2024 MIT Science Bowl High School Invitational

Round 14

TOSS UP

1) PHYSICS *Multiple Choice* A sprinkler on a flat plane can release water at a constant velocity at any angle from 0 to 90 degrees from the horizontal. As the sprinkler's launch angle is varied, the vertical position of the apex of the resulting stream of water is recorded. What shape is traced out by graphing these vertical apexes against the sine of the launch angle?

  W) Line
  X) Circle
  Y) Parabola
  Z) Cycloid

ANSWER: Y) Parabola

VISUAL BONUS

1) PHYSICS *Short Answer* Your next bonus is visual. Shown in this image are two point charges with equal magnitudes but opposite signs, that are equidistant from a horizontal infinite conducting metal plate. Considering points P above the plate along the axis of symmetry of the charges, to what power of the distance above the charges' midpoint does the electric field's magnitude vary proportionally to, far away from the charges?

ANSWER: -4

TOSS UP

2) EARTH AND SPACE *Multiple Choice* Which of the following classes of variable stars is the youngest?

  W) Classical cephied
  X) RR Lyrae
  Y) T Tauri
  Z) Mira

ANSWER: Y) T Tauri

BONUS

2) EARTH AND SPACE *Short Answer* Identify all of the following three coastal features that are depositional in origin:

  1) Berm
  2) Spit
  3) Cove

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

TOSS UP

3) CHEMISTRY *Multiple Choice* The energy of which of the following quantum mechanical models in chemistry scales linearly with the system's quantum number?

  W) Particle trapped in a one dimensional infinite potential well
  X) Particle trapped in a spherical potential well
  Y) Particle trapped in a harmonic potential
  Z) Particle trapped in a rigid rotor potential

ANSWER: Y) Particle trapped in a harmonic potential

VISUAL BONUS

3) CHEMISTRY *Short Answer* Your next bonus is visual. Shown in the image are the mass spectra for hydrocarbons A and B. Given that one of the hydrocarbons is a straight-chain alkane and the other contains a ring, what are the IUPAC names for hydrocarbons A and B, respectively?

ANSWER: A: Methylcyclohexane, B: Heptane (ACCEPT: A: 1-Methylcyclohexane, B: n-Heptane)

TOSS UP

4) ENERGY *Multiple Choice* Researchers at the Deverman Lab have been studying vectors for in vivo delivery of CRISPR components. Which of the following vectors is most common for CRISPR delivery and propagation despite immunogenicity and carcinogenicity concerns?

  W) Viral vector
  X) Lipid nanoparticle
  Y) Gene gun
  Z) Cell-penetrating peptides

ANSWER: W) Viral vector

VISUAL BONUS

4) ENERGY *Short Answer* Your next bonus is visual. Researchers at the Lamason Lab recently discovered new compounds that are released by Ricksettia, an intracellular bacterial pathogen. Answer the following two questions about this figure from their recent paper:

  1) In part a, the reaction labeled "click" was the subject of the 2022 Nobel Prize in Chemistry. This reaction was catalyzed by ions of what element?
  2) In part d, what common stain colored the DNA blue?

ANSWER: 1) Copper, 2) DAPI

TOSS UP

5) MATH *Short Answer* Four real numbers are chosen at random uniformly and independently in the interval from 0 to 1. Given that the first number is larger than the second and third number, what is the probability that the first number is larger than the fourth number as well?

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

BONUS

5) MATH *Short Answer* In the evening, a vertical pole with height 6 meters casts a shadow of length 12 meters on the ground. Over some time, the sun sets in the sky by 0.01 radians. To the nearest tenth of a meter, what is the new length of the shadow?

ANSWER: 12.3

TOSS UP

6) BIOLOGY *Short Answer* Order the following three treatments in increasing amount of lipolysis in adipose tissue:

1) Treatment with epinephrine
2) Treatment with T4
3) Treatment with both epinephrine and T4

ANSWER: 2, 1, 3

BONUS

6) BIOLOGY *Short Answer* Identify all the following three phyla of protists that underwent a secondary endosymbiosis of a green algae:

1) Euglenids
2) Rhizarians
3) Alveolates

ANSWER: 1 only

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7) ENERGY *Multiple Choice* Researchers at the Karger group in CSAIL are studying algorithms for efficient information retrieval. Which of the following data structures has the most efficient expected time complexity for retrieving information from a large dataset?

  W) Heap
  X) Hashmap
  Y) Queue
  Z) Stack

ANSWER: X) Hashmap

VISUAL BONUS

7) ENERGY *Short Answer* Your next bonus is visual. Researchers in the Movassaghi group at MIT are studying pathways to make synthetic alkaloids. Shown in the image is one such pathway, which uses diazene-directed assembly for carbon-carbon bond formation. By letter, pair each of the reagents DMAP, NCS, and tin tetrachloride in the pathway with one of the following three possible roles: A) Electrophilic catalyst; B) Nucleophilic catalyst; C) Oxidizing agent.

