

2022 MIT Science Bowl High School Invitational

Round 9

TOSS UP

1) ENERGY *Multiple Choice* The Wilson Lab at MIT recently developed a protocol on the use of H mazes in investigating the spatial memory of animals. Spatial information is primarily stored in which of the following regions of the brain's temporal lobe?

- W) Amygdala
- X) Hippocampus
- Y) Cerebellum
- Z) Pons

ANSWER: X) Hippocampus

BONUS

1) ENERGY *Multiple Choice* Researchers in the Calo Lab at MIT recently showed that DNA-dependent protein kinase, or DNA-PK, plays an unexpected role in rRNA biogenesis, in addition to its canonical role as a factor in DNA repair. Which of the following repair pathways does DNA-PK participate in, which is known for its error-prone insertions and deletions?

- W) Base excision repair
- X) Mismatch repair
- Y) Homologous recombination
- Z) Non-homologous end joining

ANSWER: Z) Non-homologous end joining

TOSS UP

2) CHEMISTRY *Multiple Choice* 5-Dehydro-*m*-xylylene (*ZAI-luh-leen*), also known as DMX, is an aromatic organic triradical with three unpaired electrons in three singly occupied molecular orbitals. In the ground state of DMX, one of these electrons has a spin state opposed to the other two, resulting in a low spin state with only one net unopposed spin. Which of the following physical laws is violated by the ground state of DMX?

- W) Aufbau principle
- X) Pauli exclusion principle
- Y) Hund's rule
- Z) Conservation of angular momentum

ANSWER: Y) Hund's rule

BONUS

2) CHEMISTRY *Short Answer* By name or number, rank the following three carboxylic acid derivatives by increasing carbonyl stretching frequency in infrared spectroscopy:

- 1) Thioester
- 2) Acyl (*ey-sil*) bromide
- 3) Amide

ANSWER: 3, 1, 2

TOSS UP

3) EARTH AND SPACE *Multiple Choice* The low-velocity zone in the mantle, which is generally more evident beneath oceanic crust, best translates to which of the following regions?

- W) Mohorovičić (*moh-haw-ROH-vuh-chich*) discontinuity
- X) Upper asthenosphere
- Y) Mantle transition zone
- Z) D'' (read: *D double prime*) layer

ANSWER: X) Upper asthenosphere

BONUS

3) EARTH AND SPACE *Short Answer* By name or number, identify all of the following four statements that are true of horst and graben topography:

- 1) Grabens are the foot-wall block
- 2) Horsts are the hanging-wall block
- 3) Normal faults are orientated in an antiparallel manner
- 4) It is indicative of extensional regions

ANSWER: 3 and 4

TOSS UP

4) PHYSICS *Short Answer* The Polar Express is traveling in the absence of friction at a constant velocity of 10 meters per second. Snow falls and sticks to the train at a rate of 2 kilograms per second. Assuming the initial momentum of the snow is negligible, what power in watts must be exerted by the train's engines to maintain a constant velocity?

ANSWER: 200

BONUS

4) PHYSICS *Short Answer* A violin string sounds at a frequency of 400 hertz. A cello string is twice as long, has twice the tension, and has twice as much mass per unit length. At what frequency in hertz does the cello string sound?

ANSWER: 200

TOSS UP

5) BIOLOGY *Short Answer* Tyler has recently been hit in the head with a coconut. While he suffered no nerve damage, he has lost the ability to detect acceleration in one axis and some of his bone has been forcibly distorted. What structure in the inner ear was most likely damaged?

ANSWER: Semicircular canal

BONUS

5) BIOLOGY *Multiple Choice* Which of the following structures is incorrectly paired with its function?

- W) Semicircular canal and balance
- X) Cochlea (*KOH-klee-uh*) and sound detection
- Y) Cupula (*KEW-pew-luh*) and sound transmission
- Z) Middle ear and sound amplification

ANSWER: Y) Cupula and sound transmission

TOSS UP

6) MATH *Multiple Choice* A quadratic polynomial $f(x)$ satisfies $f(1) = 5$, $f(2) = 6$, and $f(3) = 10$. What is the value of $f(4)$?

- W) 17
- X) 18
- Y) 19
- Z) 20

ANSWER: W) 17

BONUS

6) MATH *Short Answer* What is the probability that three vertices of an octagon chosen uniformly at random form an obtuse triangle?

ANSWER: 3/7

TOSS UP

7) ENERGY *Short Answer* Scientists in the MIT Department of Electrical Engineering and Computer Science are studying superconducting nanowires which have many potential uses, such as sensitive detection of magnetic fields. Underlying many of these superconductors is what type of junction, consisting of two superconductors separated by a thin insulator?

ANSWER: Josephson junction

BONUS

7) ENERGY *Short Answer* Scientists in MIT's Research Laboratory of Electronics have found a way to store quantum information in qubits (*KYOO-bit*), which consist of vibrating pairs of atoms. Unlike classical bits, a qubit can exist in a superposition of two orthogonal states. These states of superposition can be represented as points on what two dimensional surface?

