

# 2024 MIT Science Bowl High School Invitational

## Round 11

### TOSS UP

1) EARTH AND SPACE *Multiple Choice* The volume of a white dwarf is proportional to mass raised to which of the following powers?

- W)  $-1/2$
- X)  $-1/3$
- Y)  $1/3$
- Z)  $1/2$

ANSWER: X)  $-1/3$

### BONUS

1) EARTH AND SPACE *Short Answer* Folds are geologic structures indicative of deformation. What is the term for folds with straight limbs and sharp hinges?

ANSWER: Chevron folds (ACCEPT: Chevrons)

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## TOSS UP

2) PHYSICS *Multiple Choice* A particle with mass  $m$  has a momentum of  $mc$ . What is its Lorentz factor?

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

ANSWER: Y)  $\sqrt{2}$

## BONUS

2) PHYSICS *Multiple Choice* A flat isosceles right triangle has a moment of inertia  $I$  (read:  $i$ ) with respect to one of its legs. What is its moment of inertia with respect to its hypotenuse?

- W)  $\frac{I}{2}$  (read:  $i$  divided by 2)
- X)  $\frac{I}{\sqrt{2}}$  (read:  $i$  divided by the square root of 2)
- Y)  $I$  (read:  $i$ )
- Z)  $2I$  (read: 2 times  $i$ )

ANSWER: W)  $\frac{I}{2}$  (read:  $i$  divided by 2)

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## **TOSS UP**

3) CHEMISTRY *Short Answer* How many unique signals are in sodium cyclopentadienide's carbon-13 NMR spectrum?

ANSWER: 1

## **BONUS**

3) CHEMISTRY *Short Answer* Tim is trying to determine the molar heat of dissolution of ammonium chloride through coffee cup calorimetry. Identify all of the following three errors that would lead to an overestimate in the molar heat of dissolution of ammonium chloride:

- 1) The thermometer used to measure temperatures consistently underreported the true temperature by 1 degree celsius
- 2) The ammonium chloride sample tested was contaminated by table salt
- 3) Exactly 10% of the water in the calorimeter evaporated before the ammonium chloride was added

ANSWER: 3 only

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## **TOSS UP**

4) BIOLOGY *Short Answer* Rank the following three genes on the lac operon from closest to the operator to furthest from it:

- 1) lacA
- 2) lacY
- 3) lacZ

ANSWER: 3, 2, 1

## **BONUS**

4) BIOLOGY *Short Answer* Rank the following three clades by increasing relatedness to brown algae:

- 1) Diatoms
- 2) Red algae
- 3) Dinoflagellates

ANSWER: 2, 3, 1

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## **TOSS UP**

5) ENERGY *Short Answer* Researchers in the MIT Materials Research Laboratory are studying solid materials that exhibit high levels of symmetry in their microscopic structures, but lack the periodicity associated with normal crystals. What is the name for these types of materials?

ANSWER: Quasicrystal

## **BONUS**

5) ENERGY *Short Answer* Researchers in the Movassaghi group at MIT are studying pathways to make synthetic alkaloids. One of these pathways involves stereoselective addition of substituents to a meso intermediate to form a chiral product. The meso molecule exemplifies what type of molecule that can be converted from achiral to chiral in a single step?

ANSWER: Prochiral

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## **TOSS UP**

6) MATH *Multiple Choice* How many real values of  $x$  satisfy  $\cos(\sin x) = 0$  (read: *the cosine of the sine of x equals zero*)?

- W) 0
- X) 1
- Y) 2
- Z) Infinitely many

ANSWER: W) 0

## **BONUS**

6) MATH *Short Answer* Polynomial  $x^3 + 4x + 1$  (read: *x cubed plus 4 x plus 1*) has 3 roots  $a, b, c$ . When two is subtracted from each root, what is the product of these 3 resulting numbers?

