ASTR/GEOL-2040-001: Sample Quiz #2 model solutions
Search for Life in the Universe (November 13, 2017)

Note: this time, there is only one correct answer! Mark it with a circle.
Please provide brief answers; short phrases are acceptable (and preferable) to short novels.
Out of questions 16–23, only the 6 best ones will be counted.

1. Match the following extremophiles to the appropriate environments in which they would be found: thermophiles, piezophiles, halophiles, radiophiles, and psychrophiles. (Write their names behind the colons below.)
   (a) temperatures below 15°C (= 60°F): psychrophiles
   (b) temperatures in the range 50°C–80°C (120°F–180°F): thermophiles
   (c) salinity in the range 15%–38% salt: halophiles
   (d) a radiation dose of up to 5,000 Gy: radiophiles
   (e) pressures up to 130 MPa: piezophiles

2. A bacterium is recovered from a hot spring in the Andes Mountains, an environment typified by extremely high temperatures, low pH, and high ultraviolet radiation. Which of the following extremophile names best describe this bacterium?
   (a) hyperpsychrohalophile
   (b) piezoxerophile
   (c) thermoradioacidophile
   (d) anaeroboalkalimetallophile

3. Two bacteria, A and B, are recovered from hostile environments on Earth: A is recovered from a deep sea floor vent in the Pacific ocean, and B is recovered from a highly acidic evaporate lake in southern Africa. Both are introduced to standard environmental conditions in separate petri dishes – bacterium A quickly dies off, but bacterium B continues to survive. Which of the following best describes the two bacteria?
   (a) Bacterium A is an ordinary alkalophile; bacterium B is an ordinary barophile.
   (b) Bacterium A is an obligate piezophile; bacterium B is an ordinary acidophile.
   (c) Bacterium A is an ordinary piezophile; bacterium B is an obligate halophile.
   (d) Bacterium A is an obligate metallophile; bacterium B is an obligate acidophile.

4. A planet is tidally locked if

   (a) its rotation axis always points in the same direction
   (b) its orbital period is twice the period of the next inner planet
   (c) always the same position on the planet's surface faces the host star
   (d) an observer on the planet always sees the same side of the star
   (e) an observer on the planet always sees the same side of the moon

5. Methane, the principal condensable material on Titan, is unstable when exposed to UV light – it reacts with itself to form ethane on short geologic timescales. What does this tell us about the source of methane on Titan?

   (a) Methane must have an active, possibly volcanic source from below.
   (b) Titan must receive periodic injections of methane from Saturn.
   (c) Methane must be supplied from intense comet bombardment.
   (d) We are witnessing the end of Titan's methane cycle.

6. Where do we suspect the sulfur in the sulfates found on Europa's surface comes from?

   (a) Europa itself – sulfur is disgorged from below the icy crust.
   (b) Jupiter – the gas giant attracts sulfur-rich impactors that hit the surface.
   (c) Io – Ionian volcanoes blast sulfur into space which then collides with Europa.
   (d) Ganymede – quakes on Ganymedes surface produce ballistic sulfur vents.

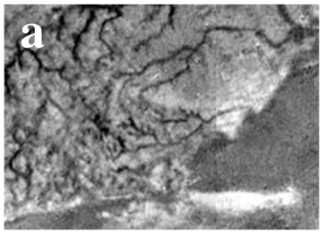
7. Measuring the mass of the satellites of Jupiter and Saturn during fly-bys has been important for the realization that the satellites

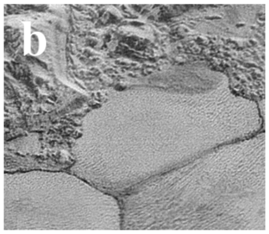
   (a) are tidally locked
   (b) have significant geological activity
   (c) have an extended icy crust
   (d) have a liquid subsurface ocean
   (e) have significant amounts of water in frozen or liquid form

