2023 MIT Science Bowl High School Invitational Round 11

TOSS UP

1) EARTH AND SPACE *Multiple Choice* Continental flood basalts require significant igneous structures to support and feed them. Which of the following terms best describes the group of structures that transport magma to the surface in large volumes?

W) Volcanic pipe
X) Fissures
Y) Sills
Z) Dike swarms

ANSWER: Z) Dike swarms

BONUS

1) EARTH AND SPACE *Multiple Choice* River flow volumes often are not consistent throughout its course, even if no significant tributaries contribute to the measured flow volumes. Which of the following terms best describes the region which contributes to the variability of flow volumes?

W) Hyporheic zone
X) Vadose zone
Y) Phreatic zone
Z) Capillary fringe

ANSWER: W) Hyporheic zone

TOSS UP

2) PHYSICS *Multiple Choice* Two identical stationary masses are placed infinitely far apart, and then allowed to move towards each other due to their gravitational attraction. When they are 4 kilometers away from each other, each mass has accumulated a velocity of 10 meters per second. In meters per second, what will be the velocity of one of the masses when they are separated by 1 kilometer?

W) 20
X) 40
Y) 80
Z) 160

ANSWER: W) 20

BONUS

2) PHYSICS *Multiple Choice* Which of the following statements is NOT true about an object in motion through spacetime with a constant proper acceleration?

W) The path as observed in an inertial reference frame traces out the shape of a hyperbola on a spacetime diagram
X) An observer in a frame that is always moving with the object will feel a constant force due to the acceleration
Y) The object will never reach the speed of light
Z) Any light ray that begins behind the object and travels towards it will eventually pass it

ANSWER: Z) Any light ray that begins behind the object and travels towards it will eventually pass it

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TOSS UP

3) CHEMISTRY *Multiple Choice* Which of the following solvents is the most suitable for SN2 reactions?

W) Water
X) Methanol
Y) Acetone
Z) Benzene

ANSWER: Y) Acetone

BONUS

3) CHEMISTRY *Short Answer* Place the following three mechanistic steps in order from first to last in the radical bromination of an alkane:

1) Formation of carbon radical
2) Formation of atomic bromine
3) Radical recombination of the carbon and bromine atom

ANSWER: 2, 1, 3

TOSS UP

4) BIOLOGY *Multiple Choice* In the citric acid cycle, which of the following intermediates is produced alongside a carbon dioxide molecule?

W) Oxaloacetate
X) Citrate
Y) Isocitrate
Z) Alpha-ketoglutarate

ANSWER: Z) Alpha-ketoglutarate

BONUS

4) BIOLOGY *Short Answer* Identify all of the following three statements that are TRUE regarding transposons:

1) Transposase activity can result in the formation of pseudogenes
2) Retrotransposons employ a cut-and-paste mechanism
3) LINEs are a type of retrotransposon

ANSWER: 1 and 3

TOSS UP

5) ENERGY *Short Answer* Researchers in the Batista Lab at MIT are studying B-cells, specifically how and where they are activated in the body. Which process, taking place in the germinal center of lymph nodes, involves the mutation of B-cell receptors for improved antigen affinity?

ANSWER: Somatic hypermutation

BONUS

5) ENERGY *Short Answer* Researchers in the Housman Lab at MIT are trying to understand how different genes may be associated with Huntington's disease, which is caused by a trinucleotide repeat expansion. Identify all of the following four processes that contribute to trinucleotide repeat expansions:

1) Hairpin formation
2) DNA replication
3) DNA repair
4) Slippage of DNA polymerase

ANSWER: 1, 2, 3, and 4 (ACCEPT: All)

TOSS UP

6) MATH *Short Answer* What is the remainder when 11! (read: *eleven factorial*) is divided by 13?

ANSWER: 1

BONUS

6) MATH *Short Answer* A unit square centered at the origin is dilated by a factor of 4, then rotated by 45 degrees. How many lattice points are contained within or along the new square?

ANSWER: 25

TOSS UP

7) BIOLOGY *Multiple Choice* Which of the following statements is NOT true regarding basidiomycetes (*buh-sideo-my-seats*)?

W) Basidiomycetes are more closely related to ascomycetes than they are to zygomycetes.
X) Each basidium contains four basidiospores.
Y) Basidiomycetes possess septate hyphae.
Z) During sexual reproduction, meiosis precedes karyogamy (*carry-ah-guh-me*).

ANSWER: Z) During sexual reproduction, meiosis precedes karyogamy.

BONUS

7) BIOLOGY *Short Answer* Order the following four events that occur during the contraction of the heart following an isovolumetric contraction:

1) Filling of the ventricles
2) Isovolumetric relaxation
3) Emptying of the ventricles
4) Closing of the mitral valve

ANSWER: 3, 2, 1, 4

TOSS UP

8) MATH *Short Answer* To the nearest whole number, what is the sum of the base-ten logarithm of each of the first seven positive integers?

