2022 MIT Science Bowl High School Invitational Round 7

TOSS UP

1) MATH *Multiple Choice* What is the dimension of the nullspace of the 3×3 (read: *three by three*) matrix with all entries 1?

W) 0
X) 1
Y) 2
Z) 3

ANSWER: Y) 2

BONUS

1) MATH *Short Answer* What is the area of the set of all points which are within a distance of at most one unit from the boundary of a square of side length 7?

ANSWER: $52 + \pi$

TOSS UP

2) PHYSICS *Short Answer* A telescope consists of a concave spherical mirror with a radius of 160 centimeters, and is pointed vertically towards stars at the zenith. How far above the bottom of the mirror, in centimeters, should a detector be placed to properly form an image of the stars?

ANSWER: 80

BONUS

2) PHYSICS *Short Answer* By name or number, identify all of the following three statements regarding cosmic inflation that are true:

1) Cosmic inflation has been theorized to solve the flatness problem by exponentially growing the universe out of any curvature
2) The inflationary era of the universe is theorized to have occurred at around 0.01 seconds after the Big Bang
3) The principles of cosmic inflation explain the isotropy of the universe

ANSWER: 1 and 3

TOSS UP

3) ENERGY *Short Answer* Researchers in the Knouse (*NAUS*) Lab at MIT used a newly developed system to search for genes important to hepatocyte viability, and discovered that MHC genes involved with antigen presentation are especially essential. What does the term MHC stand for?

ANSWER: Major histocompatibility complex

BONUS

3) ENERGY *Short Answer* The Knouse (*NAUS*) Lab at MIT has recently developed genome-wide CRISPR screening in the mouse liver, which uses lentiviruses encoding one of the necessary components of the CRISPR-Cas9 system. What is this component that is the synthetic combination of crRNA and tracrRNA?

ANSWER: sgRNA (ACCEPT: Single-guide RNA)

TOSS UP

4) EARTH AND SPACE *Short Answer* What term describes the area where the northeast and southeast trade winds meet?

ANSWER: Intertropical Convergence Zone (ACCEPT: ITCZ)

BONUS

4) EARTH AND SPACE *Short Answer* River A has the same cross-sectional area but twice the velocity as River B. How many times greater is River A's competence and capacity, respectively, when compared with River B?

ANSWER: 4 and 2 (ACCEPT: Quadruple and double; DO NOT ACCEPT: 2 and 4)

TOSS UP

5) BIOLOGY *Short Answer* Which amino acid, known for its anti-helix properties, is characterized by a ring in its structure?

ANSWER: Proline

BONUS

5) BIOLOGY *Multiple Choice* Which of the following amino acids is incorrectly paired with its polar properties?

W) Serine (*SEHR-een*), polar
X) Arginine (*AAR-juh-neen*), polar
Y) Tryptophan (*TRIP-tuh-fan*), polar
Z) Leucine (*LOO-seen*), nonpolar

ANSWER: Y) Tryptophan, polar

TOSS UP

6) CHEMISTRY *Multiple Choice* A saturated aqueous solution of which of the following barium salts would have the lowest boiling point?

W) Barium hydroxide
X) Barium cyanide
Y) Barium sulfate
Z) Barium acetate

ANSWER: Y) Barium sulfate

BONUS

6) CHEMISTRY *Short Answer* By name or number, identify all of the following three compounds that contain an sp^2 hybridized nitrogen atom:

1) N_2Cl_2
2) N_2H_4
3) NH_2CHO

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

TOSS UP

7) CHEMISTRY *Multiple Choice* In the gas phase, strong hydrogen bonding between two molecules of acetic acid will cause them to bond together, forming a dimer. This reaction is spontaneous at which of the following temperatures?

W) Spontaneous at low temperatures only
X) Spontaneous at high temperatures only
Y) Always spontaneous
Z) Never spontaneous

ANSWER: W) Spontaneous at low temperatures only

BONUS

7) CHEMISTRY *Short Answer* Cellulose is a polysaccharide consisting of hundreds to thousands of D-glucose units. During the polymerization of D-glucose to form cellulose, condensation reactions occur to form glycosidic bonds between adjacent glucose molecules. Expressed in terms of n, and rounding all terms to the nearest gram per mole, what is the molar mass of a cellulose strand formed from n glucose units?

ANSWER: $162n + 18$

TOSS UP

8) EARTH AND SPACE *Short Answer* By name or number, order the following three mountain ranges from youngest to oldest:

1) Appalachians
2) Andes
3) Himalayas

ANSWER: 3, 2, 1

BONUS

8) EARTH AND SPACE *Multiple Choice* Olivine is best categorized as which of the following types of silicates (*SIL-ih-kit*)?

