

### TOSS-UP

1) PHYSICS *Multiple Choice* Which of the following best describes the intensity of the transmitted light when natural light is passed through an ideal polarizing filter ?

- W) 0 times the intensity of the unpolarized light
- X)  $\frac{1}{4}$  the intensity of the unpolarized light
- Y)  $\frac{1}{2}$  the intensity of the unpolarized light
- Z) 1 times the intensity of the unpolarized light

ANSWER: Y)  $\frac{1}{2}$  TIMES THE INTENSITY OF THE UNPOLARIZED LIGHT

### BONUS

1) PHYSICS *Short Answer* Natural light is incident upon a polarizing filter, and a second polarizer is placed behind the first, where  $\theta$  is the angle between the polarizing axes of the first and second polarizers, respectively. Assuming the original intensity of the incident light is given by  $I_0$ , what is the intensity of the light after it passes through the second filter, if  $\theta = 45^\circ$ ? Leave your answer in terms of  $I_0$ .

ANSWER:  $\frac{1}{4} I_0$

### TOSS-UP

2) EARTH AND SPACE *Multiple Choice* Which of the following fossil structures is formed when the hollow spaces within a shell or other figure are subsequently filled with mineral matter?

- W) mold
- X) cast
- Y) impression
- Z) replacement

ANSWER: X) CAST

### BONUS

2) EARTH AND SPACE *Short Answer* What proposed hypothesis suggests that the two bright lobes of a radio source are inflated as cavities in the intergalactic medium when the active galaxies emit high-energy jets of fast gas, creating hot spots?

ANSWER: DOUBLE-EXHAUST MODEL

### TOSS-UP

3) BIOLOGY *Multiple Choice* Which of the following steps occurs first when Gram staining a bacterial sample?

- W) counterstaining with safranin
- X) decolorizing with alcohol
- Y) adding of a mordant
- Z) applying crystal violet

ANSWER: Z) APPLYING CRYSTAL VIOLET

### BONUS

3) BIOLOGY *Short Answer* Which two of the following four bacterial species will stain purple or blue in the Gram staining process?

- 1: E.coli
- 2: salmonella
- 3: bacillus
- 4: staphylococcus

ANSWER: 3 AND 4

### TOSS-UP

4) MATHEMATICS *Short Answer* Given that vector  $v = \langle -2, 5 \rangle$  and  $w = \langle 3, 4 \rangle$ , what is  $v + 2w$ ?

ANSWER:  $\langle 4, 13 \rangle$

### BONUS

4) MATHEMATICS *Multiple Choice* Given that vector  $u = \langle 3, -1, 2 \rangle$ ,  $v = \langle -4, 0, 2 \rangle$ ,  $w = \langle 1, -1, -2 \rangle$ , and  $z = \langle 2, 0, -1 \rangle$ , which of the following pairs of vectors is orthogonal?

- W)  $u$  and  $v$
- X)  $u$  and  $w$
- Y)  $v$  and  $z$
- Z)  $w$  and  $z$

ANSWER: X)  $u$  AND  $w$

### TOSS-UP

5) CHEMISTRY *Short Answer* Given that  ${}^{145}_{64}\text{Gd}$  is a nuclide that lies below the band of stability on a graph of atomic number vs. mass number, indicate, by name or number, all of the following 4 types of decay that it can be predicted to undergo:

- 1: electron capture
- 2: proton emission
- 3: beta-minus emission
- 4: beta-plus emission

ANSWER: 1, 2, AND 4

### BONUS

5) CHEMISTRY *Multiple Choice* Which of the following units of radiation, which is not commonly in use anymore, is defined to be  $3.7 \times 10^{10}$  disintegrations per second, roughly equal to the decay of 1 gram of  ${}^{226}\text{Ra}$ ?

- W) Becquerel
- X) Curie
- Y) Gray
- Z) Sievert

ANSWER: X) CURIE

**TOSS-UP**

6) ENERGY *Multiple Choice* Which of the following first-generation biofuels consists of methane that is produced by the process of anaerobic digestion of organic material by anaerobes, and can be produced either from biodegradable waste material or from energy crops fed into anaerobic digesters?

