

### **TOSS-UP**

1. Chemistry *Multiple Choice* Which of the following is NOT a strong field ligand?

- W)  $\text{NO}_2^+$
- X) CO
- Y)  $\text{CN}^-$
- Z)  $\text{H}_2\text{O}$

ANSWER: Z)  $\text{H}_2\text{O}$  [AY]

### **BONUS**

1. Chemistry *Short Answer* At approximately 3000 K, the vibrational mode of molecular nitrogen is excited. If U is the change in internal energy upon heating 1 mol of  $\text{N}_2$  from 300 to 500 K, in terms of U what is the change in internal energy upon heating 1 mol of  $\text{N}_2$  from 4500 to 5000 K?

ANSWER: 3U [YL]

### **TOSS-UP**

2. Math *Short Answer* The supplement of angle A is 6 times its complement. What is the measure of A, in degrees?

ANSWER: 72 [EZ]

### **BONUS**

2. Math *Multiple Choice* How many terms are in the expansion of  $(x + 2y + 3z + 4)^{12}$ ?

ANSWER: 455 [EZ]

### **TOSS-UP**

3. Earth and Space *Multiple Choice* Which of the following would you expect during an El Nino event?

- W) Southward shift of the Pacific ITCZ
- X) More rain over Australia
- Y) Colder water along the coast of Peru
- Z) Stronger North Equatorial Current

ANSWER: W) SOUTHWARD SHIFT OF THE PACIFIC ITCZ [KW]

### **BONUS**

3. Earth and Space Multiple Choice Which of the following choices does not consist of a planet and a small body population that they gravitationally dominate?

- W) Jupiter, Greeks
- X) Earth, Minimoons
- Y) Saturn, Centaurs
- Z) Neptune, Plutinos

ANSWER: Y) SATURN, CENTAURS [SC]

#### TOSS-UP

4. Biology *Short Answer* Pyrosequencing, a common DNA sequencing-by-synthesis technique, uses what enzyme obtained from fireflies that luminesces as each nucleotide is added to the elongating strand?

ANSWER: LUCIFERASE [KD]

#### BONUS

4. Biology *Short Answer* A population is in Hardy-Weinberg Equilibrium for a gene whose dominant allele has 50% penetrance in heterozygotes. If the frequency of the recessive allele is 0.4, what is the frequency of the dominant phenotype in this population?

ANSWER: 60% (ACCEPT: 0.60) [KD]

#### TOSS-UP

5. Physics *Multiple Choice* Stephen climbs into a spaceship and uniformly accelerates in a straight line to relativistic speeds. What type of curve will Stephen's world line trace on a Minkowski diagram?

- W) Line
- X) Ellipse
- Y) Parabola
- Z) Hyperbola

ANSWER: Z) HYPERBOLA [YL]

#### BONUS

5. Physics *Multiple Choice* Which of the following is NOT TRUE of lightcones?

- W) Lightcones bound the set of valid worldlines for massive particles

- X) Lightcones mark the boundary between timelike and spacelike intervals
- Y) The invariant interval between an event on a lightcone and the present is constant
- Z) The lightcones for a given object are the same when observed across all frames

ANSWER: Y) THE INVARIANT INTERVAL BETWEEN AN EVENT ON A LIGHTCONE AND THE PRESENT IS CONSTANT [SC]

### TOSS-UP

6. Chemistry *Short Answer* On a Frost-Ebsworth diagram, a species in a “trough”, or lying below the line connecting its two neighbors, is likely to form from what type of reaction?

ANSWER: COMPROPORTIONATION (DO NOT ACCEPT: DISPROPORTIONATION) [YL]

### BONUS

6. Chemistry *Multiple Choice* The  $K_{sp}$  of copper (ii) hydroxide is  $1.6 \times 10^{-19}$ , so a 0.1 molar solution of CuSO<sub>4</sub> is expected to precipitate when the concentration of OH<sup>-</sup> is  $1.26 \times 10^{-9}$ . This means that in neutral or even slightly acidic solution, a precipitate of Cu(OH)<sub>2</sub> would be predicted to be formed. However, copper (ii) sulfate solutions in reality do not form any precipitates. Which of the following best explains this discrepancy?