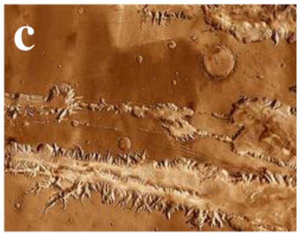
8. The iceballs on Titan's surface are roundish because

   (a) they have been ejected through cryovolcanism
   (b) there have been surface currents of methane some time in the past
   (c) there is significant sublimation during Titan's summer
   (d) the surface is constantly bombarded by micrometeorites

9. Which of the following pictures is from Titan? (a) (b) (c)







10. The surface temperature on Titan is roughly (a) 94°C (b) -94°C [✓ (c) 94 K] (d) -94 K

11. The nitrogen in Titan's atmosphere is the result of dissociation of
    (a) water (b) methane (c) ethane [✓ (d) ammonia] (e) none of these

12. The mean densities of the Galilean moons decreases with increasing distance to Jupiter: Io has a mean density of $3570\,\mathrm{kg\,m^{-3}}$, Europa has $2970\,\mathrm{kg\,m^{-3}}$, Ganymede $1940\,\mathrm{kg\,m^{-3}}$, and Callisto $1940\,\mathrm{kg\,m^{-3}}$. What does this tell you about the differences in their compositions?

    The inner moons (Io, Europa) have less water and more rock, while the outer ones have more water (in frozen or liquid form).

13. Name the three most abundant gases in the Martian atmosphere: CO_2, N_2, Ar

14. Name the three most abundant gases in Titan's atmosphere: N_2, CH_4, H_2

15. In salty water, an ice raft floats (a) deeper [✓ (b) shallower] than in fresh water.

16. Explain your answer to the previous question.

    The density of salty water is higher than that of fresh water. The buoyancy of the raft equals the weight of the displaced water mass, but because a certain volume of salty water is heavier than that of fresh water, we need less of it, and thus, it won't sink as deeply.

17. Assume that the inner 50% (by radius) of a planet has a density of $3000\,\mathrm{kg\,m^{-3}}$, and the outer 50% (by radius) has a density of $1000\,\mathrm{kg\,m^{-3}}$.

    (a) What is the fractional volume of the inner, denser part?

    The volume is proportional to the cube of the radius, so if the fractional radius is $1/2$, then the fractional volume is $1/2^3 = 1/8$.

    (b) What is the average density of the planet?

    We call the fractional volume x, for which we found $1/8$. The remaining fraction is $1 - x = 7/8$.
    The mean density is given by

$$\overline{\rho} = x\rho_{\text{dense}} + (1-x)\rho_{\text{light}},$$

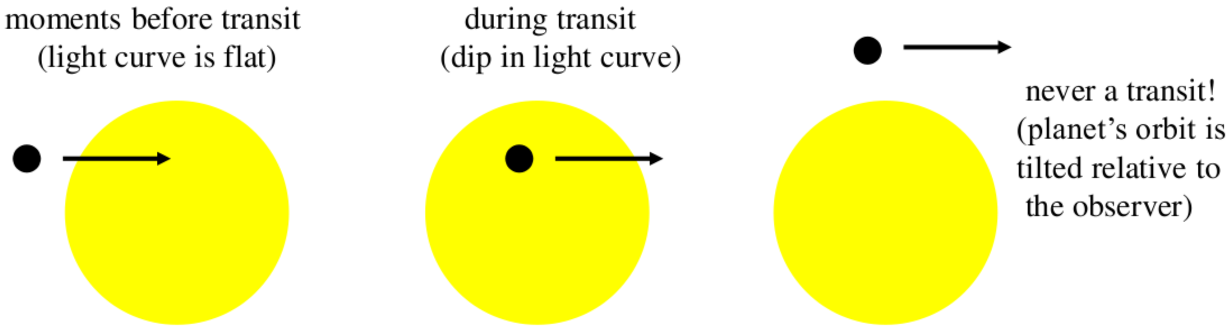
    so

$$\overline{\rho} = \frac{1}{8}\times 3000\,\mathrm{kg\,m^{-3}} + \frac{7}{8}\times 3000\,\mathrm{kg\,m^{-3}} = \frac{3+7}{8}\times 1000\,\mathrm{kg\,m^{-3}} = \frac{10}{8}\times 1000\,\mathrm{kg\,m^{-3}} = 1250\,\mathrm{kg\,m^{-3}},$$

    because $10/8 = 5/4 = 1.25$. So $1250\,\mathrm{kg\,m^{-3}}$ is just a little denser than ice.