ANSWER: -17

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## **TOSS UP**

7) BIOLOGY *Short Answer* Identify all of the following three clades of organisms for which it is appropriate to apply the biological species concept to its members:

- 1) Proteobacteria
- 2) Mammalia
- 3) Ascomycota (*ASS-co-my-co-ta*)

ANSWER: 2 and 3

## **BONUS**

7) BIOLOGY *Multiple Choice* A budding biologist is performing a gram stain on E. coli. However, when they view their slide under a microscope, their bacterial sample appears purple. Which of the following errors have they most likely committed?

- W) They forgot to use a mordant after counterstaining the slide with safranin and washed out the pink color
- X) They smeared a large amount of bacterial cells on the slide, so multiple layers of cells were present
- Y) They used excessive force when rinsing their slide with acetone, causing endospore formation
- Z) They counterstained using carbol fuchsin (read: *fewk-sin*) instead of crystal violet, so the bacteria could not be decolorized

ANSWER: X) They smeared a large amount of bacterial cells on the slide, so multiple layers of cells were present

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## **TOSS UP**

8) MATH *Short Answer* Emmy has a triangle with two sides of length 3 and 4. If the angle between the two sides is one degree, they calculate that the area of this triangle rounded to two significant figures is 0.10. Rounded to one significant figure, what is the area of a triangle with two sides of length 2 and 18 separated by an angle of two degrees?

ANSWER: 0.6

## **BONUS**

8) MATH *Short Answer* A parametric curve defined by  $x = t^2 - 4$  and  $y = t^3 - 5t + 4$  crosses itself. Compute the ordered pair  $(x, y)$  where this crossing occurs.

ANSWER: (1, 4)

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## **TOSS UP**

9) PHYSICS *Short Answer* Because neutrinos and anti-neutrinos are both neutral fermions, they could in theory be identical particles. What class of fermions, contrasted with Dirac fermions, would neutrinos belong to under this theory?

ANSWER: Majorana

## **BONUS**

9) PHYSICS *Multiple Choice* Avni sets up a single-slit diffraction experiment using a coherent light source, a slit with an appropriate width, and a photosensitive screen. She records the location of each diffraction peak as well as its brightness. Excluding the central peak, which of the following best describes the spacing of the peaks and their relative intensities?

- W) Both the spacing and the intensity of the peaks are constant
- X) The spacing of the peaks is constant, and the intensity decreases as they go further out
- Y) The spacing of the peaks increases as they go further out, and the intensity is constant
- Z) The spacing of the peaks increases and the intensity decreases as they go further out

ANSWER: Z) The spacing of the peaks increases and the intensity decreases as they go further out

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## **TOSS UP**

10) ENERGY *Multiple Choice* Scientists at MIT Nano are experimenting with organic photoresists. These photoresists can be used for which of the following depositional techniques in semiconductor manufacturing?

- W) Epitaxy
- X) Chemical vapor deposition
- Y) Lithography
- Z) Etching

ANSWER: Y) Lithography

## **BONUS**

10) ENERGY *Multiple Choice* Researchers at MIT CSAIL are developing natural language classifiers to binary problems. Which of the following activation functions is best for solving binary classification problems on a finite dataset?

- W) Linear
- X) Sinusoidal
- Y) Sigmoidal
- Z) Logarithmic

ANSWER: Y) Sigmoidal

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## TOSS UP

11) CHEMISTRY *Short Answer* What type of molecular orbital is lowest unoccupied molecular orbital in nucleophilic attack on an imine?

ANSWER: Pi star

## BONUS

11) CHEMISTRY *Multiple Choice* Which of the following statements is true about triplet and singlet oxygen?

- W) Triplet oxygen is weakly attracted to an external magnetic field
- X) Singlet oxygen is an example of a biradical
- Y) Triplet oxygen is a stronger oxidizing agent than singlet oxygen
- Z) Triplet oxygen can participate in pericyclic reactions more readily than singlet oxygen

ANSWER: W) Triplet oxygen is weakly attracted to an external magnetic field

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## TOSS UP

12) EARTH AND SPACE *Multiple Choice* Which of the following observations would signal the presence of a warm front?

