

# 2024 MIT Science Bowl High School Invitational

## Round 8

### TOSS UP

1) PHYSICS *Multiple Choice* While falling through the atmosphere at terminal velocity, Timurag drops a ball with a higher terminal velocity than himself. Which of the following best describes the acceleration of the ball in Timurag's reference frame right after he drops it and after a long time, respectively?

- W)  $g$ , and a positive constant less than  $g$
- X)  $g$ , and 0
- Y) A positive constant less than  $g$ , and a positive constant less than  $g$
- Z) A positive constant less than  $g$ , and 0

ANSWER: Z) A positive constant less than  $g$ , and 0

### BONUS

1) PHYSICS *Multiple Choice* A sample of a gas expands adiabatically from a volume of 1 liter to 5 liters, with an initial temperature of 273 kelvin. Which of the following gases would have the highest temperature following this process?

- W) Helium
- X) Dioxygen
- Y) Carbon dioxide
- Z) Sulfur dioxide

ANSWER: Z) Sulfur dioxide

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### TOSS UP

2) ENERGY *Multiple Choice* Researchers at the Rajbhandari Lab worked with Moderna scientists to study the N-formylation of certain amino acids in bacteria since it is involved in protein synthesis. In bacteria, N-formylation likely occurs most often on which amino acid?

- W) Cysteine
- X) Methionine
- Y) Arginine
- Z) Aspartate

ANSWER: X) Methionine

### BONUS

2) ENERGY *Multiple Choice* Researchers in the McGuire group at MIT are using absorption spectroscopy to study rotational spectrums of molecules in interstellar space. Which of the following wavelengths of light could be used for rotational spectroscopy?

- W) 1 meter
- X) 1 millimeter
- Y) 1 micrometer
- Z) 1 nanometer

ANSWER: X) 1 millimeter

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### TOSS UP

3) EARTH AND SPACE *Short Answer* The Younger Dryas (*DRY-as*) was most likely caused by the weakening of what ocean current system located in the Northern Atlantic Ocean?

ANSWER: Atlantic Meridional Overturning Circulation (ACCEPT: AMOC)

### BONUS

3) EARTH AND SPACE *Multiple Choice* Which of the following correctly matches a solution to the Einstein field equations to the spacetime environment it describes?

- W) Kerr metric - rotating uncharged black hole
- X) Schwarzschild (*Sh-warts-shild*) metric - rotating charged black hole
- Y) Kerr-Newman metric - nonrotating uncharged black hole
- Z) Kerr–Nordström (*NORD-strohm*) - nonrotating charged black hole

ANSWER: W) Kerr metric - rotating uncharged black hole

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### TOSS UP

4) CHEMISTRY *Multiple Choice* In the titration of a weak acid with sodium hydroxide, two equivalence points are observed at 6 milliliters and 18 milliliters of titrant added, respectively. Which of the following could be the weak acid?

- W) Acetic acid
- X) Oxalic acid
- Y) Carbonic acid
- Z) Phosphoric acid

ANSWER: Z) Phosphoric acid

### BONUS

4) CHEMISTRY *Short Answer* 1 mole of a reactant decays with a rate-constant of 0.5 inverse moles inverse seconds. To one significant figure and in seconds, how long will the reaction take until 90% of the reactant has been consumed?

ANSWER: 20

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### TOSS UP

5) BIOLOGY *Multiple Choice* Keratin often forms coiled coils, making it intermediate in width between microtubules and microfilaments. Keratin would most likely be found in which of the following intercellular junctions?

- W) Gap junctions
- X) Adherens junctions
- Y) Desmosomes
- Z) Tight junctions

ANSWER: Y) Desmosomes

### BONUS

5) BIOLOGY *Short Answer* Identify all of the following three statements that are true concerning human hemoglobin:

- 1) Adult hemoglobin has a higher affinity for oxygen than fetal hemoglobin
- 2) Hemoglobin can bind to  $H^+$  but not  $CO_2$
- 3) Bilirubin is a product of hemoglobin breakdown.

ANSWER: 3 only

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### TOSS UP

6) MATH *Multiple Choice* Which of the following functions has the greatest average value on the closed interval from zero to one?

