

**TOSS-UP**

1) EARTH AND SPACE *Short Answer* What is the steep-sided, pyramidal rock pinnacle that is formed by expansive erosion of the headwalls where three or more cirques intersect?

ANSWER: HORN

**BONUS**

1) EARTH AND SPACE *Multiple Choice* If the evolution of a medium-mass star as it enters the giant stage is studied, its path on the H-R diagram resembles an elongated, compressed form of the letter “s”. Which of the following choices best represents what is occurring in the star as it crosses its rightmost point, completing a loop before moving across to the right?

- W) core hydrogen fusion
- X) shell hydrogen fusion with an inert helium core
- Y) core helium fusion and shell hydrogen fusion
- Z) shell helium and hydrogen fusion with an inert carbon core

ANSWER: Y) CORE HELIUM FUSION AND SHELL HYDROGEN FUSION

**TOSS-UP**

2) PHYSICS *Short Answer* What two elementary fermions make up the lowest-mass first-generation quarks?

ANSWER: UP AND DOWN

**BONUS**

2) PHYSICS *Short Answer* A certain solenoid consists of 150 turns of wire, and has a length of 15 cm. Assuming the permeability of free space to be  $1.3 \times 10^{-6} \text{ T m A}^{-1}$  and presenting your answer to two significant digits, what is the magnetic field inside the solenoid in T if it carries a current of 0.5 A?

ANSWER:  $6.5 \times 10^{-4} \text{ T}$

**TOSS-UP**

3) CHEMISTRY *Multiple Choice* A cylinder filled with liquid water at a constant temperature of 60 °C is fitted with a piston, and the pressure exerted by the piston is 1 atm. By removing some weights on the piston, and keeping the temperature constant, the pressure within the cylinder is reduced to 0.20 atm, the vapor pressure of water at that temperature. Which of the following is true if the piston is pulled out further?

- W) the volume of the liquid decreases and the volume of the water vapor decreases
- X) the volume of the liquid decreases and the volume of the water vapor increases
- Y) the volume of the liquid increases and the volume of the water vapor decreases
- Z) the volume of the liquid increases and the volume of the water vapor increases

ANSWER: X) THE VOLUME OF THE LIQUID DECREASES AND THE VOLUME OF THE WATER VAPOR INCREASES

**BONUS**

3) CHEMISTRY *Multiple Choice* Assume that the formation of a solution takes place in three distinct

steps. In step 1, the solute is broken up into individual components; in step 2, the intermolecular forces in the solvent are overcome; in step 3, the solute and solvent interact to form the solution.  $\Delta H_{\text{soln}}$  represents the total enthalpy of solution, and is equal to  $\Delta H_1 + \Delta H_2 + \Delta H_3$ , while  $\Delta H_{\text{hyd}}$  represents the enthalpy of hydration and is equal to  $\Delta H_2 + \Delta H_3$ . For which of the following types of solutes and solvents can it be predicted for  $\Delta H_1$  to be largely positive,  $\Delta H_2$  to be positive, and  $\Delta H_3$  to be largely negative, such that  $\Delta H_{\text{hyd}}$  is essentially very large and makes for a small  $\Delta H_{\text{soln}}$ ?

- W) polar solvent and polar solute
- X) polar solvent and nonpolar solute
- Y) nonpolar solvent and polar solute
- Z) nonpolar solvent and nonpolar solute

ANSWER: W) POLAR SOLVENT AND POLAR SOLUTE

#### TOSS-UP

4) MATHEMATICS *Short Answer* Evaluate  $\lim_{x \rightarrow 1} \frac{\ln x^2}{x^2 - 1}$ .

ANSWER: 1

#### BONUS

4) MATHEMATICS *Short Answer* What is the formula for the  $n$ th term of a sequence whose first five terms are  $-\frac{2}{1}, \frac{8}{2}, -\frac{26}{6}, \frac{80}{24}, -\frac{242}{120} \dots$ ?

ANSWER:  $a_n = (-1)^n \left( \frac{3^n - 1}{n!} \right)$

#### TOSS-UP

5) ENERGY *Short Answer* What is the term given to the emergency shutdown of a boiling water reactor, which can be achieved by the immediate insertion of neutron-absorbing control rods into the core of the reactor?

ANSWER: SCRAM

#### BONUS

5) ENERGY *Short Answer* Classify whether the result is a  $p$ -type semiconductor or an  $n$ -type semiconductor when each of the following 4 metals is used as a dopant with silicon:

- 1: phosphorus
- 2: boron
- 3: gallium
- 4: arsenic

ANSWER: 1:  $N$ -TYPE; 2:  $P$ -TYPE; 3:  $P$ -TYPE; 4:  $N$ -TYPE

#### TOSS-UP

6) BIOLOGY *Multiple Choice* What structural DNA-binding motif is created where a region on one of the subunits containing several hydrophobic amino acids interacts with a similar region on the other subunit, creating a “Y” shape where the two arms are helical regions that fit into the groove of the DNA?