- W) An increase in atmospheric pressure
- X) A series of gradually ascending stratus clouds
- Y) A decrease in dew point temperature
- Z) Heavy rain with thunderstorms

ANSWER: X) A series of gradually ascending stratus clouds

## BONUS

12) EARTH AND SPACE *Short Answer* What is the term for the instability that occurs when a lighter fluid intrudes into a heavier fluid, such as when a volcanic explosion forces hot gas into the surrounding atmosphere?

ANSWER: Rayleigh-Taylor (ACCEPT: RT)

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## **TOSS UP**

13) MATH *Multiple Choice* On a 64 by 64 grid of lattice points, 64 lines are drawn from the bottom left corner to each point on the right edge of the grid. How many of these lines do not pass through any other points in the grid?

- W) 30
- X) 32
- Y) 34
- Z) 36

ANSWER: Z) 36

## **BONUS**

13) MATH *Short Answer* When the reciprocals of the divisors of 12 are sorted in increasing order, the first four terms form an arithmetic progression. What is the smallest positive integer  $n$  such that when the reciprocals of the divisors of  $n$  are sorted in increasing order, the first six terms form an arithmetic progression?

ANSWER: 60

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## **TOSS UP**

14) BIOLOGY *Short Answer* The RYR2 isoform of what class of membrane receptors, named after the plant alkaloid that they have a high affinity for, is the major mediator of the calcium-induced calcium release from the sarcoplasmic reticulum in human muscle?

ANSWER: Ryanodine receptors

## **BONUS**

14) BIOLOGY *Short Answer* Identify all of the following 3 statements that are true about NAD<sup>+</sup> and NADP:

- 1) Healthy eukaryotic cells usually have a high ratio of NAD<sup>+</sup> to NADH
- 2) Healthy eukaryotic cells usually have a high ratio of NADP<sup>+</sup> to NADPH
- 3) While NAD<sup>+</sup> is commonly used in anabolic pathways, NADP is commonly used in catabolic pathways.

ANSWER: 1 only

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## TOSS UP

15) CHEMISTRY *Short Answer* The Mandelin reagent, which is used to detect ketamine and PMA, contains ammonium metavanadate (*me-ta-va-na-date*) as the active reagent. Negative tests are indicated by yellow colors. What is the oxidation of vanadium in ammonium metavanadate?

ANSWER: +5 (ACCEPT: 5)

## BONUS

15) CHEMISTRY *Multiple Choice* Cyclic carbohydrates often contain an exocyclic carbon oxygen bond adjacent to an oxygen atom. Which of the following best describes how the anomeric effect impacts this exocyclic carbon oxygen bond?

- W) Lengthens exocyclic carbon oxygen bond and favors axial position
- X) Lengthens exocyclic carbon oxygen bond and favors equatorial position
- Y) Shortens exocyclic carbon oxygen bond and favors axial position
- Z) Shortens exocyclic carbon oxygen bond and favors equatorial position

ANSWER: W) Lengthens exocyclic carbon oxygen bond and favors axial position

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## **TOSS UP**

16) PHYSICS *Multiple Choice* Sand falls vertically at a constant rate into a massless boat that rests on a lake. After the sand begins hitting the boat, which of the following best describes a graph of the depth that the boat is submerged over time?

- W) A line with a y-intercept equal to 0
- X) A line with a y-intercept greater than 0
- Y) A parabola with a y-intercept equal to 0
- Z) A parabola with a y-intercept greater than 0

ANSWER: X) A line with a y-intercept greater than 0

## **BONUS**

16) PHYSICS *Short Answer* A thin, conductive, spherical, and electrically charged soap bubble has an equilibrium radius that depends on the interaction between electrostatic forces, surface tension, and pressure differentials. Identify all of the following three changes that would increase the equilibrium radius of the bubble:

- 1) Increasing the charge on the bubble
- 2) Increasing the surface tension of the bubble
- 3) Decreasing the relative permittivity of the material of the bubble

ANSWER: 1 only

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## **TOSS UP**

17) EARTH AND SPACE *Short Answer* Identify all of the following three methods by which compositional discontinuities in the mantle are detected:

- 1) Seismic wave velocity anomalies
- 2) Seismic wave reflections
- 3) Seismic wave refractions

ANSWER: All (ACCEPT: 1, 2, and 3)

## **BONUS**

17) EARTH AND SPACE *Multiple Choice* Which of the following is NOT true about kimberlite geochemistry?