18. Of the methods used to discover exoplanetary systems, the transit method has risen to the forefront in recent years due to the success of the *Kepler* spacecraft. In the space below, briefly describe (with words and a diagram) how this method works and detail what kind of selection bias(es) this method suffers from.

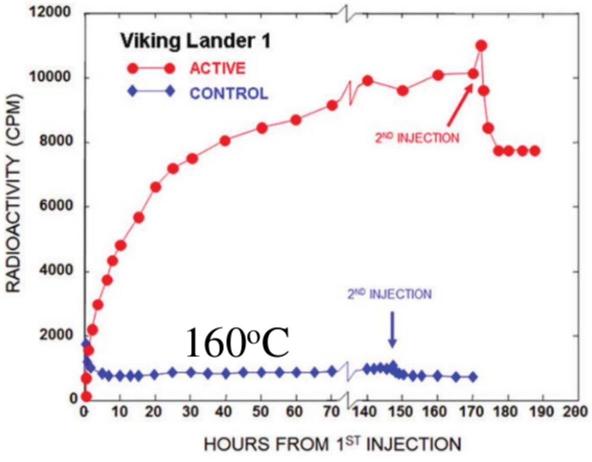
The planet occults part of the stellar surface, leading to a dip in the light curve. However, we can only detect planets that lie in the plane of the observer, i.e., if we observe the planetary system edge-on; see the sketch below.

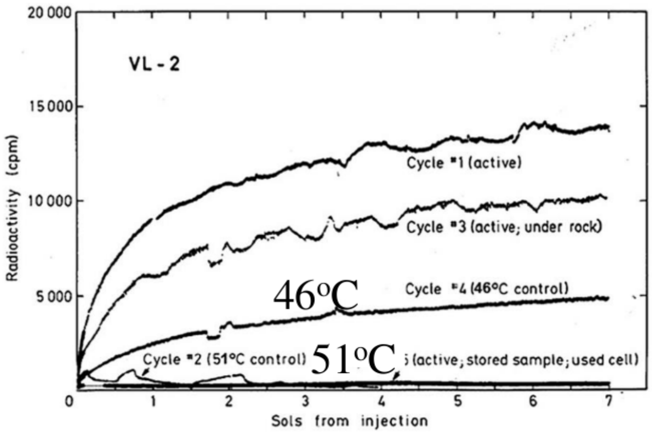


19. Where on Earth would you want to go to find a thermophilic lifeform? What about a barophilic lifeform? Is it surprising that many extremophiles qualify for multiple extreme environmental descriptions? Why or why not?

Thermophilic lifeforms in hot springs.
Barophilic lifeforms near the ocean floor.
Not surprising, because, like in this example, they can occur together as hydrothermal vents.

20. The Viking Landers exposed Martian soil to organic nutrients (e.g., NH_2–CH_2–COOH), in which the carbon atoms were radioactive ^{14}C. Radioactive gases (presumably CO_2) were detected and their amount plotted as a function of time. The agent that produced these gases is unknown.

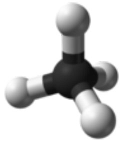




What can be learnt about the properties of this agent by looking at the control experiments with pre-heated soil (160°C, lower line in the left plot, and 46°C or 51°C in the right plot)?

The agent helping to convert the organic "nutrients" to CO_2 does not survive temperatures above about 50°C.