- W) helix-turn-helix
- X) homeodomain
- Y) zinc finger
- Z) leucine zipper

ANSWER: Z) LEUCINE ZIPPER

#### BONUS

6) BIOLOGY *Multiple Choice* Which major animal phylum includes comb jellies and sea walnuts, and consists of organisms that are gelatinous, bioluminescent marine animals, with eight bands of cilia, and a complete digestive tract with an anal pore?

- W) brachiopoda
- X) ctenophora
- Y) phoronida
- Z) loricifera

ANSWER: X) CTENOPHORA

#### TOSS-UP

7) EARTH AND SPACE *Short Answer* For every two carbon-12 atoms formed in the triple alpha process for helium fusion, how many gamma rays are emitted?

ANSWER: 4

#### BONUS

7) EARTH AND SPACE *Multiple Choice* Which of the following best describes the difference between drumlins and roche moutonnées?

- W) drumlins are asymmetrical while roche moutonnées are symmetrical
- X) drumlins are composed of till while roche moutonnées are composed of eroded bedrock
- Y) drumlins occur near a mountain glacier while roche moutonnées occur in continental ice sheets
- Z) drumlins occur in isolation while roche moutonnées occur in groups

ANSWER: X) DRUMLINS ARE COMPOSED OF TILL WHILE ROCHE MOUTONNÉES ARE COMPOSED OF ERODED BEDROCK

#### TOSS-UP

8) PHYSICS *Short Answer* Consider a setup where an evacuated glass tube, or photocell, contains a metal plate *a* connected to the negative terminal of a variable power supply and another metal plate *b* maintained at a positive potential by the power supply. When plate *a* is illuminated with light above its threshold frequency, an ammeter detects a photocurrent in the circuit. Which two of the following four statements are true about this photoelectric effect apparatus?

- 1: increasing the frequency of the light incident upon plate *a* increases the maximum kinetic energy of the photoelectrons
- 2: increasing the intensity of the light incident upon plate *a* increases the maximum kinetic energy of the photoelectrons
- 3: electrons are emitted from plate *a* more than  $10^{-3}$  s after it is illuminated, because it takes time for the absorbed energy to exceed the work function
- 4: when the frequency of the incident light on plate *a* is equal to the threshold frequency, the stopping potential is zero

ANSWER: 1 AND 4

### BONUS

8) PHYSICS *Short Answer* A copper surface is illuminated with light of wavelength  $3 \times 10^{-8}$  m. The work function of copper is 4.70 eV. Assuming that this incident light is enough to eject electrons from the copper surface, what is the maximum kinetic energy of the photoelectrons emitted, in eV to two significant digits?

ANSWER: 40

### TOSS-UP

9) CHEMISTRY *Multiple Choice* For compounds of similar molecular weight, which of the following four classes of organic compounds could be predicted to have the highest boiling point?

- W) alkanes
- X) ketones
- Y) alcohols
- Z) carboxylic acids

ANSWER: Z) CARBOXYLIC ACIDS

### BONUS

9) CHEMISTRY *Short Answer* A constant-volume calorimeter showed that the combustion of hexane in the reaction  $2 \text{C}_6\text{H}_{14} + 19 \text{O}_2 \rightarrow 14 \text{H}_2\text{O} + 12 \text{CO}_2$  releases 8,282 kJ of energy at 300 K, so  $\Delta U$  for this reaction is -8,282 kJ. Assuming the ideal gas constant is  $8.3 \text{ J mol}^{-1} \text{ K}^{-1}$ , what is the change in enthalpy for this reaction, to two significant digits?

ANSWER: -8200 kJ

### TOSS-UP

10) MATHEMATICS *Short Answer* The length of the radius of a circle is equal to the length of the side of a square. What is the ratio of the area of the square to the area of the circle?

ANSWER:  $\frac{1}{\pi}$

### BONUS

10) MATHEMATICS *Short Answer* Give the center and vertices of the ellipse given by  $4x^2 + y^2 - 8x + 4y - 8 = 0$ .

ANSWER: CENTER: (1, -2); VERTICES: (1, -6) AND (1, 2)

**TOSS-UP**

11) ENERGY *Multiple Choice* In what temperature interval is water's coefficient of volume expansion negative?

- W) below 0 °C
- X) between 0 °C and 4 °C
- Y) between 4 °C and 100 °C
- Z) above 100 °C

ANSWER: X) BETWEEN 0 °C AND 4 °C

**BONUS**

11) ENERGY *Short Answer* For the ammonia synthesis reaction given by  $\text{N}_2(\text{g}) + 3 \text{H}_2(\text{g}) \rightarrow 2 \text{NH}_3(\text{g})$ , calculate the standard change in Gibbs free energy at 298 K if  $\Delta G_f^\circ$  for  $\text{NH}_3$  is  $-16.45 \text{ kJ mol}^{-1}$ .

