within a species: *microevolution*
   From one species to another closely related sister species: *speciation*
   Large-scale transformations, such as whales from raccoon-like creatures or birds from dinosaurs: *macroevolution*

9. Which level of evolutionary change remains controversial?
   *Macroevolution*

    By leading researchers to a better understanding of how life differs from inanimate matter

11. Why is an agreed-upon definition of life important? pp. 30-31
    1. In order to understand how life might have emerged from non-living systems.
    2. In order to search for life beyond Earth that may exist there in a very different form from Earth life.
    3. In order to identify life created in the lab.
Chapter 3:

1. What four major steps has Craig Ventner's organization employed in generating a non-natural life form?  p. 35
   1. Systematically eliminating genes from a genome to identify the essential genes;
   2. Synthesizing the minimal genome from scratch, starting with nucleotides;
   3. Introducing the minimal genome into the cytoplasm of a cell that has had its original genome deleted;
   4. Initiating the growth and replication of the organism that harbors the synthetic the synthetic genome.

2. How do you think advances in synthetic biology might benefit society?

3. What potential dangers do you see, or not see, in the advances of synthetic biology?

4. What test must a minimal genome pass?  p. 35
   It must grow and reproduce itself.

5. How does Ventner's team hope to produce useful and potentially commercial results from their work?  p. 36
   By adding different genes to the minimal genome to produce a variety of beneficial artificial microbes that do not appear in nature.

6. To what extent does Ventner's team use living natural components in their process of producing “synthetic” life?  p. 46
   Total

7. What is the primary ingredient required for creating synthetic life?  pp. 36 and 47
   Intelligence

8. What do the answers to questions 6 and 7 suggest about the origin of life?

9. How many genes does minimal life require?  p. 47
   Hundreds

10. How does the complexity of basic life forms impact the likelihood that life arose without the intervention of a Creator?  p. 47

11. In addition to remarkable complexity of life’s structural components, what evidence do you see (or not see) of intentionality and design in the processes that sustain life and enable it to reproduce?

12. Would you argue that the complex structure and processes alone are sufficient to produce life, or do other influences seem necessary?  If so, how would you describe such influences?

13. Christians and many scholarly atheists agree that in order for life to have ultimate meaning and purpose that there must be a Creator with whom we can have an eternal relationship, and that without such a relationship, any meaning and purpose is either temporal or arbitrary or both.  What evidence do you see (or not see) that life on Earth is essentially relational?  What implications does your answer hold for the existence of a Creator God?
Chapter 4:

1. What biochemical reengineering activities form the basis of the biotech industry?  p. 50
   Isolating a single gene from one organism and adding it to the genome of a microbe to enable it to engage in biochemical activities that are unnatural for it

2. How many amino acids are specified by the natural genetic code?  p. 62
   Twenty

3. How many novel amino acids are contained in various proteins?  p. 62
   Well over 100

4. What process generates novel amino acids from the 20 basic amino acids?  p. 62
   Posttranslational modification

5. Have synthetic biologists and biochemists made proteins with genetic codes that specify more than 20 amino acids?  p. 62
   Yes

6. Why produce proteins with more than 20 amino acids in their genetic code?  p. 62
   To enable modified microbes to reproduce

7. What evidence do “naturalist” scientists use to argue against intelligent design?  pp. 63-64
   Numerous examples of microbes that appear to have spontaneously undergone changes that impart new metabolic capabilities.

8. Dr. Rana describes the universal genetic code as clearly “optimized.” Do most researchers agree with this depiction?  p. 67
   Yes

9. What evidence do you see (or not see) of intentionality and design in the universal genetic code?

10. What evidence do “naturalist” scientists cite in arguing for the undirected (spontaneous) evolution of the “optimized design” of the genetic code?  p. 67
    The existence of non-universal genetic codes

11. Do non-universal genetic codes exist in general or special circumstances?  p. 68
    Special circumstances

12. What does Dr. Rana say about the time required to produce the “optimized” universal genetic code researchers observe?  p. 68
    The time required for such evolution to occur exceeds the time available in Earth’s history.
Chapter 5:

1. When scientists succeed in creating artificial cells, what claims about God’s role in bringing life into existence can we anticipate from naturalists (nontheists)? from Christians?