- W) bioalcohol
- X) green diesel
- Y) bioether
- Z) biogas

ANSWER: Z) BIOGAS

**BONUS**

6) ENERGY *Short Answer* In what clean coal technology is crushed coal mixed with limestone and suspended on jets of air inside a boiler, where the limestone acts like a sponge and captures 90% of the organic sulfur that is released, and nitrogen and sulfur oxides are kept in check because the temperature is below the threshold where pollutants form?

ANSWER: FLUIDIZED BED COMBUSTOR

**TOSS-UP**

7) PHYSICS *Short Answer* A passenger with a mass of 50-kg is in an elevator which is accelerating  $2 \text{ ms}^{-2}$  upward. Assuming  $g$  to be  $10 \text{ ms}^{-2}$ , what is the passenger's apparent weight in newtons?

ANSWER: 600

**BONUS**

7) PHYSICS *Short Answer* A disk of radius 0.10 m is oriented with its normal unit vector  $n$  at  $60^\circ$  to a uniform electric field  $E$  of magnitude  $4.0 \times 10^4 \text{ N/C}$ . Leaving your answer in terms of  $\pi$ , what is the electric flux through the disk, in  $\text{N m}^2 \text{ C}^{-1}$ ?

ANSWER:  $200\pi$

**TOSS-UP**

8) EARTH AND SPACE *Multiple Choice* Which of the following statements best describes the circumstances under which the big rip will occur?

- W) when the universe is closed
- X) when  $\rho_{\text{ave}} > \rho_{\text{critical}}$
- Y) when dark energy is described by quintessence
- Z) when dark matter is composed of WIMPs

ANSWER: Y) WHEN DARK ENERGY IS DESCRIBED BY QUINTESSENCE

**BONUS**

8) EARTH AND SPACE *Short Answer* The “shelf valleys” that appear to be extensions of river valleys

into the continental shelf were most likely formed in what epoch in the geologic time scale?

ANSWER: PLEISTOCENE

**TOSS-UP**

9) BIOLOGY *Multiple Choice* Which of the following types of cell signaling is exemplified by a signal molecule that remains in the extracellular fluid and can travel throughout the body, an example of which is the steroids that are secreted from the testes of humans to stimulate peripheral events such as muscle growth?

- W) direct
- X) paracrine
- Y) endocrine
- Z) synaptic

ANSWER: Y) ENDOCRINE

**BONUS**

9) BIOLOGY *Short Answer* What are the enzymes that phosphorylate the serine and threonine amino acids of key cellular enzymes and other proteins, and which thus initiate the activities that carry the cycle past the G<sub>1</sub> and G<sub>2</sub> checkpoints into mitosis?

ANSWER: CYCLIN-DEPENDENT PROTEIN KINASES (ACCEPT: Cdk's)

**TOSS-UP**

10) MATHEMATICS *Multiple Choice* Which of the following polar equations has a graph of a circle?

- W)  $2 \sin 3\theta$
- X)  $2 + 3\cos\theta$
- Y)  $4 \sin\theta$
- Z)  $4 \sin 2\theta$

ANSWER: Y)  $4 \sin\theta$

**BONUS**

10) MATHEMATICS *Short Answer* For the curve given by the parametric equations  $x = \sqrt{t}$  and  $y = \frac{1}{4}(t^2 - 4)$  for all  $t \geq 0$ , what is the slope at the point (2,3)?

ANSWER: 8

**TOSS-UP**

11) CHEMISTRY *Short Answer* Arrange the following ionic structures in order of increasing radius ratio,  $\rho$ : cesium chloride, rock-salt, zinc-blende

ANSWER: 3, 2, 1

### BONUS

11) CHEMISTRY *Short Answer* The emf of the Daniell cell for certain concentrations of Cu and Zn ions is 1.04 V. Given that  $n = 2$  mol and assuming Faraday's constant equals  $9.6 \times 10^4 \text{ C mol}^{-1}$ , what is the reaction Gibbs free energy, to 2 significant digits?

ANSWER:  $-2.0 \times 10^5$

### TOSS-UP

12) ENERGY *Short Answer* What type of jet engine consists of an inlet, combustor, and nozzle, and does not slow the oncoming airflow to subsonic speeds for combustion, differing from its counterpart by taking advantage of the compression generated from shock waves to combust?

ANSWER: SCRAMJET

### BONUS

12) ENERGY *Short Answer* Calculate the change in molar Gibbs free energy for the process  $\text{H}_2\text{O(s)} \rightarrow \text{H}_2\text{O(l)}$  at 1 atm and 273 K, if the enthalpy of fusion is  $6.01 \text{ kJ mol}^{-1}$  and entropy of fusion is  $22.0 \text{ J K}^{-1} \text{ mol}^{-1}$ .