ANSWER:  $-32.90 \text{ kJ mol}^{-1}$

**TOSS-UP**

12) BIOLOGY *Short Answer* What is the anal cavity that is present in sea cucumbers, which is significant in pulling in and pushing out water through contractions and in giving rise to extensive internal branching systems known as respiratory trees?

ANSWER: CLOACA

**BONUS**

12) BIOLOGY *Short Answer* By name or number, indicate all of the following 5 classes of plant hormones that can be produced in the apical meristems:

- 1: auxins
- 2: gibberellins
- 3: cytokinins
- 4: ethylene
- 5: oligosaccharins

ANSWER: 1, 3, AND 4

**TOSS-UP**

13) EARTH AND SPACE *Short Answer* Also known as a gizzard stone, what object is common to crocodiles, alligators, and other animals, was sometimes used as a ballast in some ancient organisms, and is a highly polished stomach stone that was mainly used in the grinding of food by some extinct reptiles?

ANSWER: GASTROLITH

**BONUS**

13) EARTH AND SPACE *Multiple Choice* For a group of asteroids in the same Hirayama family,

which of the following properties would not be shared?

- W) eccentricity
- X) inclination
- Y) obliquity
- Z) average distance from the Sun

ANSWER: Y) OBLIQUITY

**TOSS-UP**

14) PHYSICS *Short Answer* Give, by name or number, all of the following four properties of the Higgs boson that is/are non-zero:

- 1: electric charge
- 2: color charge
- 3: spin
- 4: mass

ANSWER: 4 ONLY

**BONUS**

14) PHYSICS *Multiple Choice* In an R-C circuit setup, a resistor is connected in series with a capacitor. Before the switch is closed at time  $t = 0$ , the capacitor is uncharged. Let  $Q$  equal the maximum possible charge for the capacitor. Which of the following choices is closest to the value of actual charge on the capacitor,  $q$ , in the period of time equal to the passage of one time constant after  $t = 0$ ?

- W)  $0.15Q$
- X)  $0.39Q$
- Y)  $0.63Q$
- Z)  $0.87Q$

ANSWER: Y)  $0.63Q$

**TOSS-UP**

15) CHEMISTRY *Short Answer* When heated in the presence of a concentrated acid, what is the major product in the dehydration reaction of 2-butanol?

ANSWER: 2-BUTENE

**BONUS**

15) CHEMISTRY *Short Answer* Classify each of the following 3 reactions as either oxidation or reduction:

- 1: benzoic acid to benzaldehyde
- 2: 2-pentanol to 2-pentanone
- 3: acetone to 2-propanol

ANSWER: 1: REDUCTION; 2: OXIDATION; 3: REDUCTION

**TOSS-UP**

16) MATHEMATICS *Short Answer* Sid places 60 marbles into boxes A, B, C, D, and E. The sum of the marbles in A and B is 24, B and C is 15, C and D is 18, and D and E is 30. How many marbles are in box A?

ANSWER: 15

**BONUS**

16) MATHEMATICS *Short Answer* Find the area of the region bounded by the graphs of  $y = x^2 + 2$ ,  $y = -x$ ,  $x = 0$ , and  $x = 1$ , presenting your answer as a fraction simplified to lowest terms.

ANSWER:  $\frac{17}{6}$

**TOSS-UP**

17) ENERGY *Short Answer* What phenomenon is the spontaneous jerking motion that can occur while two objects are sliding over or past each other, and is apparent in some parts of the San Andreas Fault where elastic energy is stored for hundreds of years before rupturing in massive earthquakes?

ANSWER: STICK-SLIP MOTION

**BONUS**

17) ENERGY *Multiple Choice* In the CNO cycle, the reaction of which of the following nuclides results in the ejection of an alpha particle and the subsequent return to carbon-12?

- W) nitrogen-15
- X) oxygen-15
- Y) nitrogen-14
- Z) carbon-13

ANSWER: W) NITROGEN-15

**TOSS-UP**

18) BIOLOGY *Short Answer* What is the molecule that is secreted by macrophages when they process foreign antigens, which functions to stimulates cell division and proliferation of T cells?

ANSWER: INTERLEUKIN-1

**BONUS**

18) BIOLOGY *Short Answer* What major type of interferon binds to a specific cell surface receptor complex known as the IFN- $\alpha$  receptor, and is only present in humans as IFN- $\alpha$ , IFN- $\beta$ , and IFN- $\omega$ ?