2. How does Jack Szostak’s approach to creating artificial life forms differ from Craig Ventner’s top-down approach? p. 71
   - Szostak begins with simple chemicals and looks for ways to combine them into increasingly complex supramolecular entities that serve as models for simple cells.

3. What are Szostak’s supramolecular entities called? p. 71
   - Protocells

4. What does Szostak hope that his ensembles and aggregates of molecules will do? p. 72
   - Begin to operate as living systems

5. Given that no suitable definition for life currently exists, how will Szostak know that his supramolecular complexes are “alive”? p. 72
   - By the preponderance of terrestrial-life characteristics they manifest

6. What enables a cell to maintain a chemical distinctiveness from its environment? p. 72
   - The membrane, or vesicle

7. What three functions must be built into the vesicle membrane? pp. 72-73
   - 1. Ability to allow transport across vesicle boundaries
   - 2. Ability to generate energy to power chemical and physical processes within the vesicle’s interior
   - 3. Ability to respond to stimuli from the environment

8. By what method do cells reproduce, and where do instructions for this reproduction process reside? p. 73
   - Cells divide into “daughter” cells, as directed by DNA

9. The fact that each daughter DNA molecule contains one newly formed DNA strand and one strand from the parent molecule is called what? p. 73
   - Semi-conservative

10. The bottom-up approach pursued by Szostak, Luisi, and Deamer is sometimes described as creating life from “scratch.” However, what compounds do their processes encapsulate or entrap from living sources? p. 74
   - Macromolecules (like proteins, RNA, and DNA) within the boundary membrane

11. Has any method yet been developed that can form stable, long-lasting vesicles? p. 76
   - No

12. Now that we have a glimpse into the formidable complexity of creating artificial life forms even when core components are included from existing living cells and massive intellectual and creative effort is focused on the process, on what basis do naturalists and materialists assert that the origin of life requires no Creator?

13. What would be your response to their assertion(s)?
Chapter 6:

1. What does the bottom-up approach strive to produce that may be distinct from that which the top-down approach produces? pp. 85-86
   Completely novel, utterly alien forms of life

2. How might top-down biologists make use of artificial proteins synthesized by bottom-up biologists? p. 86
   To synthesize pieces of DNA containing the information to produce artificial proteins and introduce these artificial genes into any organism's genome

3. Does the creation of a unique protein by altering the amino acid sequence seem a simple process, or does it require meticulous planning and execution? p. 88
   It seems an extremely complex process requiring in-depth knowledge and insight, intense effort, and direct involvement of intelligent agents.

4. What does the acronym AEGIS stand for? Explain. p. 95
   Artificially Expanded Genetic Information System

Scientists are trying to create artificial life based on some genetic material other than DNA and RNA. As a first step toward this goal, they are working to make variant DNA molecules. Steven Benner and his collaborators have designed DNA molecules that incorporate eight nonnatural nucleobases into their structure along with the four naturally occurring nucleobases (A, G, C, and T).

5. Why are researchers investing so heavily in making life in the laboratory? p. 97
   They seem to believe that creation of artificial, non-natural life forms will enable them to understand how life originated on Earth—presumably with simple chemical compounds evolving first into protocellular entities and then into true cells.

6. Dr. Rana asks (p. 91), "If creating a single protein from already-existing parts takes this much effort and intellectual input, is it reasonable to think that undirected evolutionary processes could have accomplished this task through random genetic shuffling?" In your estimation, how do you think the researchers involved in this work would answer?

7. Has the history of scientific discovery continuously revealed more complexity, intentionality, and rationality in nature or less? What are the implications of your answer?