- W)  $\sec x$  (read: *secant of x*)
- X)  $\sin x$  (read: *sine of x*)
- Y)  $\cos x$  (read: *cosine of x*)
- Z)  $\tan x$  (read: *tangent of x*)

ANSWER: W)  $\sec x$  (read: *secant of x*)

### BONUS

6) MATH *Short Answer* Two real numbers have a quotient of 4 and a product of 9. What are all possible values for their sum?

ANSWER: 7.5 and -7.5

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### TOSS UP

7) ENERGY *Multiple Choice* Researchers at the Page Lab have been studying the maturation of microglia. Which of the following is NOT true about microglia?

- W) Microglia are found in the central nervous system
- X) Microglia phagocytose plaques and infectious agents
- Y) Microglia act as antigen-presenting cells
- Z) Microglia form the blood-brain barrier

ANSWER: Z) Microglia form the blood-brain barrier

### BONUS

7) ENERGY *Short Answer* Researchers at the MIT Kamrin Group are studying Beverloo's Law and its implications on sand flow in containers. If the volumetric flow rate of sand in an hourglass only depends on the cross-sectional area of the funnel and the gravitational acceleration, what power of the funnel's cross-sectional area is the volumetric flow rate proportional to?

ANSWER: 1.25

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### TOSS UP

8) MATH *Multiple Choice* What is the area bounded by the curve  $y = \frac{1}{x^2+1}$  (read: *y equals 1 over open bracket x squared plus one close bracket*),  $x = 1$ ,  $x = -1$  and the x-axis?

W)  $1/4$

X)  $\pi/4$

Y)  $1/2$

Z)  $\pi/2$

ANSWER: Z)  $\pi/2$

### BONUS

8) MATH *Short Answer* In triangle ABC, angles A and B have measures 30 and 45 degrees, respectively, and side BC has length 4 units. What is the area of triangle ABC?

ANSWER:  $4 + 4\sqrt{3}$

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### TOSS UP

9) BIOLOGY *Multiple Choice* Which of the following features does NOT exhibit negative frequency dependent selection?

- W) Plant self incompatibility alleles
- X) Batesian mimicry
- Y) Cryptic coloration
- Z) Aposematic coloration

ANSWER: Z) Aposematic coloration

### BONUS

9) BIOLOGY *Multiple Choice* Some unicellular eukaryotes undergo a unique form of cell division called closed mitosis, where the nuclear envelope remains intact. In which group of organisms are microtubules known to pass through cytoplasmic tunnels within the nucleus during closed mitosis?

- W) Ciliates
- X) Dinoflagellates
- Y) Diatoms
- Z) Yeasts

ANSWER: X) Dinoflagellates

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### TOSS UP

10) PHYSICS *Short Answer* A hanging rope is supported only at its ends such that at its ends, the angle the rope makes with the horizontal is 30 degrees. If the maximum tension throughout the rope is 12 newtons, what is the minimum tension, in newtons, throughout the rope?

ANSWER:  $6\sqrt{3}$  newtons

### BONUS

10) PHYSICS *Short Answer* In terms of  $n$ , how many vibrational degrees of freedom does a linear molecule with  $n$  bonds have?

ANSWER:  $3n - 2$

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### TOSS UP

11) EARTH AND SPACE *Multiple Choice* Which of the following best describes the role of carbon in the CNO cycle?

- W) Reactant
- X) Product
- Y) Intermediate
- Z) Catalyst

ANSWER: Z) Catalyst

### BONUS

11) EARTH AND SPACE *Short Answer* What mechanism, which is evident in Jupiter and Saturn, generates heat in a star or planet when the surface of the star or planet cools, resulting in contraction that heats the core of the star or planet?

ANSWER: Kelvin-Helmholtz mechanism

### TOSS UP

12) CHEMISTRY *Multiple Choice* Which of the following salts forms a green color when dissolved in water?

- W) Cobalt (II) nitrate
- X) Copper (II) bromide
- Y) Iron (III) acetate
- Z) Nickel (II) chloride

ANSWER: Z) Nickel (II) chloride

### BONUS

12) CHEMISTRY *Short Answer* If the heat of vaporization of water at its boiling point is 41 kilojoules per mole, what is the entropy of vaporization of water at its boiling point to the nearest whole number and in joules per mole per kelvin?