- W) Cu<sup>2+</sup> forms ion pairs in solution with SO<sub>4</sub><sup>2-</sup>
- X) The hydrated form of Cu(OH)<sub>2</sub> has a much higher K<sub>sp</sub> than the anhydrous form
- Y) Cu<sup>2+</sup> is acidic and lowers the pH of the solution
- Z) SO<sub>4</sub><sup>2-</sup> is basic and raises the pH of the solution

ANSWER: Y) Cu<sup>2+</sup> is acidic and lowers the pH of the solution [W: YL, E: ; C MDE]

### TOSS-UP

7. Math *Multiple Choice* Which of the following points does NOT lie on the Euler line?

- W) Circumcenter
- X) Centroid
- Y) Incenter
- Z) Orthocenter

ANSWER: Y) INCENTER [EZ]

### BONUS

7. Math *Short Answer* A function f has a domain of size 10 and a codomain of size 15. Identify all of the following adjectives that could NOT describe the function:

- 1) Injective
- 2) Surjective
- 3) Bijective

ANSWER: 2 AND 3 [EZ]

### TOSS-UP

8. Earth and Space *Short Answer* Identify all of the following three processes that will result in the formation of gravitational waves:

- 1) Spherically symmetric type-II supernova
- 2) Planet rotating about a star
- 3) Binary star system rotating about its barycenter

ANSWER: 2 AND 3 [YL]

### BONUS

8. Earth and Space *Multiple Choice* Which of the following qualities of a stratovolcano and its environment would likely not impact the chance an eruption causes a lahar?

- W) Annual rainfall in the region
- X) Temperature of the local climate
- Y) Presence of a caldera
- Z) Height of the volcano

ANSWER: X) TEMPERATURE OF THE LOCAL CLIMATE [SC]

### TOSS-UP

9. Biology *Short Answer* Stephen's epiphyseal (*ep-ee-FIZ-ee-uhI*) plates are not being sealed properly. What enzyme, which is necessary for the production of estrogen in males, is likely malfunctioning in Stephen?

ANSWER: AROMATASE [KD]

### BONUS

9. Biology *Multiple Choice* Interestingly, in Lily plants, one of the two polar nuclei is triploid instead of haploid. Given that Lily plants are angiosperms, their endosperm following double fertilization would have which of the following ploidies?

- W Diploid
- X) Triploid
- Y) Tetraploid
- Z) Pentaploid

ANSWER: Z) PENTAPLOID [KD]

### TOSS-UP

10. Physics *Short Answer* Order the following three classes of material in order of increasing magnetic susceptibility.

- 1) Diamagnet
- 2) Paramagnet
- 3) Superconductor

ANSWER: 3, 1, 2 [SC]

### BONUS

10. Physics *Short Answer* Stephen shines a laser at a perfectly reflecting mirror moving away from him at 0.5 times the speed of light. If he shines the laser with a wavelength of 500 nm, what does he observe the wavelength of the reflected wave to be?

ANSWER: 1500 nm [SC]

### TOSS-UP

11. Chemistry *Short Answer* Identify all of the following three organic species for which the tertiary species is more stable than the primary species:

- 1) Carbocation [**car-bo-CAT-ion**]
- 2) Radical
- 3) Carbanion [**carb-AN-ion**]

ANSWER: 1 AND 2 [YL]

### BONUS

11. Chemistry *Multiple Choice* Andy isolated a sample of 1.00 gram of  $\text{FeCl}_3 \cdot 6\text{H}_2\text{O}$ . He finds the number of moles of chloride ions in the sample through the Mohr [**moor**] method, which involves titration using silver nitrate with an  $\text{Ag}_2\text{CrO}_4$  endpoint. Unfortunately, the number of moles of chloride ions that Andy measured was lower than what it is predicted to be based on the molar mass. Which of the following errors can explain this discrepancy?

- W) Andy overshot the endpoint in the titration
- X) The FeCl<sub>3</sub> solution was left standing and absorbed water from the atmosphere
- Y) Andy calculated the FeCl<sub>3</sub> as being the hexahydrate **[he-xa-HIGH-drate]** but it was actually anhydrous
- Z) Some of the chloride ions were complexed to Fe<sup>3+</sup>

ANSWER: Z) Some of the chloride ions were complexed to Fe<sup>3+</sup> **[YL]**

### **TOSS-UP**

12. Math *Multiple Choice* What theorem relates the surface integral of the curl of a vector to the line integral around the boundary of the surface?

