ASTR/GEOL-2040-001: Midterm exam model solutions
Search for Life in the Universe (October 13, 2017)

Work carefully, you'll have enough time. Give enough details, not just the numbers. Don't expect full credits if you forget to draw a sketch. For the multiple choice questions, there is only one correct/best answer! Mark it with a circle.

1. H_2O is a [2pts]
   (a) polar molecule
   (b) nonpolar (or apolar) molecule

2. The cores of the icy bodies in the solar system such as Europa or Enceladus consist mostly of [2pts]
   (a) water ice (b) liquid water (c) iron (d) rock

3. "RNA world" refers to [2pts]
   (a) the possibility that life migrated from Mars,
   (b) the idea that RNA was life's genetic material before DNA,
   (c) the idea that early life was made exclusively from RNA, needing no other organic chemicals

4. Stromatolites are [2pts]
   (a) iron-reducing lithotrophs extracting energy from the rocks they are living on,
   (b) photosynthesizing cyanobacteria growing on top of each other,
   (c) hydrothermal alkaline vents harboring methanogens that life of hydrogen and CO_2,
   (d) sedimentary rocks in Western Australia where the oldest microfossils have been found.

5. In their original experiment, Miller/Urey used the gases H_2, NH_3, and CH_4. They were chosen because they are all [2pts]
   (a) reducing gases
   (b) oxidizing gases
   (c) polar molecules
   (d) apolar molecules

6. What has the Miller/Urey experiment taught us? [2pts]
   (a) life is likely to have originated in a hydrothermal vent
   (b) life is likely to have originated in a tidal pond
   (c) the building blocks of life are easily synthesized
   (d) only left-handed amino acids can be synthesized

7. Which of these nucleobases is a component in DNA but not in RNA? [2pts]
   (a) Uracil [U] (b) Cytosine [C] (c) Adenine [A] (d) Thymine [T]

8. Two powders, one yellow and one purple, are stirred into a beaker of liquid *methane*. The purple powder dissolves completely, but the yellow powder collects on the bottom. What can you reasonably state about the chemical nature of these powders? [2pts]

   (a) Purple is polar; yellow is apolar
   (b) Neither powder is polar
   (c) Yellow is polar; purple is apolar
   (d) Both powders are apolar

9. ^{40}K decays into two daughter products: ^{40}Ca and ^{40}Ar. Why are we only concerned with the measurement of the second of these, ^{40}Ar? [2pts]

   (a) ^{40}K decays principally into ^{40}Ar
   (b) ^{40}Ca from radioactive decay is indistinguishable from most other calcium
   (c) ^{40}Ca is solid and can't be measured in a laboratory
   (d) ^{40}Ar is twice as massive as ^{40}Ca and is easier to detect

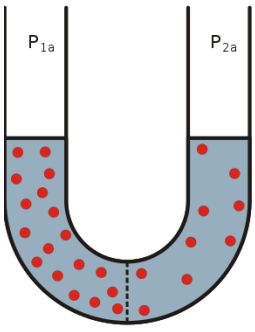
10. Wormlike structures have been found in the 3.5 Gyr old Apex Chert of Western Australia. Why does this not necessarily constitute fossil evidence of the antiquity of life? [2pts]

    (a) Wormlike structures can be made by nonbiological means.
    (b) One cannot exclude the possibility of contamination.
    (c) Similar fossil-like structures have also been found in Martian meteorites.
    (d) No organics have been found inside the chert.

11. In which of these environments would you likely find a xerophile? [2pts]

    (a) A high-altitude desert
    (b) An Amazon rain forest log
    (c) A deep-sea vent
    (d) A wall in the Chernobyl reactor

12. The two halves of the U-tube (below) are separated by a semipermeable membrane. The tube is filled with water, but on the left, there is a larger salt concentration than on the right. What will happen next? [2pts]



(a) The water on the left will rise. (b) The water on the right will rise.

13. Which of these is not necessarily needed for terrestrial life to function? [2pts]

(a) Free O_2 gas (b) Liquid water (c) A carbon source (d) Nitrogenous bases

14. Where do we think the Moon came from? [2pts]

(a) Earth captured the Moon after a close encounter between the two.
(b) The Moon formed at the same time as the Earth, already in orbit.
(c) A giant impact launched material into orbit around Earth which coalesced into the Moon.
(d) The Moon was "spat out" by a rapidly rotating liquid Earth.

15. Marble is created when limestone is subducted beneath the surface and repeatedly folded over itself in the hot mantle (without melting). Knowing this, what kind of rock is marble? [2pts]

(a) Sedimentary. (b) Metamorphic. (c) Igneous. (d) Marble is none of these types.

16. What is cryovolcanism? [2pts]

(a) Hydrothermal vents at the ocean floor of an icy world
(b) Slush ice and water erupting from an icy world
(c) The production of volcanic greenhouse gases after a Snowball Earth event
(d) Volcanos that have gone extinct

17. Which of the following rock types have *not* been found on Mars? [2pts]

(a) granite (b) basalt (c) sedimentary rock

18. In non-biological carbonates, the fraction of ^{13}C to ^{12}C isotopes has been determined to be 0.01124. Which of the following isotope fractions would you expect for an organic carbon sample? [2pts]

(a) 0.01096 (b) 0.01124 (c) 0.01152

19. Would we consider the detection of an oxygen atmosphere on another planet as a likely sign of extant extraterrestrial life? [2pts]

(a) No – oxygen is just another element.
(b) Yes – oxygen is a requirement for any kind of life.
(c) No – oxygen is a sign of extinct life forms.
(d) Yes – oxygen is highly reactive and needs to be actively replaced through photosynthesis.