ANSWER: 4

BONUS

8) MATH *Short Answer* A weighted die has the weird property that rolling a two has half the probability of rolling a one, a three has a third of a one, a four has a fourth of a one, and so on. What is the probability that a 1 or 6 is rolled?

ANSWER: 10/21

TOSS UP

9) PHYSICS *Multiple Choice* A circuit consists of an sinusoidal voltage source with a peak voltage of 18 volts in series with a resistor of 3 ohms. In watts, what is the average power dissipated by the resistor?

W) 27
X) 54
Y) 81
Z) 108

ANSWER: X) 54

BONUS

9) PHYSICS *Short Answer* A circuit consists of a 12 volt battery, a 10 ohm resistor, and an initially uncharged 0.5 farad parallel plate capacitor in series. When the capacitor is fully charged, how many joules of the battery's energy have been drained?

ANSWER: 72

TOSS UP

10) ENERGY *Multiple Choice* Researchers in the Swager group are working on methods to detect trace amounts of *n*-nitrosamines, which are highly carcinogenic. Traditionally, *n*-nitrosamines are formed by reaction of a secondary amine with which of the following acids?

W) HN_3
X) HNO
Y) HNO_2
Z) HNO_3

ANSWER: Y) HNO_2

BONUS

10) ENERGY *Multiple Choice* Researchers in the Essigman Lab at MIT developed a cisplatin-based drug containing two additional monodentate peptide ligands. What is the molecular geometry of the platinum center in their drug?

W) Tetrahedral
X) Square planar
Y) Octahedral
Z) Dodecahedral

ANSWER: Y) Octahedral

TOSS UP

11) CHEMISTRY *Multiple Choice* Which of the following molecular orbitals does the unpaired electron in the hydroxyl radical occupy?

W) Sigma bonding
X) Pi bonding
Y) Oxygen nonbonding
Z) Pi antibonding

ANSWER: Y) Oxygen nonbonding

BONUS

11) CHEMISTRY *Multiple Choice* Which of the following transition metal ions generally observes a blue color?

W) Vanadium (III) (read: *vanadium three*)
X) Chromium (III)
Y) Iron (II)
Z) Iron (III)

ANSWER: X) Chromium (III)

TOSS UP

12) EARTH AND SPACE *Multiple Choice* Zeolites, such as stilbite or heulandite, are classified as which of the following types of silicate?

W) Phyllosilicate
X) Tectosilicate
Y) Inosilicate (*In-oh-sill-i-ket*)
Z) Sorosilicate

ANSWER: X) Tectosilicate

BONUS

12) EARTH AND SPACE *Short Answer* Order the following three fronts by increasing intensity of rainfall:

1) Cold occluded front
2) Warm front
3) Warm occluded front

ANSWER: 2, 3, 1

TOSS UP

13) MATH *Short Answer* Two of the legs of a right triangle are $\sin x$ and $\cos x$ for some value of x. What is the largest possible area of the triangle?

ANSWER: 1/4

BONUS

13) MATH *Short Answer* What is the shortest distance from the origin to the curve $y = \sqrt{6x + 25}$ (read: *y equals the square root of the quantity six x plus twenty-five*)?

ANSWER: 4

TOSS UP

14) BIOLOGY *Multiple Choice* Judson develops an inhibitor for the F-type receptor and treats various regions of the heart with the inhibitor. In which of the following regions would you expect to find the cells with the most F-type receptors?

W) AV node
X) Bundle of His
Y) Purkinje fibers
Z) SA Node

ANSWER: Z) SA Node

BONUS

14) BIOLOGY *Short Answer* A patient is infected with Vibrio cholerae. Identify all of the following three enterocyte modifications that would worsen the symptoms of the patient:

1) Increased chloride ion secretion
2) Increased activity of cyclic AMP phosphodiesterase (*foss-foe-die-ester-ase*)
3) Increased activity of adenylyl cyclase

ANSWER: 1 and 3

TOSS UP

15) CHEMISTRY *Short Answer* Combustion of potassium in the atmosphere predominantly leads to the formation of what potassium-containing salt?

ANSWER: Potassium superoxide (ACCEPT: KO_2)

BONUS

15) CHEMISTRY *Short Answer* Rank the following three substituents in terms of increasing activation towards electrophilic aromatic substitution:

1) Methoxy
2) Cyano
3) Chloro

ANSWER: 2, 3, 1

TOSS UP

16) PHYSICS *Short Answer* Two sound waves with equal amplitudes and frequencies interfere at a point with a phase difference of 60 degrees. What is the ratio of the amplitude of the resultant wave to the amplitude of one of the original waves?