- W) Green's Theorem
- X) Divergence Theorem
- Y) Stokes' Theorem
- Z) Fundamental Theorem of Path Integration

ANSWER: Y) STOKES' THEOREM **[YL]**

### **BONUS**

12. Math *Short Answer* What is the maximum number of points that can be chosen inside a unit hexagon such that the distance between any two points is strictly greater than 1?

ANSWER: 5 **[EZ]**

### **TOSS-UP**

13. Earth and Space *Short Answer* Identify all of the following three groups whose shells could make up a sample of seafloor limestone:

- 1) Forams
- 2) Radiolarians
- 3) Diatoms.

ANSWER: 1 ONLY **[KW]**

### **BONUS**

13. Earth and Space *Short Answer* Jerry and his mom are using identical telescopes to observe the Orion Nebula and the Andromeda Galaxy, respectively. They notice that although Andromeda has a lower apparent magnitude than Orion, Jerry can clearly see features in his

nebula while his mom can barely see anything. This is because the Andromeda galaxy has a lower value than Orion for what apparent quantity?

ANSWER: SURFACE BRIGHTNESS [SC]

**TOSS-UP**

14. Biology *Short Answer* What type of opsin, found in the ganglion cell layer of the retina, helps communicate the presence of light to the suprachiasmatic (SOO-pruh-KY-az-mat-ic) nucleus?

ANSWER: MELANOPSIN [KW]

**BONUS**

14. Biology *Multiple Choice* Which of the following is not a function commonly performed by a non-coding RNA?

- W) Silencing transposons
- X) Inactivating X chromosomes
- Y) Guiding proteins to the Endoplasmic Reticulum
- Z) Controlling progression through the cell cycle

ANSWER: Z) CONTROLLING PROGRESSION THROUGH THE CELL CYCLE [KD]

**TOSS-UP**

15. Physics *Multiple Choice* Which of the following pendulums will have the greatest oscillation frequency?

- W) 5 kilogram weight on the end of a 2 meter massless string
- X) 10 kilogram weight on the end of a 5 meter massless string
- Y) Uniform 5 kilogram rod with length 2 meters
- Z) Uniform 10 kilogram rod with length 5 meters

ANSWER: Y) Uniform 5 kilogram rod with length 2 meters [YL]

**BONUS**

15. Physics *Short Answer* To block out an extremely loud full-spectrum speaker near his head, Stephen surrounds his ears with headphones, which are hemispheres of radius 0.17 m and have acoustic indices of refraction of 2. However, standing resonant modes appear in his headphones themselves. In Hertz, what is the frequency of the longest-wavelength mode that appears if the speed of sound is 340 m/s?

ANSWER: 500 Hz [SC]

### TOSS-UP

16. Chemistry *Multiple Choice* Evan is titrating phosphoric acid with sodium hydroxide, but he cannot see the third equivalence point because the pH change is too small. Which of the following can be added into the reaction mixture in order to better visualize the third equivalence point?

- W) Bromothymol Blue [bro-mo-THIGH-mol bloo]
- X) Pyridine [PI-ri-dine]
- Y) Dilute acetic acid
- Z) Sodium chloride

ANSWER: X) PYRIDINE [YL]

### BONUS

16. Chemistry *Short Answer* Given that the pKa of hydrofluoric acid is 3.2 and the pKb of sodium acetate is 9.2, what is the pH of a solution formed by mixing 50 mL of 0.2 molar hydrofluoric acid with 25 mL of 0.4 molar sodium acetate?

ANSWER: 4 [YL]

### TOSS-UP

17. Math *Short Answer* Anuva is walking down the road at 3 miles per hour for 30 minutes. Suddenly, it begins to rain and she runs at 10 miles per hour for 15 minutes. What is her average speed in miles per hour over the 45 minutes?

ANSWER: 16/3 [EZ]

### BONUS

17. Math *Short Answer* Identify all of the following three theorems that require that a function be differentiable across the entire interval being considered:

- 1) Intermediate value theorem
- 2) Mean value theorem
- 3) Extreme value theorem

ANSWER: 2 ONLY [EZ]

### **TOSS-UP**

18. Earth and Space *Multiple Choice* Which of the following transient astrophysical events likely *cannot* be triggered by a white dwarf?