8. Have you tried to discuss this topic with nonbelievers? If so, what has been the response? What would you see as a helpful next step in your interactions?
Chapter 7:

1. Do researchers offer any explanation for the emergence of the processes by which they think life evolved?

2. If the creation of artificial, non-natural life forms can help us understand how life originated, what about the converse? What help (in their creative effort) can researchers derive from exploring how life may have originated on Earth?  p. 101
   They hope to discover useful insights for efficient assembly of life in the lab.

3. What are panspermia models for life’s origin and how did they arise?
   Given the increasingly obvious implications of the various efforts to create life in the lab, researchers are considering the possibility that life emerged elsewhere and was transported to Earth.

4. Do these new models offer a viable explanation for the origin of life in the universe?  p. 105
   Not really. Extraterrestrial explanations must, at some point, account for life’s initial source, not to mention its safe transport.

5. All origin-of-life scenarios require a source of prebiotic compounds. Name six theoretical sources for the generation of prebiotic compounds.   pp. 104-106
   1. Atmospheric reactions
   2. Volcanic emissions
   3. Deep-sea hydrothermal vents
   4. Iron-sulfur world model
   5. Extraterrestrial delivery vehicles
   6. Pre-existing prebiotics in the gaseous nebula that condensed to form the solar system

6. Regardless of where prebiotic compounds came from or how they condensed to form more complex biomolecules, what two key biochemical features must be explained?   p. 107
   Self-replication and metabolism

7. While both the metabolism-first and the replicator-first models involve speculative developmental processes, the “chicken-and-egg” problem is especially pronounced for the replicator-first model. Can you describe the problem? pp. 108-109
   Proteins are required to synthesize and replicate DNA, while DNA is required to produce the necessary proteins.

8. What solution has been proposed as an answer to the “chicken-and-egg” problem?  p. 109
   RNA might have predated DNA and might have performed the functions of both DNA and proteins, thus operating as a self-replicator.

9. Do you see a fundamental flaw in this explanation? If so, explain.

10. A crucial step in the origin-of-life is development of a membrane that defines life’s boundaries, forms internal cell compartments, and plays a central role in energy production (among other biochemical processes). By what process do scientists assume a membrane developed?  p. 110
    Scientist suggest that once the components that form cell membranes were present, they readily, spontaneously self-assembled and self-organized in the presence of water.

11. Examine figure 7.2 (p. 104). What does it show about the likelihood that purely spontaneous, undirected, non-intelligent, self-organizing materials and processes somehow produced life?
Chapter 8:

1. What are some of the difficulties that arise from researchers’ interjecting themselves into the laboratory process of constructing (or reconstructing) life? pp. 113-115
   - When scientists do laboratory experiments, they are no longer passive observers of undirected processes. Instead, these researchers become active participants and thereby influence the results. Failure to account for this influence may, at times, cause origin-of-life researchers to appear closer to finding answers than they really are.

2. What is the main objective of proof-of-principle experiments (one of three major categories of relevant experimentation)? p. 117
   - To understand what is physically and chemically permissible to consider—thus, researchers doing these types of studies aren’t immediately concerned with how realistic the experimental conditions are with respect to the early Earth.

3. Does researcher involvement influence the outcome of proof-of-principle experiments? No

4. What is the goal of mechanistic studies? pp. 117-118
   - To develop a detailed understanding of the physics and chemistry that dictate the outcome of the process

5. Does researcher involvement influence the outcome of mechanistic studies? The more researchers involve themselves in the design and execution of a mechanistic experiment, the more artificial and unrealistic the results become.

6. Why is this involvement beneficial? Only by elaborate design and deliberate manipulation of experimental conditions can scientists tease out the critical mechanistic features of the process under investigation.