ANSWER: 110

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### TOSS UP

13) MATH *Short Answer* Consider a triangle  $ABC$ , where  $AB = 6$ ,  $BC = 10$ , and  $CA = 8$ , with incenter  $I$  and inradius 2. In simplest radical form, what is the distance  $AI$ ?

ANSWER:  $2\sqrt{2}$  (DO NOT ACCEPT:  $\sqrt{8}$ )

### BONUS

13) MATH *Short Answer* Square  $MAST$  is drawn outside triangle  $MIT$  such that  $I$  lies inside  $MAST$ . Given triangles  $MIT$  and  $AIS$  have areas of 36 and 14 respectively, find the length of  $MT$ .

ANSWER: 10

### TOSS UP

14) BIOLOGY *Short Answer* In the angiosperm reproductive cycle, the primary megaspore undergoes three mitotic divisions prior to fertilization. After these divisions, three of the resulting cells migrate to the chalazal (*chuh-lah-zal*) end of the ovule. What term describes these three cells?

ANSWER: Antipodal cells

### BONUS

14) BIOLOGY *Multiple Choice* Phoebe has identified two unlinked genes A and B. Wild-type dominant alleles for both genes code for enzymes that are possibly responsible for the production of compound C. She conducts a testcross between parents who are doubly heterozygous for A and B, obtaining a phenotypic ratio of 15 to 1. Which of the following most likely describes the biochemical roles of enzymes A and B?

- W) Only one of the enzymes produces compound C
- X) One of the enzymes produces compound C and is inhibited by the other enzyme
- Y) Both enzymes catalyze independent pathways that both produce compound C
- Z) Both enzymes catalyze intermediate steps in the same pathway

ANSWER: Y) Both enzymes catalyze independent pathways that both produce compound C

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### TOSS UP

15) ENERGY *Short Answer* Researchers at MIT CSAIL's Machine Learning group are modeling strategic games. Rational players in strategic multiplayer games seek out what locally stable configurations of actions?

ANSWER: Nash Equilibria

### BONUS

15) ENERGY *Short Answer* Physicists from the Gedik Lab discovered a strong phase transition in europium tetratelluride through gradual exposure to external stimuli such as temperature and light. The subsequent abrupt change in spin is an example of what effect, which is graphically identified by its namesake loops?

ANSWER: Hysteresis

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### TOSS UP

16) CHEMISTRY *Multiple Choice* Which of the following solvents is most likely to promote SN1 substitution over SN2 substitution?

- W) Dimethyl sulfoxide
- X) Acetone
- Y) Hexane
- Z) Ethanol

ANSWER: Z) Ethanol

### BONUS

16) CHEMISTRY *Multiple Choice* What is the average oxidation state of copper in the high temperature superconductor YBCO with chemical formula  $\text{YBa}_2\text{Cu}_3\text{O}_7$  (read: *Y B A two C U three O seven*), assuming that all other ions are in their usual oxidation state and Yttrium is in the same periodic group as Scandium?

- W) 2
- X)  $7/3$
- Y)  $8/3$
- Z) 3

ANSWER: X)  $7/3$

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### TOSS UP

17) EARTH AND SPACE *Multiple Choice* Which of the following best characterizes the seasonal shifts of the Intertropical Convergence Zone?

- W) Farther North in July than January and on average shifted North
- X) Farther North in July than January and on average shifted South
- Y) Farther South in July than January and on average shifted North
- Z) Farther South in July than January and on average shifted South

ANSWER: W) Farther North in July than January and on average shifted North

### BONUS

17) EARTH AND SPACE *Short Answer* A newly discovered star, Alpha Cambridgus, has a radius of 2 solar radii and a temperature of 5,000 Kelvin. Its neighbor Beta Cambridgus has a radius of 4 solar radii and a temperature of 15,000 Kelvin. To the nearest integer, how many times more luminous is Beta Cambridgus compared to Alpha Cambridgus?

ANSWER: 324

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### TOSS UP

18) PHYSICS *Multiple Choice* A solenoid with 50 turns and radius 2 meters is placed inside another solenoid with 100 turns and radius 4 meters such that their central axes are aligned. If the outer solenoid has a self-inductance of  $L$ , what is the self-inductance of the inner solenoid in terms of  $L$ ?

