

### **TOSS-UP**

1. Chemistry *Short Answer* A sealed 20 centimeter long tube contains hydrogen gas at one end and oxygen gas at the other end. The two gasses are simultaneously released and allowed to diffuse towards each other. In centimeters, how far away from the hydrogen end is the point where the two gasses first meet?

ANSWER: 16 [YL]

### **BONUS**

1. Chemistry *Multiple Choice* According to Baldwin's Rules, which of the following reactions would be the most disfavored? (**Read as written**)

- W) 3-exo-tet
- X) 5-endo-dig
- Y) 5-endo-trig
- Z) 7-exo-trig

ANSWER: Y) 5-ENDO-TRIG [YL]

### **TOSS-UP**

2. Math *Short Answer* Consider five irrational constants  $a$ ,  $b$ ,  $c$ ,  $d$ , and  $e$  that are not multiples of each other. Let  $G$  be the function  $\cos(f x)$ , where  $f$  is the sum of the reciprocals of  $a$ ,  $b$ ,  $c$ ,  $d$ ,  $e$ . How many peaks are in the Fourier transform of  $G$ ?

ANSWER: 5 [SC]

### **BONUS**

2. Math *Short Answer* A triangle is placed on the coordinate plane with vertices at the points  $(0, 0)$ ,  $(6, 0)$ , and  $(0, 8)$ . Three congruent circles of radius 1 are drawn centered at each vertex. Giving your answer as an ordered pair, what are the coordinates of the radical center of the three circles?

ANSWER:  $(3, 4)$  [YL]

### **TOSS-UP**

3. Earth and Space *Short Answer* As the universe ages, identify all of the following three quantities that increase:

- 1) Hubble constant

- 2) Critical density
- 3) Hubble radius

ANSWER: 3 ONLY [SC]

### BONUS

3. Earth and Space *Multiple Choice* Which of the following is FALSE about the ionosphere?

- W) The ionosphere contains currents coupled with the Earth's magnetosphere
- X) Ionospheric convection produces localized magnetic dynamos
- Y) Transitions between layers occur primarily due to atmospheric composition
- Z) Transient layers appear both during the day and night

ANSWER: Z) TRANSIENT LAYERS APPEAR BOTH DURING THE DAY AND NIGHT [SC]

### TOSS-UP

4. Biology *Multiple Choice* Which of the following statements regarding slow-oxidative and fast-glycolytic muscle fibers is NOT true:

- W) Slow-oxidative fibers contain more mitochondria
- X) Sprinters typically possess more fast-glycolytic fibers in the calf
- Y) Slow-oxidative fibers store more myoglobin
- Z) Fast-glycolytic fibers are surrounded by more blood vessels

ANSWER: Z) FAST-GLYCOLYTIC FIBERS ARE SURROUNDED BY MORE BLOOD VESSELS [KD]

### BONUS

4. Biology *Multiple Choice* Evan is studying Michaelis-Menten kinetics and finds out that chymotrypsin's  $K_m$  is approximately 0.01 Molar and its  $V_{max}$  is about 50 nanomolar per minute. If he then models chymotrypsin in the presence of a competitive inhibitor on a Lineweaver-Burk Plot, which of the following statements must be TRUE regarding the resulting graph?

- W) The X intercept is greater than -100
- X) The X intercept is less than -100
- Y) The Y intercept is greater than 0.02
- Z) The Y intercept is less than 0.02

ANSWER: W) THE X INTERCEPT IS GREATER THAN -100 [KD]

### TOSS-UP

5. Physics *Short Answer* Reva has constructed a railgun that uses a uniform magnetic field to accelerate a projectile. Once the initial currents to create the field have been supplied, no additional power is added to the railgun as it fires and spools down. The final ejection velocity of the projectile is then dependent on what factor of the intensity of the magnetic field?