7. What is the goal of Geochemical Simulation Experiments? p. 118
   - To determine whether the different steps in putative origin-of-life pathways realistically could have taken place under conditions thought to exist on early Earth

8. In the winter of 2009, science news headlines announced, "Self-Replicating Chemicals Evolve into Lifelike Ecosystem." When an article such as this appears, (assuming for the moment that the article is factual), readers with divergent frames of reference may agree on the facts but may have very different interpretations of the facts. How do you think a non-theist might interpret such findings? How do you think a theist might interpret them? p. 114

9. Significant uncertainties surround primordial Earth’s conditions, and these uncertainties have bearing on the viability of origin-of-life pathways under investigation. How do researchers compensate for these difficulties? p. 119
   - They simplify and alter geochemical simulation experiments.

10. Although deviations from geochemical reality are helpful and necessary, they often represent a frustrating trade-off for origin-of-life investigators. Briefly describe that trade-off in general terms. p. 119
    - They run the risk of making simulations unrealistic and therefore irrelevant. So although the involvement of researchers in the experiments seems helpful and necessary, it also increases the uncertainty of the relevance of the experimentally identified physicochemical processes.
Chapter 9:

1. How do assumptions about early Earth's atmosphere prevalent at the time of Stanley Miller's famous experiment differ from what is currently known? pp. 124-125

   In Miller's day, early Earth's atmosphere was thought to consist of reducing gases, (gases rich in hydrogen, such as molecular hydrogen, methane, ammonia, and water vapor). Current findings indicate the existence of a neutral atmosphere consisting of nitrogen, carbon dioxide, carbon monoxide, and water vapor.

2. What difference does this current finding make to the significance of Miller's experimental outcome?

   Under Miller's lab conditions, some biologically interesting prebiotic compounds do come together. However, a neutral atmosphere could not have sustained the production of prebiotic molecules.

3. How would you describe the oxygen-ultraviolet paradox? pp. 126-127

   If present, oxygen inhibits prebiotic chemical reactions. If absent, no ozone is generated, and prebiotic materials are rapidly destroyed by ultraviolet radiation.

4. In what three ways do mechanistic studies demonstrate the need for an intelligent, intentional, hands-on designer? pp. 129-130

   They highlight the need for (1) careful adjustment of the gas composition and concentrations, (2) selection of the right type of energy source, and (3) implementation of special features to isolate and protect the prebiotic products from their energy source once they have formed. Apart from the experimenters' efforts, "gas phase reaction would never produce organic compounds."

5. If researchers were someday able to find a realistic scenario for "natural generation" of prebiotic materials, what affect do you think that would have, in terms of logic, on the need for a Creator? pp. 135-136

   The presence of the materials alone does not constitute proof of their capacity to self-assemble. The processes are too intricate and fraught with insurmountable challenges to make this possibility realistic.
Chapter 10:

1. How would you describe the “chirality” of amino acids and sugars to a non-scientist? pp. 138-139
   Chirality refers to the way a compound’s constituent parts cluster (3-dimensionally) around a central carbon atom. Chiral molecules resemble human hands in this sense: Our right and left hands mirror each other when placed with palms together but not when placed on top of each other, palms down. Amino acids and sugars can be configured either one way or the other, in a “right-handed” or “left-handed” configuration.

2. So what is “homochirality,” and how does it impact life molecules? p. 139
   Life scientists have discovered that in living systems, neither amino acids nor sugars can be mixtures of right- and left-handed configurations. The amino acids are all left-handed, and the sugars, all right-handed (thus, homo=same, and chirality=handedness). Homochirality is a strict requirement for life.

3. Do chemical processes or reactions in which chiral molecules form typically produce homochiral molecules? pp. 140-142
   No. They typical yield a roughly half-and-half mixture of right- and left-handed products—unless a chiral excess already exists at the outset of the process or unless the reaction catalyst displays chirality.

   First, the fact that the meteorite contained amino acids, some of which are found in biological systems, and second, the fact that it contained slight chiral excesses in some of its non-biological amino acids.

5. What did researchers learn from further studies into chemical pathways toward homochirality (asymmetric autocatalysis)? pp. 143-146
   The only real-life discovery of what seems a possible pathway (the Soai reaction) is a scientific oddity, not a widespread phenomenon, and none of its reactants or products is found in biological systems. Also, chiral excesses generated by naturally occurring chemical processes are relatively short-lived.