- W)  $L/16$
- X)  $L/4$
- Y)  $4L$
- Z)  $16L$

ANSWER: W)  $L/16$

### BONUS

18) PHYSICS *Short Answer* A spinning top is placed on a flat surface at a constant angle and given an angular momentum about its axis such that it precesses with a period of 1 second. If it is instead given twice the angular momentum, what is the new period, in seconds, of precession?

ANSWER: 2

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### TOSS UP

19) EARTH AND SPACE *Multiple Choice* Which of the following are true of the bands in glacier ogives?

- W) Dark bands are formed in ice that fell over the icefall in summer
- X) Dark bands are formed in ice that fell over the icefall in winter
- Y) Dark bands are formed by ice derived from low snowfall years
- Z) Dark bands are formed by ice derived from high snowfall years

ANSWER: W) Dark bands are formed in ice that fell over the icefall in summer

### BONUS

19) EARTH AND SPACE *Short Answer* Order the following three lagerstatten (read: *lah-ger-statt-ehn*) from oldest to youngest

- 1) Burgess (*BUR-jess*) Shale
- 2) Morrison (*Moor-is-son*) Formation
- 3) Ediacara (*EE-dia-CAR-a*) Hills

ANSWER: 3, 1, 2

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### TOSS UP

20) PHYSICS *Short Answer* An electron moves in a circle under a uniform magnetic field. If the field strength is doubled, by what factor is the radius of curvature multiplied?

ANSWER:  $\frac{1}{2}$

### BONUS

20) PHYSICS *Multiple Choice* A small 1 Coulomb spherical charge is placed at the corner of a cube. The flux through one of the sides opposite the charge can be written as  $x/\epsilon_0$ , (read: *x over epsilon naught*), where  $x$  is an unknown value with units of coulombs. What is  $x$ ?

- W)  $1/24$
- X)  $1/8$
- Y)  $1/6$
- Z)  $1/3$

ANSWER: W)  $1/24$

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### TOSS UP

21) CHEMISTRY *Short Answer* The absorbance of the only reactant in a chemical reaction is measured over time, and a graph of the inverse of absorbance SQUARED is linear when plotted against time. What is the kinetic order of the chemical reaction?

ANSWER: 3

### BONUS

21) CHEMISTRY *Short Answer* At 100 degrees Celsius, polystyrene reversibly transitions from a relatively brittle form to a rubbery and viscous form. What is the name given to the temperature at which this type of transition occurs?

ANSWER: Glass transition temperature (ACCEPT:  $T_g$ , Glass transition point)

### TOSS UP

22) BIOLOGY *Multiple Choice* Connor is interested in killing a woody eudicot (*YOU-dee-cot*). Which of the following would be most effective in accomplishing this?

- W) Excising a large portion of heartwood
- X) Doubling the carbon dioxide concentration around the plant
- Y) Excising a large portion of sapwood
- Z) Doubling the argon concentration around the plant

ANSWER: Y) Excising a large portion of sapwood

### BONUS

22) BIOLOGY *Multiple Choice* Nita has two plants: a short-day plant and a long-day plant, both with a critical length of 12 hours. She then grafts the long-day plant onto the short-day plant and exposes the plant to 10 hours of light followed by 14 hours of darkness. What parts of this grafted plant will flower?

- W) Only the short-day portion of the plant will flower
- X) Only the long-day portion of the plant will flower
- Y) Both the long-day and the short-day portions of the plant will flower
- Z) Neither the long-day nor the short-day portions of the plant will flower

ANSWER: Y) Both the long-day and the short-day portions of the plant will flower

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### TOSS UP

23) MATH *Multiple Choice* How many prime numbers less than 50 have a units digit that is a composite number?

- W) 1
- X) 2
- Y) 3
- Z) 4

ANSWER: X) 2

### BONUS

23) MATH *Short Answer* A continuous function  $f(x)$  (read: *f of x*) defined on the positive real numbers satisfies  $2f(x) + f\left(\frac{1}{x}\right) = x$  (read: *two f of x plus f of one over x equals x*) for all values of  $x$ . Find  $f(2)$  (read: *f of two*).

ANSWER:  $\frac{7}{6}$