ANSWER: $\sqrt{3}$

BONUS

16) PHYSICS *Multiple Choice* Sophia places a cylindrical shell with radius 0.5 meters on a moving treadmill, which is inclined at an angle of 30 degrees. She then steadily increases the speed of the treadmill, in a way such that the cylindrical shell stays in place. Assuming the shell rolls without slipping, in terms of the gravitational acceleration g, at what rate must Sophia increase the treadmill's speed?

W) g
X) $2g$
Y) $g/2$
Z) $g/4$

ANSWER: Z) $g/4$

TOSS UP

17) EARTH AND SPACE *Short Answer* Identify all of the following three objects which are not matched with the L4 and L5 lagrange points of its correct system:

1) Kordylewski clouds: Neptune-Sun
2) Trojans: Jupiter-Sun
3) Telesto and Calypso: Tethys-Saturn

ANSWER: 1 only

BONUS

17) EARTH AND SPACE *Short Answer* If the Hubble parameter of the universe were doubled and the graviational constant were halved, by what factor would the critical density of the universe change?

ANSWER: 8

TOSS UP

18) ENERGY *Short Answer* Scientists at the LIGO collaboration supported by MIT use squeeze states of light to improve the sensitivity of their interferometry instruments. Squeeze states minimize the uncertainty in conjugate variables by taking advantage of what inequality in quantum mechanics?

ANSWER: Heisenberg inequality

BONUS

18) ENERGY *Short Answer* Researchers at MIT and University of New Hampshire studied the production of heavy elements from the merger between two neutron stars. What is the name of the theoretical upper bound to the mass of cold, non-rotating neutron stars?

ANSWER: Tolman-Oppenheimer-Volkoff limit

TOSS UP

19) BIOLOGY *Short Answer* Derek is observing cells doing a special type of receptor mediated endocytosis. Interestingly, he notices it doesn't proceed via a clathrate involution mechanism. Instead, the contents are directly delivered to the cytosol after endocytosis. What form of endocytosis is he studying?

ANSWER: Potocytosis

BONUS

19) BIOLOGY *Short Answer* Scientists are finding ways to manipulate the Cas9 protein for improved genome editing. Identify all of the following four reasons why scientists may generate mutations in the HNH or RuvC endonuclease domains of Cas9:

1) Generation of a Cas9 nickase
2) Production of dCas9
3) Increased binding specificity of Cas9 to target DNA
4) Promotion of non-homologous end joining

ANSWER: 1 and 2

TOSS UP

20) MATH *Multiple Choice* What value does the fraction with numerator $x^3 - 27$ (read: *x cubed minus 27*) and denominator $x - 3$ (read: *x minus 3*) approach as x approaches 3?

W) 9
X) 18
Y) 27
Z) 36

ANSWER: Y) 27

BONUS

20) MATH *Short Answer* How many three digit numbers are there that when written in base-8 are palindromes?

ANSWER: 58

TOSS UP

21) EARTH AND SPACE *Multiple Choice* Which of the following cosmological problems addresses the reason for the observed density of the universe equaling the critical density?

W) Horizon problem
X) Flatness problem
Y) Final parsec problem
Z) Cosmological constant problem

ANSWER: X) Flatness problem

BONUS

21) EARTH AND SPACE *Multiple Choice* Forbidden spectral lines arise at low densities often found in space. What phenomena de-excites these molecules at normal pressures?

W) Collisions with other molecules
X) Hydrogen bonding
Y) Translation into kinetic energy via equipartition theorem
Z) Hydrogen abstraction from water

ANSWER: W) Collisions with other molecules

TOSS UP

22) CHEMISTRY *Short Answer* The Marsh test, an archaic test for arsenic detection relied on the fact that when exposed to acidic and reducing conditions, arsenic oxides produce what highly toxic and flammable gas?

ANSWER: Arsine (ACCEPT: AsH_3)

BONUS

22) CHEMISTRY *Short Answer* What is the change in constant volume heat capacity, in terms of the ideal gas constant, R, for a diatomic molecule that is heated from 2 kelvin to 2000 kelvin?

ANSWER: $0.5R$ (ACCEPT: $R/2$)

TOSS UP

23) PHYSICS *Short Answer* A certain object is being heated on part of its surface and cooled on a different part of its surface. Assuming no internal heat generation, solving for the equilibrium temperature distribution inside the object involves applying what operator to the temperature distribution and setting it equal to 0?

ANSWER: Laplacian

BONUS

23) PHYSICS *Short Answer* A square swimming pool has side length 10 meters and depth 1 meter, and is filled with water. Expressing your answer in scientific notation to one significant figure, what is the force, in newtons, exerted by the water on one of the sides of the pool?

ANSWER: 1×10^6