6. Could hydrothermal vents have contributed to homochirality? pp. 146-147
   Not really, because the process that drives slight chiral excesses back to balanced mixtures (racemization) work effectively under hydrothermal vent conditions.

7. Where did researchers turn next in the quest to discover a natural pathway toward homochirality, and what have they found thus far? pp. 147-150
   They looked for possible physical (as opposed to chemical) mechanisms for it, but none proved realistic in terms of early Earth’s conditions, and then they began to consider possible astronomical mechanisms. Here again, none of the proposed explanations, such as exposure to circularly polarized ultraviolet radiation, provides even a remotely realistic answer.

8. What has research shown to be the most important aspect in laboratory experiments yielding even a slight homochiral excess? pp. 151-152
   The careful, mindful intervention of the researchers.

9. How would your views be impacted, if at all, should researchers discover some “natural” source for homochirality? Explain.
Chapter 11:

1. On page 154, Dr. Rana says the work of some origin-of-life researchers ironically echoes the biblical narrative of the Creator’s activity. To what research is he referring?
   That of scientists such as Graham Cairns-Smith and, more recently, James Ferris, who see Earth’s minerals and clays—in other words, “the dust of the ground”—as playing an integral role in the genesis of life, specifically in the replicator-first hypothesis.

2. What shocking response did Robert Shapiro give to Ferris’s opening presentation at the 2002 international conference of origin-of-life researchers? p. 155
   Shapiro objected to this entire body of work, claiming it provided elegant proof of intelligent design.

3. Briefly summarize the replicator-first scenario, or the RNA world hypothesis discussed in this chapter (as well as in chapter 7). pp. 156-157
   RNA initially took on the functions of both proteins and DNA, and over time these functions became more specialized into the current distinct roles of RNA (an intermediary), proteins, and DNA.

4. Does research reveal any trace of the supposed ancestral RNA molecules?
   No

5. To solve what Leslie Orgel calls “the problem of the origin of the RNA world,” what are some of the processes researchers must find a way to explain? p. 157
   - chemical routes to generate RNA’s building blocks
   - a route to assembly of the building blocks into larger building blocks (ribonucleotides)
   - a reaction scheme to activate these building blocks
   - a route to stringing these blocks into long enough chains to form catalysts (ribozymes)
   - emergence of the ribozymes’ capacity to carry out a wide range of catalytic activities
   - emergence of an RNA self-replicator

6. How would Orgel (and Dr. Rana) say researchers have fared in identifying geochemically relevant processes for the production of RNA’s components? pp. 158-162
   To quote Orgel, “It would take a miracle if a strand of RNA ever appeared on the primitive Earth.”

7. What breakthrough reawakened hopes of rescuing the RNA world hypothesis? pp. 162-163
   By intermingling, rather than separating, sugar and nucleobase chemistries, researchers allowed the two chemistries to work together. Thus, they discovered a simple chemical route to produce activated (chemically complex) ribonucleotides.

8. What major barriers does this line of research still face? p. 163-164
   - No route has yet been found for two of the four essential ribonucleotides.
   - Possible side reactions may frustrate the crucial reaction sequence.
   - UV radiation would have interfered as much as it helped.
   - Chemical reactivity would have interfered.
   - Phosphate levels on early Earth would have been insufficient.

9. What additional problems does the RNA world hypothesis need to solve? pp. 164-171
   - assembly of RNA molecules
   - homopolymer problem
   - emergence of self-replicating RNA molecules

10. Despite the brilliant, breakthrough work of these RNA-world researchers, what is the one obstacle still standing in the way of the naturalistic conclusion they hope for?
    Geochemical relevance
Chapter 12:

1. In what way does “metabolism recapitulate biogenesis?” What does this expression mean? p. 175

Some researchers suggest that metabolic pathways observed in cells represent molecular “fossils” of sorts, as if their existence provides evidence for metabolism-first models for life’s origin.