ANSWER: 0

### TOSS-UP

13) PHYSICS *Short Answer* What empirical law, discovered and published in 1913, and historically important in quantitatively justifying the nuclear model of the atom, relates the X-ray frequencies of an atom to its atomic number,  $Z$ ?

ANSWER: MOSELEY'S LAW

### BONUS

13) PHYSICS *Short Answer* By name or number, indicate all of the following 4 leptons that is/are unstable:

- 1: electron neutrino
- 2: muon
- 3: tau
- 4: tau neutrino

ANSWER: 2 AND 3

### TOSS-UP

14) EARTH AND SPACE *Short Answer* Which two of the following four organisms commonly produce calcareous oozes, composed of  $\text{CaCO}_3$ ?

- 1: radiolarians
- 2: foraminifera
- 3: coccolithophores
- 4: diatoms

ANSWER: 2 AND 3

### BONUS

14) EARTH AND SPACE *Short Answer* What region in the H-R diagram, which is populated by low-to-medium-mass stars that have completed helium fusion but have not developed a full carbon core, is considered to be a period of stellar evolution that is undertaken by all smaller-mass stars towards the end of their lives?

ANSWER: ASYMPTOTIC GIANT BRANCH (ACCEPT: AGB)

### TOSS-UP

15) BIOLOGY *Short Answer* What balloon-like fluid reservoir, which is present in echinoderms, is found attached to a hollow, muscular structure attached to the tube foot, and is used to control the movement of the tube foot muscles by pumping water into and out of its reservoir, and thus allowing the organism to move across the sea floor?

ANSWER: AMPULLA

### BONUS

15) BIOLOGY *Multiple Choice* Which of the following cells of the immune system is the initiator of the inflammatory response, thus aiding the arrival of leukocytes at the site of infection? It also secretes histamine and is significant in allergic responses.

- W) B cell
- X) plasma cell
- Y) mast cell
- Z) macrophage

ANSWER: Y) MAST CELL

### TOSS-UP

16) MATHEMATICS *Short Answer* Evaluate  $\lim_{x \rightarrow 0} \frac{e^{2x} - 1}{x}$ .

ANSWER: 2

### BONUS

16) MATHEMATICS *Short Answer* Find  $\lim_{x \rightarrow -\infty} \frac{x^2}{e^{-x}}$ .

ANSWER: 0

### TOSS-UP

17) CHEMISTRY *Multiple Choice* Which of the following properties would not be observed in a positive azeotrope?

- W) positive deviation from Raoult's Law
- X) boiling point lower than both individual components
- Y) negative enthalpy of mixing

Z) vapor pressure higher than both individual components

ANSWER: Y) NEGATIVE ENTHALPY OF MIXING

### BONUS

17) CHEMISTRY *Short Answer* By name or number, indicate all of the following 4 choices that is/are examples of an emulsion colloid:

- 1: milk
- 2: foam
- 3: mayonnaise

ANSWER: 1 AND 3

### TOSS-UP

18) ENERGY *Short Answer* What is the ratio of heat capacities for diatomic oxygen gas near room temperature?

ANSWER: 7/5 (ACCEPT: 1.4)

### BONUS

18) ENERGY *Short Answer* Name all of the following 3 statements that is/are TRUE of nuclear fission reactors:

- 1: in a chain reaction, when neutrons are slowed down, there is an increased chance that they will be absorbed by U-238 atoms
- 2: the very first reactor used graphite as a moderator to slow down the neutrons, causing increased fission in U-235 atoms
- 3: effective control rods, which prevent any runaway chain reactions, are predominantly made of boron or cadmium

ANSWER: 2 AND 3

### TOSS-UP

19) PHYSICS *Multiple Choice* The escape velocity of an object from the surface of a certain planet is given by  $v$ . When the planet's radius is reduced to  $\frac{1}{4}$  its original radius but its mass is kept constant, which of the following is the new expression for the escape velocity of the object?

- W)  $\frac{1}{4} v$
- X)  $\frac{1}{2} v$
- Y)  $2v$
- Z)  $4v$

ANSWER: Y)  $2v$

**BONUS**

19) PHYSICS *Multiple Choice* Assuming they all have the same mass,  $m$ , which of the following objects can be predicted to have the greatest moment of inertia?