W) Nesosilicates (*nee-soh-SIL-ih-kits*)
X) Inosilicates (*in-uh-SIL-ih-kits*)
Y) Tectosilicates (*tek-toh-SIL-ih-kits*)
Z) Phyllosilicates (*fil-oh-SIL-ih-kits*)

ANSWER: W) Nesosilicates

TOSS UP

9) MATH *Short Answer* What is the period of the product of the two functions $\sin(4x)$ and $\cos(4x)$?

ANSWER: $\pi/4$

BONUS

9) MATH *Short Answer* If x is less than y and $\log_x y + \log_y x = 10$ (read: *log base x of y plus log base y of x equals 10*), what is the value of $\log_x y$?

ANSWER: $5 + 2\sqrt{6}$

TOSS UP

10) BIOLOGY *Short Answer* By name or number, identify all of the following four areas in a human nephron where water is reabsorbed:

1) Proximal tubule
2) Descending limb of the Loop of Henle (*HEN-lee*)
3) Ascending limb of the Loop of Henle (*HEN-lee*)
4) Collecting duct

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

BONUS

10) BIOLOGY *Short Answer* Arthur has not been drinking enough water, and as a result, the blood pressure in his afferent arteriole (*are-TEE-ree-owl*) has dropped. What endocrine circuit, controlled by the juxtaglomerular (*juhk-stuh-gluh-MEHR-yuh-ler*) apparatus, will activate, resulting in an increase in Arthur's blood pressure?

ANSWER: Renin-angiotensin-aldosterone system (ACCEPT: RAAS)

TOSS UP

11) PHYSICS *Multiple Choice* A spring-mass system undergoes damped harmonic oscillation. After some time, the amplitude of the oscillation is 98 percent of the original amplitude. To the nearest percent, how much of the original energy has been lost?

W) 0.5
X) 1
Y) 2
Z) 4

ANSWER: Z) 4

BONUS

11) PHYSICS *Short Answer* An idealized sand timer consists of spherical sand particles with radius 0.1 millimeter funneled from a cylinder with a radius of 1 centimeter into a circular hole with a radius of 1 millimeter. The total height of the sand in the cylinder is 3 centimeters. On the surface of Earth, it takes 4 minutes for the sand to drain completely. If the same sand timer is used on a planet with a surface gravity of 3.3 meters per second squared, to the nearest minute, how long will it take for the sand to drain completely?

ANSWER: 7

TOSS UP

12) ENERGY *Short Answer* Physicists in the MIT Laboratory for Nuclear Science were recently part of a team which discovered a sudden change in the nuclear magnetic behavior of indium when the number of neutrons reached 82. What is the name for such numbers, including 2, 8, and 20, for which the nucleons are arranged into complete shells leading to increased stability and other interesting properties?

ANSWER: Magic numbers

BONUS

12) ENERGY *Short Answer* Researchers at MIT's Research Laboratory of Electronics have constructed an optical switch controlled by a single photon, allowing light to control the transmission of light. This is an optical analogue to what electrical circuit component, which can control or amplify electrical signals?

ANSWER: Transistor

TOSS UP

13) ENERGY *Short Answer* Researchers in the Cummins group at MIT are developing ways to form transient reactive intermediates, such as P_2. What is the predicted bond order of P_2 using molecular orbital theory?

ANSWER: 3

BONUS

13) ENERGY *Short Answer* Researchers in the Jamison group at MIT are working on developing various applications of epoxide-opening cascades. Low molecular weight cyclic oligomers of ethylene oxide are also known as what family of compounds?

ANSWER: Crown ethers

TOSS UP

14) PHYSICS *Multiple Choice* A block of mass 5 kilograms is at rest on a 30 degree frictionless inclined plane. If a spring with a spring constant of 98 newtons per meter is attached to a wall such that the spring is parallel to the inclined plane, which of the following is closest to the distance, in meters, that the spring must be stretched such that the block remains at rest?

W) 0.25
X) 0.5
Y) 1
Z) 3

ANSWER: W) 0.25

BONUS

14) PHYSICS *Multiple Choice* A person weighing 50 kilograms stands at the center of a 12 meter long raft floating on water. The person then walks to the edge of the raft. If the raft weighs 100 kilograms, how much, in meters, does the raft move?

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

ANSWER: X) 2

TOSS UP

15) EARTH AND SPACE *Multiple Choice* The energy density of a universe filled with photons scales with what power of distance?

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

ANSWER: W) -4

BONUS

15) EARTH AND SPACE *Multiple Choice* A quasar lensed by a dwarf elliptical galaxy that has a uniform, highly eccentric ellipsoidal mass distribution would appear as which of the following types of objects?

W) Einstein ring
X) Einstein Cross
Y) Multiple arcs and arclets
Z) Four equally spaced arcs

ANSWER: X) Einstein Cross

TOSS UP

16) CHEMISTRY *Multiple Choice* Given that the three pK_a's of H_3PO_4 are 2, 7, and 12, which of the following is closest to the pH of a 1 molar solution of sodium dihydrogen phosphate?