2. According to Robert Shapiro, what five requirements apply to virtually all metabolism-first scenarios? p. 175

1. Emergence of a boundary to segregate protometabolic pathways from the rest of the environment
2. An energy source to power protometabolic interactions
3. A coupling mechanism to link the available energy to the protometabolic pathways
4. Emergence of a chemical network comprised of interconnected cycles of reactions among small molecules
5. A means for this network to grow and reproduce

3. What are the two main challenges to the metabolism-first scenarios, as pointed out by Leslie Orgel? p. 176

1. Disruption by chemical interferents and competing side reactions
2. The chemical stability-instability paradox

4. How would you describe the chemical “Catch-22” within the stability-instability paradox? pp. 176-177

Chemical compounds must be reactive enough to take part in protometabolic cycles and networks, but this reactivity makes them susceptible to breakdown and composition, which then makes the chemical cycles and networks inherently unstable. On the other hand, chemical compounds stable enough to withstand degradation do not enter into chemical cycles and networks because they are too chemically unreactive.

5. In what way does the “reverse citric acid cycle” illustrate the major problem with metabolism-first scenarios? p. 177

This cycle—and all conceivable protometabolic cycles—would have been impossible on early Earth because the catalysts needed to drive the cycle lacked the required specificity. Each of the eleven steps in the reverse citric acid cycle requires a specific mineral catalyst.

6. Günter Wächtershäuser has demonstrated, in principle, that iron sulfide and related minerals may possibly have had a role in the origin of life. So what two barriers stand in the way of this explanation for life’s origin? p. 180

1. It is geochemically unrealistic.
2. It requires the design and control exerted by intelligent agents.
1. What critical roles does the cell membrane perform? pp. 182-183
- keeps harmful materials out
- keeps essential, beneficial compounds inside
- regulates traffic in and out of the cell
- serves as the site for photosynthesis and energy production

2. What is so puzzling about how cell membranes emerged in the first place? p. 183
The single bilayer of phospholipids that comprise the membrane don’t form spontaneously. Instead, phospholipids organize spontaneously into sheets or spherical structures consisting of stacks of multiple bilayers.

3. How do phospholipids form in the first place? p. 185
Through a complex process involving development of fatty acids, that additional reactions with glycerin and phosphate.

4. What happens to this highly complex set of processes if any water is present? p. 185
It not only stops, it reverses the reactions and breaks down phospholipids.

5. How did researchers react to the phospholipid findings published by Drs. Thaxton, Bradley, and Olsen? pp. 185-186
They began to appeal to the infall of extraterrestrial materials as the source of bilayer-forming compounds.

6. If by some extraterrestrial means the right components appeared in the right time and place on early Earth under exactly the right conditions, what three processes would still be required to form the first cell membrane? p. 187
- encapsulation of DNA molecules
- development of permeability (lipid bilayers are generally impermeable)
- growth and development of spontaneous division without the aid of biomolecular machinery

7. What are the major challenges to the natural/spontaneous occurrence of each of these processes? pp. 188-189
- insufficient quantities and unstability of component parts
- the presence of salt, which causes primitive membranes to fall apart
- the need for exacting control and selection
- strict dependence on lipid identity

8. What do you see as the implications of research showing that stable single-bilayer phases similar to those that constitute cell membranes form only under unique and exacting conditions? pp. 190-194
These findings underscore the unlikelihood that chemical and physical processes operating on early Earth could have produced the precise phospholipid composition to form the stable single-bilayer phase that universally defines cell membranes.
Epilogue:

1. From a Christian/biblical perspective, what are some reasons to be concerned about advances in synthetic biology?

2. What are some reasons to be supportive of advances in synthetic biology? Focus your discussion to the following issues:
   - Caring for the ill and disabled
   - Caring for the planet
   - Debate over the necessity of the biblical Creator
   - Bringing glory to God