ANSWER: DMAP: B, NCS: C, Tin tetrachloride: A

TOSS UP

8) CHEMISTRY *Short Answer* When toluene is treated with concentrated nitric and sulfuric acid in the presence of an aluminum catalyst, what is the IUPAC name for the major product?

ANSWER: Para nitro toluene (ACCEPT: 4-nitro toluene; DO NOT ACCEPT: Nitro toluene)

VISUAL BONUS

8) CHEMISTRY *Short Answer* Your next bonus is visual. Shown in the image is a catalyst for the reduction of hydrazine. Answer the following two questions about this catalyst:

1) What is the oxidation state of the uranium metal center?
2) What is the total electron count of the metal center in this complex?

ANSWER: 1) +4; 2) 22

TOSS UP

9) EARTH AND SPACE *Multiple Choice* Which of the following is NOT true of the lambda-CDM model

  W) Dark energy has constant scalar energy density
  X) The Friedmann equations can be applied under this model
  Y) Sterile neutrinos, gravitons, and axions compose a larger percentage of the dark matter energy density than WIMPS
  Z) The cosmological equations of state can't be applied before 0.1 seconds after the big bang

ANSWER: Y) Sterile neutrinos, gravitons, and axions compose a larger percentage of the dark matter energy density than WIMPS

BONUS

9) EARTH AND SPACE *Multiple Choice* At which of the following locations on a galaxy color-magnitude diagram would the Milky Way galaxy be found?

  W) Red sequence
  X) Yellow stream
  Y) Green valley
  Z) Blue cloud

ANSWER: Y) Green valley

TOSS UP

10) PHYSICS *Short Answer* What theorem in modern physics determined that quantum mechanics is incompatible with local hidden variable approaches?

ANSWER: Bell's Theorem

BONUS

10) PHYSICS *Multiple Choice* When an ensemble of non-interacting up and down spins experiences a strong enough magnetic field, two non-degenerate energy levels emerge. Which of the following describes how the entropy of the magnetically split ensemble scales with the number of fermions?

  W) Logarithmically
  X) Linearly
  Y) Quadratically
  Z) Exponentially

ANSWER: X) Linearly

TOSS UP

11) BIOLOGY *Multiple Choice* Which of the following hormones is both positively and negatively regulated directly by hypothalamic hormones?

 W) ACTH
 X) Growth Hormone
 Y) Oxytocin
 Z) Prolactin

ANSWER: Z) Prolactin

VISUAL BONUS

11) BIOLOGY *Short Answer* Your next bonus is visual. The image shows a method commonly used to modify plasmids called around-the-horn replication. Identify all of the following that are true of this process:

 1) Since the primers point in opposite directions; ligation is required to produce a circular product
 2) This process can be used to both add and remove DNA from the plasmid
 3) Without the use of specific restriction enzymes, this process will have low background

ANSWER: 1 and 2

TOSS UP

12) MATH *Short Answer* Vectors A and B have magnitudes 8 and 15, respectively. If $A \cdot B = -72$ (read: *A dot B is negative seventy-two*), what is the magnitude of $A \times B$ (read: *A cross B*)?

ANSWER: 96

BONUS

12) MATH *Short Answer* What is the sum of all possible values for x among the integer solutions to the equation $xy - x - y = 2^{2024} - 1$?

ANSWER: 4050

TOSS UP

13) PHYSICS *Short Answer* A circuit is constructed from an infinite set of parallel resistors such that the nth resistor has resistance $\frac{1}{n}$ (read: *one over n*). What is the overall resistance of the circuit constructed by these infinite resistors?

ANSWER: 0

BONUS

13) PHYSICS *Short Answer* Two sound waves with wavelengths 8 and 12 meters interfere in phase with one another. The resulting wave can be written as a high frequency oscillation modulated by a low frequency envelope. In meters, what is the wavelength of the low frequency envelope?

ANSWER: 48

TOSS UP

14) ENERGY *Short Answer* Physicists at MIT's Laboratory for Nuclear Science accurately measured the radii of silicon-32 atoms produced by the decay of long-lived excited isotopes. What term describes the out-of-equilibrium behavior of these long-lived excited isotopes?

ANSWER: Metastable (ACCEPT: Metastability)

BONUS

14) ENERGY *Short Answer* Physicists from MIT are collaborating with the Department of Energy to excite atoms with attosecond X-ray laser pulses, then observe the core electrons emitted when these excited atoms relax. What effect are the scientists observing through their experiment?

ANSWER: Auger Effect (ACCEPT: Auger)

TOSS UP

15) CHEMISTRY *Multiple Choice* Sylvia mixes a colorless volatile liquid into water, and observes the formation of a white powdery substance. Which of the following could be the identity of the powder?

  W) Silicon Dioxide
  X) Calcium Hydroxide
  Y) Silver Oxide
  Z) Lead Hydroxide

ANSWER: W) Silicon Dioxide

BONUS

15) CHEMISTRY *Short Answer* What principle explains why ultraviolet-visible absorption spectra have broad bands by approximating electronic transitions as occurring on a much faster timescale than the motion of nuclei?