- W) They are enriched in potassium oxide relative to aluminum oxide
- X) They are deficient in volatiles
- Y) They are enriched in rare earth elements
- Z) They are enriched in magnesium and nickel

ANSWER: X) They are deficient in volatiles

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## **TOSS UP**

18) ENERGY *Short Answer* Researchers in the Collins Lab studied AlphaFold's ability to classify unseen drug-protein interactions, and found the model to be no better than randomly guessing. If the researchers were to improve AlphaFold's precision, what other metric of the model would likely decrease?

ANSWER: Recall

## **BONUS**

18) ENERGY *Short Answer* Physicists at MIT's Levitov Group showed that when infrared light is focused on impurities in graphene, bosonic quasiparticles known as polaritons are produced which describe the dispersion of light with interacting resonance in graphene's lattice. These polaritons are produced by the coupling of what two distinct bosons?

ANSWER: Photon and phonon (ACCEPT: Phonon and photon)

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## **TOSS UP**

19) BIOLOGY *Short Answer* Order the following three steps of a Western blot in chronological order:

- 1) Blocking with milk protein
- 2) Transferring to nitrocellulose
- 3) Running SDS-PAGE;

ANSWER: 3, 2, 1

## **BONUS**

19) BIOLOGY *Short Answer* Assuming no additional inbreeding, what fraction of your genes would you expect to share with your sibling if your parents were also siblings?

ANSWER:  $\frac{3}{4}$

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## **TOSS UP**

20) MATH *Multiple Choice* Let  $f(n)$  (read: *f of n*) denote the sum of the reciprocals of the factors of n. For which value of n does  $f(n) = 2$ ?

- W) 24
- X) 26
- Y) 28
- Z) 30

ANSWER: Y) 28

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## **BONUS**

20) MATH *Short Answer* An isoceles trapezoid has edge lengths 4, 4, 4 and 5. What is the length of the two equal diagonals?

ANSWER: 6

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## **TOSS UP**

21) EARTH AND SPACE *Short Answer* Rank the following three types of eruptions in order of increasing Volcanic Explosivity Index:

- 1) Hawaiian
- 2) Vulcanian
- 3) Plinian

ANSWER: 1, 2, 3

## **BONUS**

21) EARTH AND SPACE *Short Answer* Stars A and B become gravitationally bound and form a binary system. If the ratio of the mass of star A to the mass of star B is 0.2, what is the ratio of the distance of star A to the distance of star B from the binary system's center of mass?

ANSWER: 5

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## **TOSS UP**

22) CHEMISTRY *Short Answer* Rank the following three pure compounds by increasing boiling point at standard conditions:

- 1) Iodine
- 2) Dichloromethane
- 3) Benzene

ANSWER: 2, 3, 1

## **BONUS**

22) CHEMISTRY *Short Answer* Identify all of the following three compounds that are antiaromatic:

- 1) 1,3-cyclobutadiene (*cy-clo-bu-ta-di-ene*)
- 2) 1,3,5-cyclohexatriene (*cy-clo-he-xa-tri-ene*)
- 3) 1,3,5,7-cyclooctatetraene (*cy-clo-oc-ta-te-tra-ene*)

ANSWER: 1 only

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## **TOSS UP**

23) PHYSICS *Short Answer* What operator is the generator for time translations in quantum mechanics?

ANSWER: Hamiltonian

## **BONUS**

23) PHYSICS *Short Answer* A large parallel plate capacitor has a uniform electric field of 3 Volts per meter inside it. If an observer moves parallel to the plane of the plates at a speed of 0.8 times the speed of light, what is the electric field strength in the observer's frame, in volts per meter?

ANSWER: 5