- W)  $-\frac{1}{2}$
- X)  $\frac{1}{2}$
- Y) 1
- Z) 2

ANSWER: Y) 1 [SC]

### BONUS

5. Physics *Short Answer* A ring and a rod are made of the same material, with the rod being the same length as the diameter of the ring. They are placed on the same surface such that they see the same coefficient of friction. When these two objects are given the same angular velocity, what is the ratio of the time it takes for the ring to stop to that of the rod?

ANSWER: 2/3 [SC]

### TOSS-UP

6. Chemistry *Short Answer* Identify all of the following three terms in the Michaelis-Menten [mi-KELL-is MENT-en] equation that, when doubled, doubles the rate of the reaction:

- 1)  $V_{\max}$
- 2)  $K_m$
- 3) Concentration of the substrate

ANSWER: 1 ONLY [YL]

### BONUS

6. Chemistry *Short Answer* The reaction between an acyl chloride and an alcohol is often promoted by adding pyridines such as DMAP [DEE-map]. Identify all of the following four roles that DMAP [DEE-map] plays in this reaction:

- 1) Base
- 2) Nucleophile [NOO-clee-oh-file]
- 3) Electrophile [ee-LEC-tro-file]
- 4) Good leaving group

ANSWER: 1, 2, AND 4 [YL]

### TOSS-UP

7. Math *Short Answer* For which of the following four ordered pairs do the 2-dimensional Dirac delta and the Kronecker delta have the same value?

- 1) (0, 0)
- 2) (1, 0)
- 3) (1, 1)
- 4) (0,1)

ANSWER: 1, 2, 4 [SC]

### BONUS

7. Math *Short Answer* Kian the frog is hopping along the vertices of a tetrahedron. Every second he has a  $\frac{1}{3}$  chance of going to one of the other vertices. What is the expected number of hops it will take him to return to his original vertex?

ANSWER: 4 [EZ]

### TOSS-UP

8. Earth and Space *Short Answer* When solving the hydrostatic equation for a planet made of a polytropic fluid, a possible end goal is a differential equation for relative density in terms of radius. What is the term for this equation?

ANSWER: LANE-EMDEN EQUATION [SC]

### BONUS

8. Earth and Space *Multiple Choice* A region has alternating beds of sandstone and shale that have been deformed into synclines and anticlines. Erosion has been at work on this surface for millions of years. Which of the following drainage patterns is most likely to form here?

- W) Rectangular
- X) Radial
- Y) Trellis
- Z) Deranged

ANSWER: Y) TRELLIS [KW]

### **TOSS-UP**

9. Biology *Multiple Choice* Katherine just ate a food item, activating a large number of G-Protein Coupled Receptors in her taste buds. Which of the following foods did she LEAST likely eat?

- W) Candy
- X) Coffee powder
- Y) Mushrooms
- Z) Lemon

ANSWER: Z) LEMON [KD]

### **BONUS**

9. Biology *Multiple Choice* Given that creatinine is secreted in small amounts into the filtrate but NOT reabsorbed from the filtrate, which of the following best compares the creatinine clearance to the glomerular filtration rate, or GFR?

- W) The creatinine clearance is an underestimate of GFR
- X) The creatinine clearance is equal to GFR
- Y) The creatinine clearance is an overestimate of GFR
- Z) The creatinine clearance could be an overestimate or underestimate of GFR depending on how much is secreted

ANSWER: Y) THE CREATININE CLEARANCE IS AN OVERESTIMATE OF GFR [KD]

### **TOSS-UP**

10. Physics *Multiple Choice* A particle of mass  $m$  is placed at the origin in a one-dimensional potential well  $U$  and is given a small displacement. Which of the following values of  $U$ , in terms of displacement  $x$ , would result in the largest period of oscillations?