ANSWER: Frank-Condon principle

TOSS UP

16) MATH *Short Answer* What is the maximum number of points that 5 identical circles can intersect at, assuming none of them share the same center?

ANSWER: 20

BONUS

16) MATH *Multiple Choice* Alex is estimating the complex-valued function $f(z) = e^z - z - 1$. In which of the quadrants of the complex plane does $f(0.01 + 0.02i)$ (read: *f of the quantity 0.01 + 0.02 i*) lie?

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

ANSWER: X) Quadrant 2

TOSS UP

17) BIOLOGY *Multiple Choice* Which of the following macromolecules is analyzed via pulsed-field gel electrophoresis?

  W) Carbohydrates
  X) Lipids
  Y) Proteins
  Z) Nucleic Acids

ANSWER: Z) Nucleic Acids

BONUS

17) BIOLOGY *Short Answer* Identify all of the following three choices that are derived characteristics of vascular plants:

  1) Presence of vessel elements
  2) Homosporous spore production
  3) Lignified tissue

ANSWER: None

TOSS UP

18) EARTH AND SPACE *Short Answer* Identify all of the following THREE choices which are true regarding vorticity (*vort-i-city*):

1) The equator has maximum absolute vorticity
2) Barotropic flow conserves absolute vorticity
3) An increase in horizontal wind shear increases vorticity

ANSWER: 2 and 3

BONUS

18) EARTH AND SPACE *Short Answer* Identify all of the following three comparisons that are TRUE regarding the relationship between quintessence and the cosmological constant:

1) Quintessence can have positive value, while the cosmological constant must always have a negative value
2) Quintessence is described with a high dimension vector field, while the cosmological constant is described with a scalar field
3) Universes where quintessence applies allow for the interior angles of squares to sum to greater than 360 degrees in one region and less than 360 degrees in another region

ANSWER: 3 only

TOSS UP

19) MATH *Short Answer* Expressed as a simplified fraction and in terms of π (read: *pi*), find the area integral over the region $x^2 + y^2 \leq 4$ (read: *x squared plus y squared is less than or equal to four*) of $\sqrt{4 - x^2 - y^2}$ (read: *the square root of the quantity four minus x squared minus y squared*).

ANSWER: $16\pi/3$ (read: *sixteen pi over three*)

VISUAL BONUS

19) MATH *Short Answer* Your next bonus is visual. In right triangle ABC, X and Y are the perpendicular feet of B and C to median AM, respectively. If XY = 14 and BC = 50, then what is AC?

ANSWER: 40

TOSS UP

20) EARTH AND SPACE *Multiple Choice* Which of the following types of telescope aberration is usually corrected for through the use of curved lenses?

  W) Spherical
  X) Astigmatism
  Y) Coma
  Z) Chromatic

ANSWER: Z) Chromatic

BONUS

20) EARTH AND SPACE *Multiple Choice* Which of the following tectonic regimes is most likely to be similar to the partial melting of the subsurface ocean on Europa that is thought to potentially result in a cryo tectonic cycle on the surface?

  W) Drip tectonics
  X) Venusian resurfacing events
  Y) Lunar tectonics
  Z) Plate tectonics

ANSWER: X) Venusian resurfacing events

TOSS UP

21) CHEMISTRY *Short Answer* In organic chemistry, what type of reactive species contains a carbon atom that is uncharged with an incomplete octet?

ANSWER: Carbene

BONUS

21) CHEMISTRY *Short Answer* Light with a wavelength of at most 120 nanometers is capable of exciting an electron from the ground state to the first excited state of a neutral hydrogen atom. To the nearest hundred nanometers, what is the maximum wavelength of light that can excite an electron from the first excited state to the third excited state of a neutral hydrogen atom?

ANSWER: 500

TOSS UP

22) PHYSICS *Multiple Choice* For a mechanical system with multiple degrees of freedom, which of the following conditions must be true at an equilibrium point for the system to be in stable mechanical equilibrium?

  W) The Jacobian of potential energy has only positive eigenvalues
  X) The Jacobian of potential energy has only negative eigenvalues
  Y) The Hessian of potential energy has only positive eigenvalues
  Z) The Hessian of potential energy has only negative eigenvalues

ANSWER: Z) The Hessian of potential energy has only negative eigenvalues

BONUS

22) PHYSICS *Short Answer* A linearly polarized light beam with intensity 16 lux is completely blocked by a polarizing sheet. A second polarizing sheet is placed in front of the first, and the resultant intensity is 1 lux. What is the smallest possible angle, in degrees, between the orientation of the two polarizing sheets?

ANSWER: 15

TOSS UP

23) BIOLOGY *Short Answer* Identify all of the following three plants for which the stomatal density on the upper side of a leaf is greater than the stomatal density on the lower side of a leaf:

1) Agave
2) Corn
3) Water Lily

ANSWER: 3 only

BONUS

23) BIOLOGY *Short Answer* Identify all of the following three metals that are cofactors required for the function of nitrogenase:

1) Iron
2) Molybdenum
3) Nickel

ANSWER: 1 and 2