2024 MIT Science Bowl High School Invitational

Round 12

TOSS UP

1) PHYSICS *Multiple Choice* The funnel of an hourglass is blocked by a stopper so that a small amount of sand is trapped above the funnel. The hourglass is placed on a scale, before the stopper is removed and the sand is allowed to fall. Which of the following describes how the scale reading changes over time from when the stopper is released until sand stops falling through the funnel, assuming the force from sand decelerating is negligible?

W) Increases, then becomes constant
X) Decreases, then becomes constant
Y) Increases, becomes constant, then decreases
Z) Decreases, becomes constant, then increases

ANSWER: Z) Decreases, becomes constant, then increases

VISUAL BONUS

1) PHYSICS *Short Answer* Your next bonus is visual. Shown in the image is a diagram of a muon undergoing decay. Answer the following two questions about the diagram:

1) What is the general name of such diagrams used to compute quantum relativistic particle interactions?
2) This process can occur even though the intermediate W boson is more massive than the muon. What is the term for such a particle, which is not real but mediates the interaction temporarily?

ANSWER: 1) Feynman diagram; 2) Virtual particle

TOSS UP

2) ENERGY *Multiple Choice* Researchers at the Silva Lab have been studying the immune system present around white adipose tissue. Which of the following is NOT true about white adipose tissue?

W) Release of insulin from the pancreas inactivates lipase in white adipose tissue
X) Brown adipose tissue can be distinguished from white adipose tissue by lysosome number
Y) The hormone leptin is primarily produced in white adipose tissue
Z) White adipose tissue is present in the bone marrow

ANSWER: X) Brown adipose tissue can be distinguished from white adipose tissue by lysosome number

BONUS

2) ENERGY *Short Answer* Researchers at the Anderson Lab have been studying computational models predicting transfection rates. Order the following three steps in endosomal escape thought to mediate transfection with lipid nanoparticle vectors:

1) Disruption of lipid membranes
2) Formation of ionizable lipid inverted cone geometry
3) Reduction in pH

ANSWER: 3, 2, 1

TOSS UP

3) EARTH AND SPACE *Short Answer* Identify all of the following conditions that are necessary for snowflakes to survive in above-freezing temperatures:

1) The air must be unsaturated
2) The dry bulb temperature must be at or below 0 degrees Celsius
3) The wet bulb temperature must be at or below 0 degrees Celsius

ANSWER: 1 and 3

BONUS

3) EARTH AND SPACE *Short Answer* Identify all of the following three choices that correctly match the atmospheric scale with present equilibria:

1) Synoptic (*sin-opt-ic*) scale - geostrophic and hydrostatic equilibrium
2) Mesoscale - hydrostatic equilibrium only
3) Microscale - neither geostrophic nor hydrostatic equilibrium

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

TOSS UP

4) MATH *Multiple Choice* What is the multiplicative inverse of 34 modulo 37?

W) 3
X) 12
Y) 21
Z) 30

ANSWER: X) 12

BONUS

4) MATH *Short Answer* Find the population standard deviation of the roots of the polynomial $x^3 - 24x + 5$ (read: *x cubed minus twenty-four x plus five*).

ANSWER: 4

TOSS UP

5) CHEMISTRY *Multiple Choice* The click reaction between an azide and an alkyne follows which of the following types of reaction mechanisms?

W) Nucleophilic
X) Ionic
Y) Radical
Z) Cycloaddition

ANSWER: Z) Cycloaddition

VISUAL BONUS

5) CHEMISTRY *Short Answer* Your next bonus is visual. Shown in the image is a natural pathway for the synthesis of an important biomolecule. Answer the following two questions about this pathway:

1) What important biomolecule is produced during the second step?
2) Under what conditions does the first step proceed?

ANSWER: 1) Vitamin D; 2) Photochemically (ACCEPT: any indication that light is involved)

TOSS UP

6) BIOLOGY *Short Answer* Many patients with late-stage cancer, AIDS, and tuberculosis suffer from a devastating wasting disorder called cachexia (*ca-chek-sia*), which is associated with the dysfunction of brain receptors for what anterior pituitary hormone?

ANSWER: MSH (ACCEPT: Melanocyte-stimulating hormone)

BONUS

6) BIOLOGY *Multiple Choice* Aryan is studying protists and he finds hydrogenosomes (*high-draw-jih-no-zomes*), which are reduced mitochondria that generate energy anaerobically (*an-nah-ro-bi-cally*). Which of the following protists could he be studying?

