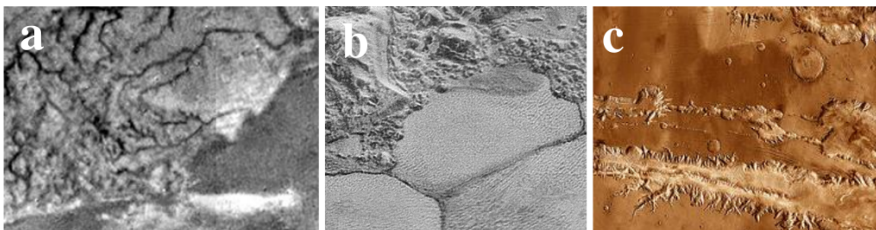


*Work carefully*, you'll have enough time. Give relevant details and brief *explanations*, not just the final numbers or facts. Short phrases are acceptable (and preferable) to short novels. Don't expect full credits if you forget to draw a sketch when requested. For the multiple choice questions, there is only one correct/best answer! Mark it with a circle.

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

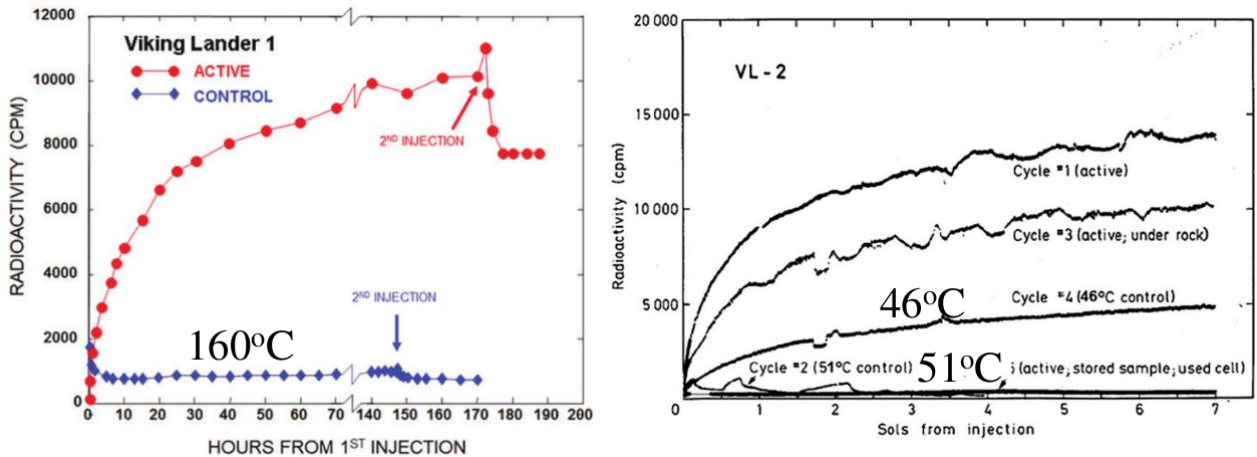


10. The surface temperature on Titan is roughly (a)  $94^{\circ}\text{C}$  (b)  $-94^{\circ}\text{C}$  (c)  $94\text{ K}$  (d)  $-94\text{ K}$
11. The nitrogen in Titan's atmosphere is the result of dissociation of  
(a) water (b) methane (c) ethane (d) ammonia (e) none of these
12. The mean densities of the Galilean moons decreases with increasing distance to Jupiter: Io has a mean density of  $3570\text{ kg m}^{-3}$ , Europa has  $2970\text{ kg m}^{-3}$ , Ganymede  $1940\text{ kg m}^{-3}$ , and Callisto  $1940\text{ kg m}^{-3}$ . What does this tell you about the differences in their compositions?
13. Name the three most abundant gases in the Martian atmosphere
14. Name the three most abundant gases in Titan's atmosphere
15. In salty water, an ice raft floats (a) deeper (b) shallower than in fresh water.
16. Explain your answer to the previous question.
17. Assume that the inner 50% (by radius) of a planet has a density of  $3000\text{ kg m}^{-3}$ , and the outer 50% (by radius) has a density of  $1000\text{ kg m}^{-3}$ .
- (a) What is the fractional volume of the inner, denser part?
- (b) What is the average density of the planet?

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.

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?

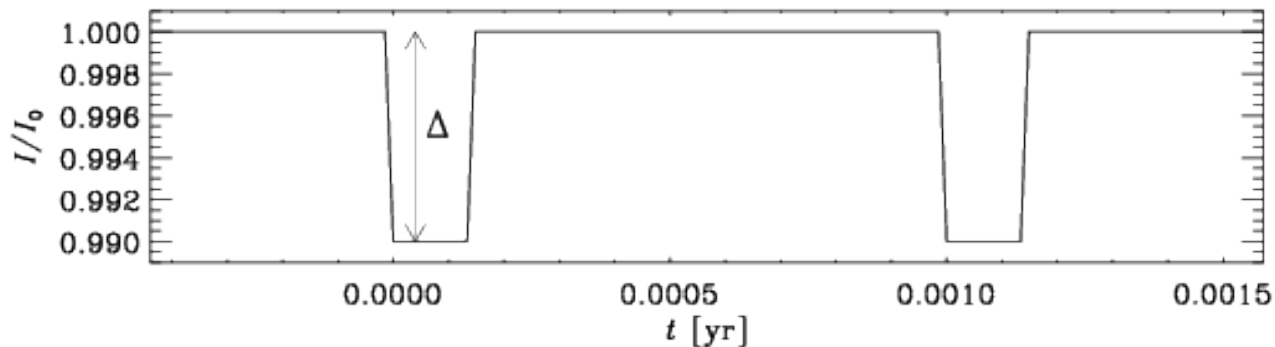
20. The Viking Landers exposed Martian soil to organic nutrients (e.g.,  $\text{NH}_2\text{-CH}_2\text{-COOH}$ ), in which the carbon atoms were radioactive  $^{14}\text{C}$ . Radioactive gases (presumably  $\text{CO}_2$ ) were detected and their amount plotted as a function of time. The agent that produced 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)?



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 ( $R = 700,000$  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  $D$ ?
- (b) Assume that the dip is caused by a transiting planet, what is its radius (in km)?
- (c) How long is the orbital period  $P$  of the planet (in yr)?
- (d) What is the radius  $r$  of the planet’s orbit (in AU)?