ANSWER: TYPE-1 INTERFERON

**TOSS-UP**

19) EARTH AND SPACE *Short Answer* What components of Jupiter's planetary system, which are densest at the orbits of the moons Amalthea and Thebe, present evidence that ring particles are being blasted into space by impacts on the moons, and are faint rings that extend twice as far as Jupiter's main

rings?

ANSWER: GOSSAMER RINGS

**BONUS**

19) EARTH AND SPACE *Multiple Choice* Of the following four gases, which was present in the least amounts in Earth's primitive atmosphere?

- W) nitrogen
- X) water vapor
- Y) carbon dioxide
- Z) sulfur dioxide

ANSWER: W) NITROGEN

**TOSS-UP**

20) PHYSICS *Short Answer* The position of a particle is given by the function  $x(t) = t^4 - 4t^3$ . If it starts moving at time  $t = 0$ , at what value of  $t$  after it starts moving is its acceleration zero?

ANSWER:  $t = 2$

**BONUS**

20) PHYSICS *Short Answer* The area of a plate in a parallel-plate capacitor is  $4 \times 10^{-1} \text{ m}^2$  and the plates are separated by a distance of 2 mm. Assuming the permittivity of free space is  $8.9 \times 10^{-12} \text{ F m}^{-1}$  and presenting your answer to two significant digits, what is the capacitance of the parallel-plate capacitor, in farads?

ANSWER:  $1.8 \times 10^{-9}$

**TOSS-UP**

21) CHEMISTRY *Multiple Choice* In the electrochemical series, which of the following choices would be the strongest oxidizing agent?

- W)  $\text{Al}^{3+}$
- X)  $\text{Cu}^{2+}$
- Y)  $\text{Br}_2$
- Z)  $\text{F}_2$

ANSWER: Z)  $\text{F}_2$

**BONUS**

21) CHEMISTRY *Multiple Choice* Which of the following coordination complexes is an example of a metallocene, a subset of “sandwich compounds”?

- W)  $[\text{Fe}(\text{CN})_6]^{4-}$
- X)  $[\text{CoCl}_4]^{2-}$
- Y)  $[\text{Fe}(\text{C}_5\text{H}_5)_2]$
- Z)  $\text{Hg}(\text{CH}_3)_2$



ANSWER: Y)  $[\text{Fe}(\text{C}_5\text{H}_5)_2]$

**TOSS-UP**

22) MATHEMATICS *Short Answer* What value of  $x$  satisfies the following equation?

$$4^4 + 4(4^4) + 6(4^4) + 4(4^4) + 4^4 = 2^x$$

ANSWER: 12

**BONUS**

22) MATHEMATICS *Short Answer* Daniel and his friends have some marbles. When Daniel tried to distribute the total number of marbles among himself and his friends by giving 4 to each person, one of his friends received 0 marbles. When Daniel and each of his friends took 3 marbles each, there was one marble left over. What is the difference of the total number of marbles and the number of people present (including Daniel)?

ANSWER: 11

**TOSS-UP**

23) ENERGY *Short Answer* By the “rule of Dulong and Petit”, the molar heat capacities for most elemental solids is close to what value, in J/mol K?

ANSWER: 25

**BONUS**

23) ENERGY *Multiple Choice* In which of the following regions of the United States can it most likely be expected to find a reserve of oil and gas?

- W) off the coast of California
- X) the deserts of Nevada
- Y) the hills of South Dakota
- Z) the forests of North Carolina

ANSWER: W) OFF THE COAST OF CALIFORNIA

**TOSS-UP**

24) BIOLOGY *Multiple Choice* What hormone is a steroid that stimulates the development of secondary sex characteristics in females?

- W) testosterone
- X) melatonin
- Y) progesterone
- Z) estradiol

ANSWER: Z) ESTRADIOL

**BONUS**

24) BIOLOGY *Multiple Choice* Which of the following choices is a direct effect of the secretion of

ADH by the posterior pituitary?

- W) reduced urine volume
- X) increased water retention in the kidney
- Y) dehydration
- Z) higher blood pressure

ANSWER: W) REDUCED URINE VOLUME

### **TOSS-UP**

25) EARTH AND SPACE *Short Answer* Arrange the following three supercontinents in order of occurrence chronologically: Pangaea, Rodinia, Gondwana

ANSWER: 2, 3, 1

### **BONUS**

25) EARTH AND SPACE *Multiple Choice* Which of the following choices best describes why the P-wave shadow zone exists?

- W) because P-waves do not travel through the outer core
- X) because P-waves are refracted downward through the outer core
- Y) because P-waves are refracted sharply at the inner core
- Z) because P-waves are diffracted around the core and are recorded at the other side of the planet

ANSWER: X) BECAUSE P-WAVES ARE REFRACTED DOWNWARD THROUGH THE OUTER CORE