- W)  $5x^2$
- X)  $4x^4 + 3x^3 + 2x^2$
- Y)  $x^2 - 2x + 1$
- Z)  $x^3 + 6x^2 + 2$

ANSWER: Y)  $x^2 - 2x + 1$  [SC]

### **BONUS**

10. Physics *Multiple Choice* A missile is launched in a parabolic trajectory, but stops and glides down in a line at an angle of 45 degrees to the vertical after it reaches its maximum height.

Which of the following is always true when comparing this missile to a ballistic one launched at the same angle and speed? Assume the ground is horizontal and flat.

- W) The gliding missile's range is longer
- X) The gliding missile's time of flight is longer
- Y) The gliding missile's average horizontal speed is higher
- Z) The gliding missile's distance traveled is longer

ANSWER: X) THE GLIDING MISSILE'S FLIGHT TIME IS LONGER [SC]

#### TOSS-UP

11. Chemistry *Short Answer* What rule states that when drawing a tie line on a T-X diagram, the ratio of the lengths of the two tie line segments equals the ratio of the mole fractions of the vapor and liquid phases?

ANSWER: LEVER RULE [YL]

#### BONUS

11. Chemistry *Multiple Choice* Coupling and the Nuclear Overhauser [**OH-ver-house-er**] Effect are two ways spin-nuclei can interact with each other. Which of the following gives the correct forms of interaction for coupling and the Nuclear Overhauser Effect, respectively?

- W) Through-bond, through-bond
- X) Through-bond, through-space
- Y) Through-space, through-bond
- Z) Through-space, through space

ANSWER: X) THROUGH-BOND, THROUGH-SPACE [YL]

#### TOSS-UP

12. Math *Multiple Choice* Which of the following conditions does not imply A is a singular matrix?

- W) Zero is an eigenvalue of A
- X) The zero matrix is a power of A
- Y) The row-reduced form of A has a row of zeros
- Z) The zero vector is not in the kernel of A

ANSWER: Z) THE ZERO VECTOR IS NOT IN THE KERNEL [SC]

## BONUS

12. Math *Short Answer* How many subsets of the set of integers from 1 to 8 contain no consecutive elements?

ANSWER: 55 [EZ]

## TOSS-UP

13 . Earth and Space *Multiple Choice* The Laplace-Runge-Lenz or LRL vector is a conserved quantity in Keplerian orbits. At an arbitrary point in such an orbit, which of the following is accurate about the LRL vector's direction?

- W) Parallel to the major axis of the orbit
- X) Parallel to the minor axis of the orbit
- Y) Normal to the plane of the orbit
- Z) Pointing towards a focus of the orbit

ANSWER: W) PARALLEL TO THE MAJOR AXIS OF THE ORBIT [SC]

## BONUS

13. Earth and Space *Multiple Choice* The Moon's orbit, when drawn in the Sun's reference frame, possesses which of the following four qualities?

- W) Smooth
- X) Concave
- Y) Self-intersecting
- Z) Regular

ANSWER: W) SMOOTH [SC]

## TOSS-UP

14. Biology *Multiple Choice* Evan was recently hit in the head, suffering severe damage to his thalamus. Which of the following of Evan's senses would most likely remain unaffected following this damage?

- W) Gustation
- X) Audition
- Y) Olfaction
- Z) Vision

ANSWER: Y) OLFACTION [KD]

## BONUS

14. Biology *Multiple Choice* Katherine goes into a cell and artificially deactivates phospholipase (*FOS-fo-LY-pase*) C. Which of the following molecules would you expect to increase in concentration in this cell following this deactivation?

- W) Diacylglycerol (*di-AY-suhl-gliss-er-awl*)
- X) Inositol (*in-O-sit-awl*) triphosphate
- Y) Cyclic AMP
- Z) Phosphatidylinositol (*fos-fa-TY-duhl-in-O-sit-awl*) Bisphosphate

ANSWER: Z) PHOSPHATIDYLINOSITOL BISPHOSPHATE [KD]

## TOSS-UP

15. Physics *Multiple Choice* A laser is shone onto the top of a flat tank of water, hitting the surface with an angle theta to the horizontal. A photometer measures the reflected flux. As theta is increased from 0 to 90 degrees, which of the following describes this flux?