- W) Nova
- X) Kilonova
- Y) Supernova
- Z) Hypernova

ANSWER: Z) HYPERNOVA [SC]

### **BONUS**

18. Earth and Space *Short Answer* An island near a subduction zone is approaching the relevant continental plate. As the island collides with the continental plate, order the following three stages of its evolution from earliest to latest. 1) Accretionary wedge 2) Terrane 3) Accretionary complex

ANSWER: 312 [SC]

### **TOSS-UP**

19. Biology *Short Answer* Identify all of the following 3 locations in the cell where disulfide bridges are likely to be found:

- 1) Peroxisome
- 2) Mitochondria
- 3) Cytoplasm

ANSWER: 1 ONLY [KD]

### **BONUS**

19. Biology *Short Answer* Identify all of the following 4 molecules that upregulate phosphofructokinase-1:

- 1) ATP
- 2) Citrate
- 3) Fructose 1,6-bisphosphate
- 4) Fructose 2,6-bisphosphate

ANSWER: 4 ONLY [KD]

### **TOSS-UP**

20. Physics *Short Answer* Two light sources have intensities 25 watts per square meter and 49 watts per square meter. If these two waves are perfectly in phase, what is the intensity of the resulting wave?

ANSWER: 144 [YL]

### **BONUS**

20. Physics *Short Answer* A stream of colored fluid falls a long distance from its source and impacts a pool of a different, clear fluid. Which of the following instabilities would be observed in this system?

- 1) Plateau-Rayleigh
- 2) Rayleigh-Taylor
- 3) Saffman-Taylor

ANSWER: 12 [SC]

### **TOSS-UP**

21. Chemistry *Short Answer* The analysis of iron nuclei would most likely involve what type of spectroscopy that is based on recoilless gamma-ray emission and absorption?

ANSWER: MOSSBAUER SPECTROSCOPY [YL]

### **BONUS**

21. Chemistry *Short Answer* Assuming the temperature required for  $\text{PF}_5$  to undergo Berry pseudorotation [**SUE-do-ro-ta-tion**] is approximately 100 K, how many signals will be seen in the fluorine-19 NMR spectrum of  $\text{PF}_5$  at 50 K and at 300 K respectively?

ANSWER: 2 AND 1 (MUST BE IN THAT ORDER) [YL]

### **TOSS-UP**

22. Math *Multiple Choice* Which of the following base 15 numbers is divisible by 7?

- W) 123
- X) 1234
- Y) 12345
- Z) 123456

ANSWER: Z) 123456 [KD]

**BONUS**

22. Math *Short Answer* What is the remainder when  $11^{2024}$  is divided by 100?

ANSWER: 41 [YL]

**TOSS-UP**

23. Earth and Space *Short Answer* A large shield volcano is rapidly generated over the course of 200,000 years by an exceptionally hot mantle plume. What type of large-scale arrangement of igneous intrusions likely exists beneath the volcano, parallel to its slope?

ANSWER: DIKE SWARM [SC]

**BONUS**

23. Earth and Space *Short Answer* Katherine is observing an active galactic nucleus, but only sees a single jet. She notes that this jet lies in front of the host galaxy from her perspective. What phenomenon is causing only one jet to be visible?

ANSWER: RELATIVISTIC BEAMING (ACCEPT: HEADLIGHT EFFECT, DOPPLER BEAMING) [SC]

**TOSS-UP**

24. Biology *Multiple Choice* Yunyi is attempting to pick up his piano using his bicep muscles, however the piano is not budging. Which of the following terms best describes the type of contraction Yunyi's biceps are undergoing?

- W) Isotonic
- X) Isometric
- Y) Concentric
- Z) Eccentric

ANSWER: X) ISOMETRIC [KD]

**BONUS**

24. Biology *Short Answer* Identify all of the following 4 hormones that peak in concentration within one day of ovulation during the menstrual cycle:

- 1) FSH
- 2) LH
- 3) Progesterone
- 4) Estradiol

ANSWER: 1, 2, 4 [KD]

#### TOSS-UP

25. Physics *Short Answer* In certain plasma flows, the Lorentz force strongly contracts parallel currents. What is the term for this effect, which was implemented in many early magnetic confinement fusion reactors?

ANSWER: Z-PINCH [SC]

#### BONUS

25. Physics *Short Answer* A convex spherical lens is made of glass with an index of refraction of 1.5 and has a radius of curvature of 60 cm. When placed in air with an index of refraction of 1, what is the focal length of this lens in centimeters?

ANSWER: 60 [YL]