20. "Snowball Earth" refers to [2pts]

(a) One in a series of deep ice ages that occurred > 0.5 Gyr ago.
(b) The idea that Earth would be frozen without greenhouse effect.
(c) Any of the ice ages that occurred in the past few million years.

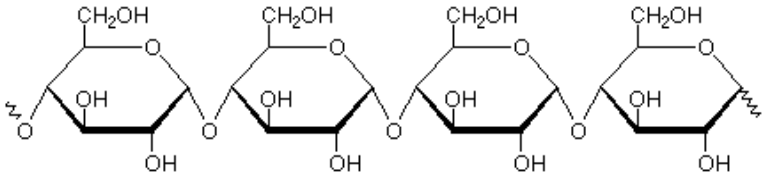
21. In contrast to the black smokers, alkaline vents produce mainly [2pts]

(a) CO_2 (b) N_2O (c) H_2S (d) H_2

22. Earth's first atmosphere was chemically similar to those of Mars and Venus. How did our current atmosphere become so drastically different from our nearest neighbors'? [2pts]

(a) Life – early photosynthetic organisms consumed CO_2 and exhaled O_2.
(b) Volcanism & Tectonics – Earth's numerous volcanoes expel O_2 gas while plate tectonics undertakes carbonate rocks.
(c) Asteroids – Impacts from space debris converted CO_2 into O_2 by impact ablation and high energy explosions.
(d) Water – Earth's liquid oceans provide a natural filter that strips the carbon from CO_2, leaving the O_2.

23. What kind of macromolecule is [2pts]



(a) lipid (b) polysaccharide (c) protein (d) nucleic acid

24. In the reaction $CO_2 + H_2O + \text{light} \rightarrow CH_2O + O_2$, [4pts]

the energy comes from: (sunlight/molecules), so the relevant prefix is (photo/chemo)

the electron donor is: H_2O, which is inorganic, so "litho",

and the carbon source is: CO_2, which is inorganic, so "auto",

and so it is a: photolithoautotroph.

25. Name two extremophilic properties that can often be found together in the same extremophile & explain why. [4pts]

- resistant to temperature & pressures: extremophiles in hydrothermal vents can sustain high temperatures & high pressures.
- resistant to radiation & desiccation: many extremophiles that are resistant to certain levels of radiation are also xerophile. *Deinococcus radiodurans* is an example.

26. Name the three basic rock types and explain them in a few words. [4pts]

- Igneous rock: forms from molten rock, which then cools and solidifies
- Metamorphic rock: chemically/structurally altered by pressure/temperature, not molten
- sedimentary rock: formed from compression of sediments

27. A 16 kg block of pure radioactive ^{235}U is left on a shelf... [4pts]

(a) How many half-lives would I have to wait until only 2 kg of ^{235}U is left?

$$\frac{2\,\mathrm{kg}}{16\,\mathrm{kg}} = \frac{1}{8} = \frac{1}{2^3},$$

so one has wait 3 half-lives.

(b) If the half-life of ^{235}U is 0.7 Gyr, how long will I be waiting?

3 times the half-life, i.e., $3 \times 0.7\,\mathrm{Gyr} = 2.1\,\mathrm{Gyr}$.

(c) Approximately, how many Gyr is this less than the age of the Earth?

The age of the Earth is approximately 4.6 Gyr, so 2.1 Gyr is approximately 2.5 Gyr less.

(d) Assume that ^{235}U decays only into ^{207}Pb...
How much ^{235}U and ^{207}Pb will I have after my waiting?

Once the 16 kg decayed completely into ^{207}Pb, we are left with 2 kg of ^{235}U and 14 kg of ^{207}Pb.

28. Explain why the simultaneous detection of oxygen (or ozone) together with methane in the infrared spectrum of an exoplanet's atmosphere constitutes strong evidence for life on that planet? *(Hint: can oxygen and methane coexist under equilibrium conditions?)* [4pts]

Ozone is highly oxidizing and rapidly destroys methane. The simultaneous occurrence of both ozone and methane means that they are continuously being reproduced, and faster than being destroyed. This can only be done by life, which produces both methane and oxygen, which in turn leads to easily detectable ozone in the upper atmosphere.

29. What are three of Darwin's primary tenets for evolution by natural selection? [4pts]

Darwinian evolution assumes that during replication, life forms can undergo *small variations*. It also assumes that these life forms have to *struggle for survival*, so not all of them will survive. Introducing new medicines reduces the survival of the bacteria and thus increases their struggle for survival. However, the occurrence of small variations during replication continues, which means that those variations that tend to be immune to the new medicine continue to survive and replicate. Thus, these bacteria *have evolved*, just as predicted by Darwin.

30. *Streptococcus mitis* has been found inside the camera of Surveyor 3 that the astronauts of Apollo 12 returned to Earth. If those bacteria really did survive for over 2 years on the Moon, why would scientists still not call them extremophiles? [4pts]

    - These microbes merely survived and did not grow or replicate.
    - Extremophiles thrive (grow & replicate) under extreme conditions.

31. The atmosphere of Mars contains 1.6% of argon-40 (^{40}Ar). Based on what you know about argon in the Earth's atmosphere, explain what the reason for this might be. [4pts]

    - Rocky material contains a certain amount of radioactive potassium.
    - This ^{40}K decays into ^{40}Ar.
    - Each time this rock is exposed to the surface in molten form, this ^{40}Ar gas is released into the atmosphere

32. Give two arguments why life on Earth may have started in hydrothermal vents at the ocean floor. [4pts]

    - Well protected from vaporizing impacts
    - Energy-rich molecules available (reduced mineals interact with sea water)
    - Phylogeny shows that thermophiles are near the root of the tree