- W) Zero, then a nonzero constant
- X) A nonzero constant, then zero
- Y) Increases monotonically from zero
- Z) Decreases monotonically from a nonzero constant

ANSWER: Z) DECREASES MONOTONICALLY FROM A NONZERO CONSTANT [SC]

## BONUS

15. Physics *Multiple Choice* One end of a Hookean spring is attached to a mass of m, and the other is fixed to an inclined plane with some coefficient of friction of mu. Let the inclined plane make an angle of theta to the horizontal. Which of the following describes the time it takes for the mass to come to rest from an arbitrary displacement as a function of theta between 0 and 90 degrees?

- W) Increases without bound
- X) Decreases without bound
- Y) Increases, then decreases
- Z) Decreases, then increases

ANSWER: Z) DECREASES, THEN INCREASES [SC]

## TOSS-UP

16. Chemistry *Short Answer* How many stereoisomers [**STARE-ee-oh-ICE-oh-mers**] does 2,3-dibromobutane [**die-bro-mo-BUTE-ain**] have?

ANSWER: 3 [**YL**]

### BONUS

16. Chemistry *Short Answer*  $\text{NiCl}_4^{2-}$  is a tetrahedral coordinate complex with 8 d electrons. As a fraction in terms of  $\Delta_O$  (**READ AS: delta O**), the octahedral splitting parameter, calculate the crystal field stabilization energy of  $\text{NiCl}_4^{2-}$ .

ANSWER:  $-16/45 \Delta_O$  [**YL**]

### TOSS-UP

17. Math *Short Answer* Kian has an unfair coin where the probability of landing heads is %. What is the expected number of times Kian must flip his coin in order to obtain 10 heads?

ANSWER: 25 [**YL**]

### BONUS

17. Math *Short Answer*  $f(x) = x^5 - 10x^3 + 20x^2 - 8x + 5$ . What is the x coordinate of the point of inflection for  $f(x)$ ?

ANSWER: -2 [**EZ**]

### TOSS-UP

18. Earth and Space *Multiple Choice* As a globular cluster ages, what describes the motion of its turnoff point on the H-R Diagram?

- W) Up and to the right
- X) Up and to the left
- Y) Down and to the right
- Z) Down and to the left

ANSWER: Y) DOWN AND TO THE RIGHT [**SC**]

### BONUS

18. Earth and Space *Multiple Choice* According to the Nice model, the long-term migration of the Jovian planets in the early solar system was most strongly driven by protracted interactions with what?

- W) Small protoplanets
- X) Terrestrial planets
- Y) Now-ejected gas giants
- Z) Nearby stars

ANSWER: W) SMALL PROTOPLANETS [SC]

### TOSS-UP

19. Biology *Multiple Choice* An Ni-affinity chromatography is run on a series of peptides in a test tube. Which of the following peptide sequences is LEAST likely to wash through the column?

- W) EEE
- X) RRR
- Y) HHH
- Z) DDD

ANSWER: Y) HHH [KD]

### BONUS

19. Biology *Multiple Choice* In a certain gene, the probability of a transition mutation occurring is  $\frac{1}{2}$  and the probability of a transversion mutation occurring is  $\frac{1}{3}$ . Using this information, what is the probability that the sequence GAC mutates directly into CCA?

ANSWER: 1/27 [KD]

### TOSSUP

20. Physics *Short Answer* To shield a sensitive instrument from magnetic fields, Brian places it inside a box made of material G. The magnetic flux through the box is now very high, while the flux reaching the instrument is very small. Which of the following three quantities must be *higher* for G than in vacuum?