W) Giardia intestinalis (*gee-ar-dee-a in-tes-ti-na-lis*)
X) Trypanosoma chagas (*truh-pa-nuh-sow-muh cha-gus*)
Y) Trichomonas vaginalis (*tri-ko-mo-nas vaginalis*)
Z) Plasmodium falciparum (*plaz-mo-dee-um fall-sih-pah-rum*)

ANSWER: Y) Trichomonas vaginalis

TOSS UP

7) ENERGY *Short Answer* Researchers at MIT's Winslow Lab are researching the hypothesized axion as a candidate for dark matter. Axions are hypothesized to preserve what type of symmetry that arises from exchanging a particle with its antiparticle under inverted coordinates?

ANSWER: Charge-Parity symmetry (ACCEPT: CP symmetry, DO NOT ACCEPT: CPT symmetry)

VISUAL BONUS

7) ENERGY *Short Answer* Your next bonus is visual. Researchers at the Vallabh/Minikel Lab recently discovered a method using CRISPRoff to target upstream prion genes. Based on the provided diagram of the CRISPRoff targeting and bisulfite sequencing results, answer the following three questions:

1) What noncleaving protein was used to target sequences?
2) What modification of H2B was most likely being studied?
3) Modifications to which nucleotide were detected by the protocol?

ANSWER: 1) dCas9; 2) Methylation; 3) Cytosine (ACCEPT: C)

TOSS UP

8) CHEMISTRY *Multiple Choice* Which of the following compounds has the smallest bond angle at oxygen?

W) Water
X) Methanol
Y) Dimethyl ether
Z) Oxygen difluoride

ANSWER: Z) Oxygen difluoride

VISUAL BONUS

8) CHEMISTRY *Short Answer* Your next bonus is visual. Shown in the image are three d-metal splitting energy diagrams, labeled A, B and C, as well as the complexes platinum (II) tetrachloride, nickel tetracarbonyl, and cobalt (III) hexaamine, labeled 1, 2, and 3, respectively. Note that the energy splittings in the image are not necessarily to scale. Answer the following two questions using this image:

1) By letter and number, pair each complex to its corresponding splitting diagram
2) By number, which of the three complexes are predicted to be diamagnetic?

ANSWER: 1) A2, B3, C1; 2) All (ACCEPT: 2) 1,2,3)

TOSS UP

9) PHYSICS *Short Answer* In the Earth's reference frame, two spaceships travel toward each other at three-fifths the speed of light. What fraction of the speed of light is the speed of one ship observed by a person on the other ship?

ANSWER: $\frac{15}{17}$

BONUS

9) PHYSICS *Short Answer* Consider a cube of 8 point charges, with alternating charges of magnitude $+q$ and $-q$. Asymptotically, with what exponent of r does the electric field $E(r)$ grow?

ANSWER: -5

TOSS UP

10) MATH *Short Answer* Identify all of the following three identities involving vector products which are true for all vectors a and b:

1) $a \cdot a = 0$ (read: *a dot a equals zero*)
2) $a \times a = 0$ (read: *a cross a equals the zero vector*)
3) $a \cdot (a \times b) = 0$ (read: *a dot the quantity a cross b equals 0*)

ANSWER: 2 and 3

BONUS

10) MATH *Short Answer* Tim has 2 blue balls and 4 red balls. He divides the balls into two groups of 3 at random, then finds the positive difference between the number of red balls in each group. What is the expected value of this difference?

ANSWER: $\frac{4}{5}$ (ACCEPT: 0.8, 80%)

TOSS UP

11) BIOLOGY *Multiple Choice* Although there are approximately 3 bonds along the carbon backbone per amino acid in a polypeptide, Ramachandran plots only consider the angle of rotation about two bonds for each amino acid. Which of the following best explains why the rotation angle about the nitrogen - alpha carbon bond is generally excluded from these plots?

W) The rotation angle about this bond is significantly more difficult to determine than the phi and psi angles
X) The rotation angle about this bond typically has low variance in most proteins
Y) The rotation angle about this bond is approximately the sum of the phi and psi angles
Z) Rotation about this bond does not significantly affect protein structure

ANSWER: X) The rotation angle about this bond typically has low variance in most proteins

BONUS

11) BIOLOGY *Multiple Choice* Verno is studying mitogen activated protein kinases, or MAPKs, which are active once they are phosphorylated at their serine residue. Which of the following amino acids, if it replaced serine, would likely cause a constitutively active protein by mimicking the electrochemical properties of the phosphorylated state?

W) Glutamate
X) Lysine
Y) Alanine
Z) Cysteine

ANSWER: W) Glutamate

TOSS UP

12) EARTH AND SPACE *Short Answer* What opacity-related mechanism powers Cepheid variable stars' pulsations?