W) 2
X) 4.5
Y) 5.5
Z) 7

ANSWER: X) 4.5

BONUS

16) CHEMISTRY *Short Answer* How many normal modes of vibration does cyclohexane have?

ANSWER: 48

TOSS UP

17) BIOLOGY *Multiple Choice* The A and B antigens on red blood cells are distinguished in the structure of which of the following types of macromolecule?

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

ANSWER: W) Carbohydrates

BONUS

17) BIOLOGY *Short Answer* By name or number, identify all of the following three statements that are true about tryptophan (*TRIP-tuh-fan*):

1) It is an aromatic amino acid
2) It is an essential amino acid
3) It is a precursor to melatonin

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

TOSS UP

18) MATH *Multiple Choice* For a given length d, which of the following solids has the greatest volume?

W) A square pyramid with base side length d and height $2d$
X) A cube with side length d
Y) A cone with radius d and height d
Z) A sphere with diameter d

ANSWER: Y) A cone with radius d and height d

BONUS

18) MATH *Short Answer* For what values of a are the vectors $7a\boldsymbol{i} + 3\boldsymbol{j} + 4a\boldsymbol{k}$ and $2\boldsymbol{i} + 10\boldsymbol{j} - a\boldsymbol{k}$ orthogonal?

ANSWER: $a = -3/2, 5$

TOSS UP

19) MATH *Short Answer* How many positive integers less than 100 are equal to the product of their digits?

ANSWER: 9

BONUS

19) MATH *Short Answer* x^2 and y are inversely proportional values, and y^4 and z are directly proportional values. If when $x = 2$ and $y = 3$, $z = 4$, what is the value of z when $x = 4$?

ANSWER: 1/64

TOSS UP

20) PHYSICS *Multiple Choice* Unlike other quarks, the top quark is not observed to form bound states with other quarks. Which of the following provides the best explanation for this phenomenon?

W) The top quark decays too quickly, before bound states can be formed
X) Its large mass prevents other quarks from getting close enough to form bound states
Y) The top quark does not interact with the strong nuclear force
Z) Experiments have only been able to produce top quarks in the absence of other quarks

ANSWER: W) The top quark decays too quickly, before bound states can be formed

BONUS

20) PHYSICS *Short Answer* An ideal Carnot (*kar-NOH*) cycle operates between reservoirs of temperature -23 degrees celsius and 27 degrees celsius. If 10 joules of work are done, how many joules of heat must be transferred to the cold reservoir?

ANSWER: 50

TOSS UP

21) BIOLOGY *Multiple Choice* To avoid predation, beavers find success by either being large to fight off potential threats or being small to run away from them. Intermediate sized beavers often are less successful. Which of the following types of selection is occurring?

W) Directional
X) Disruptive
Y) Stabilizing
Z) Normalized

ANSWER: X) Disruptive

BONUS

21) BIOLOGY *Short Answer* In a population of humans in Hardy-Weinberg equilibrium, red-green colorblindness is found in 40% of the men. What percent of women in this population are red-green colorblind?

ANSWER: 16%

TOSS UP

22) EARTH AND SPACE *Multiple Choice* At which of the following masses will the iron-rich core of a large star trigger a core-collapse supernova?

W) Jeans mass
X) Chandrasekhar (*chaan-druh-SAY-ker*) limit
Y) TOV limit
Z) Eddington limit

ANSWER: X) Chandrasekhar limit

BONUS

22) EARTH AND SPACE *Multiple Choice* Which of the following could be the progenitor of a short gamma-ray burst?

W) Core-collapse supernova
X) Hypernova
Y) Kilonova
Z) Tidal disruption event

ANSWER: Y) Kilonova

TOSS UP

23) CHEMISTRY *Multiple Choice* Which of the following statements best explains why the presence of peroxides during the addition of HBr to an alkene results in the anti-Markovnikov product?

W) The peroxide reacts with the Markovnikov product to form the anti-Markovnikov product
X) A rearrangement occurs after the Markovnikov product is formed
Y) The peroxide causes steric hindrance at the more substituted position
Z) The reaction proceeds through a radical mechanism rather than an ionic mechanism

ANSWER: Z) The reaction proceeds through a radical mechanism rather than a ionic mechanism

BONUS

23) CHEMISTRY *Short Answer* A standard galvanic cell is constructed based on the reaction $3\,Cu^{2+} + 2\,Al \longrightarrow 3\,Cu + 2\,Al^{3+}$ (read: *three C-U two plus plus two A-L yields three C-U plus two A-L three plus*), with KCl in the salt bridge. By name or number, identify all of the following three changes that would increase the cell potential:

1) Addition of sodium hydroxide solution to the aluminum half-cell
2) Replacing KCl with K_2SO_4 in the salt bridge
3) Addition of distilled water to double the volume in both half-cells

ANSWER: 1 only