- 1) Magnetic permeability
- 2) Magnetic susceptibility
- 3) Index of refraction

ANSWER: 1 AND 2 [SC]

### BONUS

20. Physics *Multiple Choice* A dipole with a dipole moment of  $20 \text{ Amp m}^2$  and moment of inertia  $10 \text{ kg m}^2$  is initially aligned with a 5 tesla magnetic field. If the dipole is slightly nudged, what is the period of the resulting oscillations, to the nearest second?

ANSWER: 2 [SC]

### TOSS-UP

21. Chemistry *Short Answer* The Mond process is an important industrial process for extracting nickel. A key intermediate step of the Mond process involves the formation of what gaseous nickel complex?

ANSWER: NICKEL TETRACARBONYL (ACCEPT:  $\text{Ni}(\text{CO})_4$ ) [YL]

### BONUS

21. Chemistry *Multiple Choice* Which of the following reasons best explains why the NMR shift of a phenyl hydrogen is further downfield than that of a vinylic hydrogen?

- W) The phenyl [FEE-nil] hydrogen is part of a conjugated system
- X) The  $\text{sp}^2$  orbital is resonance stabilized and lower in energy for the phenyl
- Y) The electron density around the phenyl hydrogen is greater
- Z) Inductive effects add to the magnetic field experienced by the hydrogen

ANSWER: Z) Inductive effects add to the magnetic field experienced by the hydrogen [YL]

### TOSS-UP

22. Math *Multiple Choice* A cube with side length 6 units is filled with water. The water is then poured into a cone with base radius 4 units, fully filling it. Which of the following is closest to the height of the cone?

- W) 10
- X) 13
- Y) 15
- Z) 18

ANSWER: X) 13 [EZ]

### BONUS

22. Math *Short Answer* An equilateral triangle is inscribed in a unit square. What is the area of the triangle?

ANSWER:  $2\sqrt{3} - 3$  [EZ]

### TOSS-UP

23. Earth and Space *Multiple Choice* Which of the following pairs of rocks would you most expect to find in an ignimbrite?

- W) Peridotite and kimberlite
- X) Basalt and komatiite
- Y) Hornfels and greenschist
- Z) Tuff and pumice

ANSWER: Z) TUFF AND PUMICE [KW]

### BONUS

23. Earth and Space *Multiple Choice* Bill is examining the gravity anomaly gradient across a mid-atlantic ridge. As he crosses from one side to the ridge valley and then to the other side, which of the following is true about the local gravity anomaly?

- W) Gravity anomaly initially increases, then decreases
- X) The deflection of the vertical does not change direction
- Y) The vertical gradient of gravity remains constant
- Z) The geoid undulation exhibits a strong dip over the ridge

ANSWER: Y) THE VERTICAL GRADIENT OF GRAVITY REMAINS CONSTANT [SC]

### TOSS-UP

24. Biology *Short Answer* Identify all of the following 3 structures that you would expect to find in higher quantities on the abaxial side of a leaf than on the adaxial side:

- 1) Spongy Mesophyll
- 2) Stomata
- 3) Chloroplasts

ANSWER: 1 AND 2 [KD]

### BONUS

24. Biology *Short Answer* An aardvark ingests 300 Joules of food but 100 J of this energy ends up in its feces. Given that the aardvark used 150 J of energy for cellular respiration, what is its production efficiency?

ANSWER: 25% [KD]

**TOSS-UP**

25. Physics *Multiple Choice* Which of the following optical effects is incorrectly matched with its type?

- W) Birefringence, refractive
- X) Purple fringing, diffractive
- Y) Glory, reflective
- Z) Twinkling, refractive

ANSWER: Y) GLORY, REFLECTIVE [SC]

**BONUS**

25. Physics *Short Answer* Neutrinos interact only with gravity and the weak force. The weak force can be mediated by W and Z bosons. The exchange of electrically neutral Z bosons results in what interaction, whose discovery precipitated the electroweak unification?

ANSWER: WEAK NEUTRAL CURRENT [YL]