ANSWER: Kappa Mechanism

VISUAL BONUS

12) EARTH AND SPACE *Short Answer* Your next bonus is visual. The image shows a graph of X-ray flux with respect to time measured from a solar flare. Answer the following three questions about solar flares:

1) Solar flares are associated with the magnetic field of the sun. What is the name of the area of the sun's corona where open magnetic fields allow for ionized gas to flow away?
2) What is the name of this ionized gas flowing away from the sun?
3) To one significant figure, how many times larger is the magnitude of the flux of a X2.8 solar flare compared to a M5.8 flare?

ANSWER: 1) Coronal hole; 2) Solar wind; 3) 5

TOSS UP

13) MATH *Multiple Choice* Penelope chooses a real number l. She draws the points $(0, 0)$ (read: *zero comma zero*), $(1, 0)$, and $(l, 1)$ in the Cartesian plane. As l increases from negative infinity to infinity, which of the following describes the inradius of the triangle?

W) Decreases monotonically
X) Increases monotonically
Y) Decreases, then increases
Z) Increases, then decreases

ANSWER: Z) Increases, then decreases

BONUS

13) MATH *Short Answer* Identify all of the following three sets that have a convergent sum:

1) The reciprocals of every positive integer that ends in the digit 9
2) The reciprocals of every positive integer that does not contain the digit 9
3) The reciprocals of every positive integer that begins in the digit 9

ANSWER: 2 only

TOSS UP

14) ENERGY *Short Answer* Astronomers from MIT and NASA successfully measured the spin of a supermassive blackhole. The spin of a blackhole is responsible for what distorting effect on the surrounding space-time?

ANSWER: Frame dragging (ACCEPT: Lense-Thirring)

BONUS

14) ENERGY *Multiple Choice* Researchers at MIT are studying cataclysmic variables, which are binaries that orbit each other in under an hour. The rate of the decay of the radius of a binary system depends solely on the cataclysmic variables' respective masses, the radius of the system, the speed of light in a vacuum c, the universal gravitational constant G (read: *big G*), and a unitless constant. If the rate of decay of the binary system's radius is proportional to G (read: *big G*) cubed, what power of the speed of light in a vacuum is the rate of radial decay proportional to?

W) -3
X) -4
Y) -5
Z) -6

ANSWER: Y) -5

TOSS UP

15) BIOLOGY *Short Answer* Consider an ecosystem with rabbit and fox populations that follow Lotka-Volterra predator-prey dynamics. Identify all of the following three changes to the ecosystem that will NOT affect the long term equilibrium population of foxes, assuming no other changes to population sizes or growth parameters:

1) Removing half the rabbits and half the wolves from an ecosystem
2) Increasing the reproduction rate of the rabbits
3) Decreasing the life expectancy of the foxes

ANSWER: 1 and 3

VISUAL BONUS

15) BIOLOGY *Short Answer* Your next bonus is visual. The image provided shows the pressure volume loop associated with a normal left ventricle of the heart. Answer the following two questions about the diagram:

1) Order the 4 points on the diagram by the sequence which the heart goes through, starting where the mitral valve opens.
2) Estimate the end diastolic volume in milliliters of the left ventricle based on this diagram. Round your answer to the nearest ten.

ANSWER: 1) 3, 4, 2, 1; 2) 120 mL

TOSS UP

16) PHYSICS *Multiple Choice* Ellie places two identical circular loops of counterclockwise current directly above each other such that their axes of symmetry coincide. Assuming that their separation l is much greater than their radii, which of the following choices best describes the direction and strength, respectively, of the force they exert on each other?

W) Attractive, proportional to l^{-3} (read: *l to the negative third*)
X) Attractive, proportional to l^{-4} (read: *l to the negative fourth*)
Y) Repulsive, proportional to l^{-3} (read: *l to the negative third*)
Z) Repulsive, proportional to l^{-4} (read: *l to the negative fourth*)

ANSWER: X) Attractive, proportional to l^{-4} (read: *l to the negative fourth*)

BONUS

16) PHYSICS *Short Answer* Three identical masses of mass m are each connected by identical massless springs of spring constant k to form a circle. The system has many possible vibrational modes. In terms of m and k, what is the largest possible angular frequency of such a mode?

ANSWER: $\sqrt{3k/m}$

TOSS UP

17) EARTH AND SPACE *Multiple Choice* Which of the following is NOT correct regarding the comparison between Mid Latitude Cyclones and Hurricanes?

W) Hurricanes and Mid Latitude Cyclones both rotate counterclockwise in the Northern Hemisphere
X) The strongest winds in a Mid Latitude Cyclone are at the surface, while the strongest winds in a Hurricane are at its top
Y) The air at the center of a hurricane is sinking, while the air in the center of a mid latitude cyclone is rising
Z) Mid latitude cyclones are formed by air temperature contrasts, while hurricanes are formed by warm water temperature

ANSWER: X) The strongest winds in a Mid Latitude Cyclone are at the surface, while the strongest winds in a Hurricane are at its top

VISUAL BONUS

17) EARTH AND SPACE *Short Answer* Your next bonus is visual. The diagram depicts the phase and chemical composition of melts with differing feldspar compositions as they crystallize. Taking a melt at position a, answer the following two questions, assuming one significant figure for each.