ANSWER: Bloch sphere

TOSS UP

8) PHYSICS *Short Answer* A ball is launched at an angle of 15 degrees with respect to the horizontal towards a stationary vertical wall 40 meters away. It collides elastically with the wall and bounces back to its initial launch point. In meters per second, what must the initial launch velocity be?

ANSWER: 40

BONUS

8) PHYSICS *Multiple Choice* Which of the following statements about color in quantum chromodynamics is NOT true?

- W) If the quark in a meson (*MEE-zaan*) has color red, the antiquark must have color antired
- X) Two up quarks with color green cannot occupy the same quantum state
- Y) Color in quantum chromodynamics is analogous to electric charge in quantum electrodynamics
- Z) All hadrons have a color of either red, green, or blue

ANSWER: Z) All hadrons have a color of either red, green, or blue

TOSS UP

9) EARTH AND SPACE *Multiple Choice* Which of the following is NOT a polymorph of aluminum silicate?

- W) Andalusite (*an-duh-LOO-site*)
- X) Kyanite (*KAI-uh-nite*)
- Y) Sillimanite (*SIL-uh-muh-nite*)
- Z) Pyrolusite (*pie-ruh-LOO-site*)

ANSWER: Z) Pyrolusite

BONUS

9) EARTH AND SPACE *Short Answer* By name or number, order the following three structures from most inland to most offshore:

- 1) Beach face
- 2) Berm
- 3) Sandbar

ANSWER: 2, 1, 3

TOSS UP

10) CHEMISTRY *Multiple Choice* For a chemical reaction which does expansion work, which of the following must be true?

- W) ΔG is less than ΔH
- X) ΔG is greater than ΔH
- Y) ΔU is less than ΔH
- Z) ΔU is greater than ΔH

ANSWER: Y) ΔU is less than ΔH

BONUS

10) CHEMISTRY *Short Answer* By name or number, rank the following three pairs of isotopes by increasing expected primary kinetic isotope effect when substituted for one another in organic chemistry:

- 1) Hydrogen and deuterium
- 2) Hydrogen and tritium
- 3) Deuterium and tritium

ANSWER: 3, 1, 2

TOSS UP

11) BIOLOGY *Short Answer* By name or number, rank the following three blood vessels by increasing flow velocity:

- 1) Capillaries
- 2) Aorta
- 3) Venules

ANSWER: 1, 3, 2

BONUS

11) BIOLOGY *Multiple Choice* Which of the following forces is NOT one of the Starling forces?

- W) Capillary hydrostatic pressure
- X) Interstitial hydrostatic pressure
- Y) Plasma protein osmotic force
- Z) Plasma ion osmotic force

ANSWER: Z) Plasma ion osmotic force

TOSS UP

12) MATH *Multiple Choice* For an integer x , how many possible remainders can $x^7 - (x - 1)^7$ (read: x to the power of seven minus x minus one quantity to the power of seven) have when divided by 7?

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

ANSWER: W) 1

BONUS

12) MATH *Short Answer* How many lattice points are on the sphere centered at $(1, 2, 0)$ with radius 3?

ANSWER: 30

TOSS UP

13) CHEMISTRY *Multiple Choice* An unknown metal chloride is dissolved in distilled water. When mixed with a concentrated solution of sodium hydroxide, a green solid precipitates out of solution. Upon standing, the precipitate turns brown. Which of the following is most likely the identity of the metal chloride?

- W) FeCl_2
- X) CoCl_2
- Y) NiCl_2
- Z) CuCl_2

ANSWER: W) FeCl_2

BONUS

13) CHEMISTRY *Multiple Choice* In a reaction where two gases A and B are in equilibrium with each other, the ground state energy of A is lower than the ground state energy of B. If the spacing between the energy levels in A and B is roughly the same, which of the following statements is true?

- W) A is strongly favored at low temperatures, and B is favored at high temperatures
- X) A is favored at both low and high temperatures
- Y) At low temperatures, A is strongly favored, and the equilibrium constant approaches 1 at high temperatures
- Z) The equilibrium constant approaches 1 at low temperatures, but A is favored at high temperatures

ANSWER: Y) At low temperatures, A is strongly favored, and the equilibrium constant approaches 1 at high temperatures

TOSS UP

14) MATH *Multiple Choice* What is the sum of the distinct prime factors of the sum of the first 40 positive square numbers?

- W) 48
- X) 49
- Y) 50
- Z) 51

ANSWER: Z) 51

BONUS

14) MATH *Short Answer* What is the volume of a cube which is inscribed in a sphere of radius 4?

ANSWER: $512\sqrt{3}/9$

TOSS UP

15) PHYSICS *Short Answer* A spherical conducting shell of radius 2 meters is centered at the origin. A 1 coulomb charge is placed on the x -axis at $x = 1$ meter. In newtons per coulomb to one significant figure, what is the magnitude of the electric field on the x -axis at $x = 3$ meters?