21. The *Cassini/Huygens* mission has clearly shown that a liquid medium, here methane, exists on Titan's surface. Sketch a ball-and-stick model of a methane molecule. Why would we still be skeptical about a possible Titanic lifeform using this molecule in its biology in the same way?

    This molecule is apolar and would, in liquid form, lipid cell walls would dissolve in it.

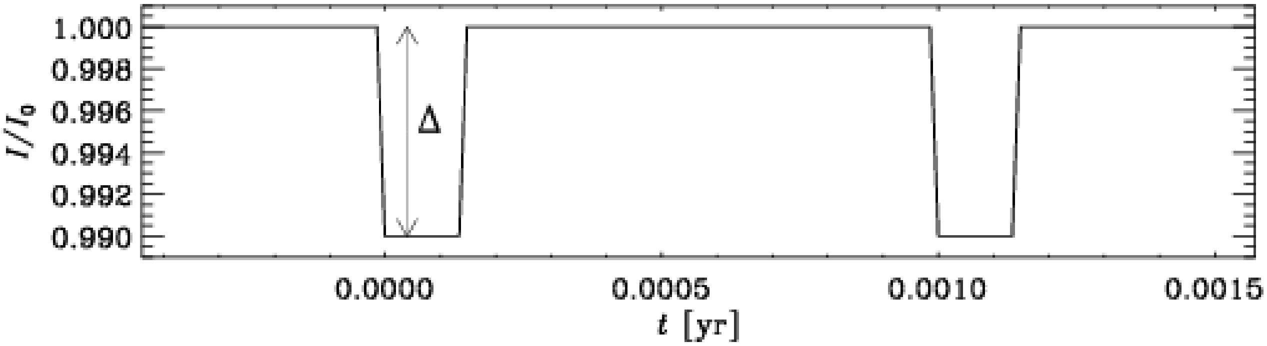
22. Why are astrobiologists so enthralled about recovering carbonaceous material from comets and asteroids like Tempel 1 or Bennu for experiments? Why can't we just use a shovel of dirt from Earth or Mars?

    The material is most pristine an unaltered by geochemical and biological "weathering".

23. A new kind of medicine is synthesized from the DNA of an anaeroboalkalopsychrophilic bacterium. What kind of environments does this lifeform thrive in? Where on Earth would you likely need to go to find one (*you are allowed some creativity on this answer*)?

    It could thrive near deep arctic sea floors where the temperatures are low, pressures are high, pH is high, and oxygen low.

24. Below is a light curve of a solar "twin" with periodic dips. Intensity I is normalized by the maximum value, I_0. This solar twin has a radius just like the Sun ($R = 700,000\,\mathrm{km}$) and the same mass as our Sun. Thus, you can write Kepler's law as $P^2 = r^3$ if the orbital period P is measured in yr and the orbital radius r is measured in AU.



(a) How deep is the dip, i.e., what is the value of D?

$D = 1.00 - 0.99 = 0.01$.

(b) Assume that the dip is caused by a transiting planet, what is its radius (in km)?

The cross-sectional area occulted by the planet of radius r is πr^2, so the fractional area, which is proportional to the fractional intensity dip for a star of radius R, is $D = \Delta I/I = r^2/R^2$. Thus, if $r^2/R^2 = 0.01$, then $r/R = 0.1$. Since $R = 700,000\,\mathrm{km}$, we have $r = 70,000\,\mathrm{km}$.

(c) How long is the orbital period P of the planet (in yr)?

From the plot we see that the period is $P = 0.001\,\mathrm{yr}$.

(d) What is the radius r of the planet's orbit (in AU)?

Since $P^2 \propto R^3$, and since (for the Sun with its one solar mass) one year corresponds to 1 AU, we can simply say that $P_{\mathrm{yr}}^2 = R_{\mathrm{AU}}^3$ without further prefactors. Thus, $R_{\mathrm{AU}} = P_{\mathrm{yr}}^{2/3} = (0.001)^{2/3}\,\mathrm{AU} = 0.1^2\,\mathrm{AU} = 0.01\,\mathrm{AU}$.