1) What percentage of the melt will be liquid at point c?
2) At what percentage Sodium Aluminum Silicate is the eutectic point located?

ANSWER: 1) 70%; 2) 30% (ACCEPT: 1) 0.7; 2) 0.3)

TOSS UP

18) CHEMISTRY *Short Answer* What model can be used to approximate the activities of solutes in non-ideal electrolyte solutions?

ANSWER: Debye-Huckel (ACCEPT: Poisson-Boltzmann)

BONUS

18) CHEMISTRY *Multiple Choice* Which of the following is closest to the energy released by the spin-flip of an electron in a ground-state hydrogen atom?

W) Between 0.1 and 10 electron-volts
X) Between 0.1 and 10 millielectron-volts
Y) Between 0.1 and 10 microelectron-volts
Z) Between 0.1 and 10 nanoelectron-volts

ANSWER: Y) Between 0.1 and 10 microelectron-volts

TOSS UP

19) EARTH AND SPACE *Multiple Choice* Which of the following numbers of cells per hemisphere are produced by ideal Stratospheric Brewer Dobson circulation patterns?

W) 1
X) 2
Y) 4
Z) 6

ANSWER: W) 1

BONUS

19) EARTH AND SPACE *Short Answer* To two significant figures and in Earth years, from the perspective of Earth, what is the time between oppositions of a superior planet with sidereal period of 5/4 of an Earth year?

ANSWER: 5

TOSS UP

20) CHEMISTRY *Multiple Choice* Which of the following best compares the general trend of thermodynamic and kinetic favorability between five membered and six membered saturated rings in organic chemistry?

W) Five membered rings are thermodynamically favored but kinetically disfavored to six membered rings
X) Five membered rings are kinetically favored but thermodynamically disfavored to six membered rings
Y) Five membered rings are thermodynamically and kinetically favored to six membered rings
Z) Five membered rings are thermodynamically and kinetically disfavored to six membered rings

ANSWER: X) Five membered rings are kinetically favored but thermodynamically disfavored to six membered rings

BONUS

20) CHEMISTRY *Multiple Choice* Which of the following correctly describes hydrogen bromide's activity in vibrational spectroscopy?

W) Hydrogen bromide is inactive in both IR and Raman spectroscopy
X) Hydrogen bromide is only active in IR spectroscopy
Y) Hydrogen bromide is only active in Raman spectroscopy
Z) Hydrogen bromide is active in both IR and Raman spectroscopy

ANSWER: Z) Hydrogen bromide is active in both IR and Raman spectroscopy

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TOSS UP

21) BIOLOGY *Short Answer* Following margination of neutrophils to a site of infection, they migrate through gaps in the blood vessels via what process?

ANSWER: Diapedesis (ACCEPT: Leukocyte extravasation)

VISUAL BONUS

21) BIOLOGY *Short Answer* Your next bonus is visual. Answer the following two questions about the plant shown in the image:

1) To what angiosperm family does this plant belong?
2) Cabbage is a result of the artificial selection of this plant primarily for what anatomical feature, associated with hormone production?

ANSWER: 1) Brassicaceae, 2) Apical Bud (ACCEPT: Axillary bud)

TOSS UP

22) MATH *Short Answer* What is the ratio of the sum of all the odd divisors of 48 to the sum of all the even divisors of 48?

ANSWER: $\frac{1}{30}$

VISUAL BONUS

22) MATH *Short Answer* Your next bonus is visual. The image shown is a representation of the Lorenz Attractor. Answer the following two questions: 1) What is the general type of system this attractor falls under, characterized by strong sensitivity to initial conditions 2) What is the term for the space in which the attractor is represented in the graph?

ANSWER: 1) Chaotic; 2) Phase space

TOSS UP

23) PHYSICS *Multiple Choice* James applies electric charge to a uniform and conducting thin circular disk. Which of the following choices best describes the charge distribution on the disk?

W) Concentrated exclusively on the circumference
X) Increases from the center to the circumference
Y) Decreases from the center to the circumference
Z) Uniformly distributed on the disk

ANSWER: X) Increases from the center to the circumference

BONUS

23) PHYSICS *Short Answer* Melody is standing on a train platform near the front of a train composed of train cars of equal length. When the train begins accelerating uniformly from rest, she notices that the first car takes one second to pass her. Expressed as a decimal rounded to one decimal place and in seconds, how much time does it take for the third car to pass her?

ANSWER: 0.3