ANSWER: 1×10^9

BONUS

15) PHYSICS *Short Answer* Isaac has 128 resistors of resistances 1 ohm, 2 ohms, 3 ohms, and so on, all the way to 128 ohms. If he connects all 128 resistors in parallel, what is their equivalent resistance, to one significant figure and in ohms?

ANSWER: 0.2 (ACCEPT: 2×10^{-1})

TOSS UP

16) ENERGY *Multiple Choice* Researchers in the Jamison group at MIT are studying epoxide-opening cascades, a mechanism which has been proposed as an explanation for the structural similarities found across the ladder polyether family of natural products. A common method of producing epoxides in organic synthesis is through oxidation of a carbon-carbon double bond. Which of the following reagents can be used to convert an alkene functionality into an epoxide?

- W) Potassium permanganate
- X) Ozone
- Y) Meta-chloroperoxybenzoic acid
- Z) Osmium tetroxide

ANSWER: Y) Meta-chloroperoxybenzoic acid

BONUS

16) ENERGY *Short Answer* Researchers in the Pentelute group at MIT are inventing new methods to modify naturally occurring proteins for medicinal use. One advantage of using naturally occurring compounds is that specific enantiomers are favored. By name or by number, identify which of the following 3 compounds are naturally occurring:

- 1) D-xylose
- 2) D-valine
- 3) L-glutamine

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

TOSS UP

17) BIOLOGY *Multiple Choice* Which of the following brain structures is most likely damaged if a patient has difficulty recalling emotional memories?

- W) Amygdala (*uh-MIG-duh-luh*)
- X) Corpus callosum
- Y) Pons
- Z) Suprachiasmatic (*soo-pruh-kee-uhz-MA-tik*) nucleus

ANSWER: W) Amygdala

BONUS

17) BIOLOGY *Short Answer* What plot is used to visualize the energetically allowed dihedral angles between amino acid residues in a protein structure?

ANSWER: Ramachandran plot

TOSS UP

18) EARTH AND SPACE *Multiple Choice* Which of the following was NOT a problem solved by the theory of inflation?

- W) Symmetry problem
- X) Horizon problem
- Y) Monopole problem
- Z) Flatness problem

ANSWER: W) Symmetry problem

BONUS

18) EARTH AND SPACE *Short Answer* What objects, often associated with star formation regions, form from the interaction of axial jets from protostars with the interstellar medium?

ANSWER: Herbig-Haro object (ACCEPT: HH object)

TOSS UP

19) BIOLOGY *Short Answer* By name or number, identify all of the following three hybrid outcomes that result in continued survival of the hybrid population in the long term:

- 1) Fusion
- 2) Reinforcement
- 3) Stability

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

BONUS

19) BIOLOGY *Short Answer* Improper joining of gene segments during what process adds genetic diversity to the sequences for T cell receptors?

ANSWER: V(D)J recombination

TOSS UP

20) PHYSICS *Short Answer* A ball moves at a constant velocity of $c/2$ from the leftmost edge of inside a space shuttle that is moving at a velocity of $3c/5$ relative to the rest frame. For an observer at rest, in terms of c , what speed will the ball appear to move at?

ANSWER: $11c/13$

BONUS

20) PHYSICS *Short Answer* A battery is connected in series with a 12 ohm resistor and a 6 ohm resistor. A 0.5 farad capacitor is then connected in parallel across the 12 ohm resistor. In seconds, what is the value of the time constant associated with the charging of the capacitor?

ANSWER: 2

TOSS UP

21) CHEMISTRY *Short Answer* By name or number, rank the following three organic compounds by increasing energy of the carbon-hydrogen bond:

- 1) C₂H₂
- 2) C₂H₄
- 3) C₂H₆

ANSWER: 3, 2, 1

BONUS

21) CHEMISTRY *Short Answer* The diatomic molecule AB has a mass of 30 atomic mass units and a reduced mass of approximately 7.467 atomic mass units. What is the identity of AB?

ANSWER: Nitric oxide (ACCEPT: NO)

TOSS UP

22) EARTH AND SPACE *Short Answer* What nuclide is the product of the radioactive decay tail observed in Type II (read: *type two*) supernovae?

ANSWER: Iron-56 (ACCEPT: Fe-56)

BONUS

22) EARTH AND SPACE *Short Answer* What process explains a change in a main sequence star's oblateness due to exposure of magnetic torque on the star's outer layers?

ANSWER: Applegate mechanism

TOSS UP

23) MATH *Multiple Choice* If 100 random dice are rolled, to the nearest percent, what is the probability that the sum of the numbers on the top face of the dice is a multiple of 20?

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

ANSWER: Y) 5

BONUS

23) MATH *Short Answer* Let R be the set of the reciprocals of all positive integers. How many elements of R have a hundredths digit of 1 when expressed as a decimal?

ANSWER: 51