- W) a solid sphere with radius 1 m
- X) a thin-walled, hollow sphere with radius 1 m
- Y) a solid cylinder with radius 2 m
- Z) a thin-walled, hollow cylinder with radius 2 m

ANSWER: Z) A THIN-WALLED, HOLLOW CYLINDER WITH RADIUS 2 m

**TOSS-UP**

20) EARTH AND SPACE *Multiple Choice* A solar eclipse is geometrically possible only during which of the following lunar phases?

- W) new moon
- X) first quarter
- Y) full moon
- Z) third quarter

ANSWER: W) NEW MOON

**BONUS**

20) EARTH AND SPACE *Short Answer* What major group in the Koppen classification system, which includes deserts and steppes, is characterized by dry to semiarid climates where precipitation is less than the potential evapotranspiration?

ANSWER: GROUP B (ACCEPT: B)

**TOSS-UP**

21) BIOLOGY *Short Answer* What structural pattern, which is present in viruses that have isometric appearances, is the basic design of the geodesic dome and is the most efficient symmetrical arrangement that linear subunits can take to form a shell with maximum internal capacity, consisting of 20 equilateral triangular facets? An example of this is the respiratory adenovirus.

ANSWER: ICOSAHEDRON

**BONUS**

21) BIOLOGY *Multiple Choice* In which of the following stages of the HIV infection cycle does the HIV virus circulate throughout the entire bloodstream, but infect only the  $CD4^+$  cells?

- W) attachment
- X) entry into macrophages
- Y) replication
- Z) entry into T cells

ANSWER: W) ATTACHMENT

**TOSS-UP**



22) MATHEMATICS *Short Answer* Find the slope of the tangent line of the graph of  $f(x) = \ln(\sec(x))$  at the point  $(\frac{\pi}{3}, f(\frac{\pi}{3}))$ .

ANSWER:  $\sqrt{3}$

**BONUS**

22) MATHEMATICS *Short Answer* Evaluate  $\int_0^1 (2t-1)^2 dt$ .

ANSWER:  $\frac{1}{3}$

**TOSS-UP**

23) CHEMISTRY *Short Answer* How many sigma and pi bonds, respectively, are present in a molecule of propene?

ANSWER: 8 SIGMA, 1 PI

**BONUS**

23) CHEMISTRY *Short Answer* Name all of the following 3 statements that is/are TRUE of standard-cell potentials:

1: the more positive the value of the standard reaction potential, the higher chance the substance on the left-hand side of the half-reaction is a strong oxidizing agent

2: if a half-reaction occurs as an oxidation when paired with the standard hydrogen electrode, the half-reaction voltage has a positive sign

3: electrode potentials depend on the nature and concentration of reactants and products, as well as the quantity of each that reacts

ANSWER: 1 ONLY

**TOSS-UP**

24) ENERGY *Short Answer* In nuclear physics, what is the term given to the mass required in order to sustain a chemical chain reaction, where the effective neutron multiplication factor is equal to 1?

ANSWER: CRITICAL MASS

**BONUS**

24) ENERGY *Short Answer* Name all of the following 3 statements that is/are TRUE:

- 1: in nuclear fusion, the binding energy per nucleon increases with mass number until nickel-62, after which the binding energy decreases
- 2: fusion of elements heavier than iron and nickel releases energy, rather than absorbing energy
- 3: an exception to the increase in binding energy with mass number is helium-4, whose binding energy is greater than that of lithium

ANSWER: 1 AND 3

### TOSS-UP

25) PHYSICS *Short Answer* For a beam of protons moving through a uniform magnetic field directed along the positive- $z$  direction, the velocity of the protons lies in the  $xz$  plane and is directed  $30^\circ$  to the  $+z$  axis. Along what axis is the force vector of the protons directed?

ANSWER: NEGATIVE Y-AXIS (ACCEPT: NEGATIVE Y DIRECTION)

### BONUS

25) PHYSICS *Short Answer* A flat surface with an area of  $3 \times 10^{-4} \text{ m}^2$  makes a  $60^\circ$  angle with a uniform magnetic field of unknown magnitude. If the magnetic flux through the surface is  $1.2 \text{ mWb}$ , what is the magnitude of the uniform magnetic field, in T?

ANSWER: 8 T