# 2022 MIT Science Bowl High School Invitational Round 13

### TOSS UP

1) MATH *Short Answer* How many ways are there to tile a $2 \times 5$ (read: *two by five*) grid of squares with $1 \times 2$ (read: *one by two*) dominoes?

ANSWER: 8

### BONUS

1) MATH *Short Answer* A geometric sequence has second term 10/49 and total sum 1. What is the greatest possible value of the common ratio between terms?

ANSWER: 5/7

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### TOSS UP

2) ENERGY *Short Answer* The Boyer Lab at MIT also uses hiPSC-directed differentiation strategies in modeling the human heart. They were able to replicate a fetal disorder in which the right and left atria are connected via what hole?

ANSWER: Patent foramen ovale (ACCEPT: PFO)

### BONUS

2) ENERGY *Short Answer* The Boyer Lab at MIT is studying gene regulatory mechanisms for cellular lineage commitment. What is the technique commonly used for lineage tracing of cells, where a unique nucleic acid sequence is inserted into the genome?

ANSWER: Barcoding (ACCEPT: Cellular barcoding, molecular barcoding, other synonymous terms)

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## TOSS UP

3) CHEMISTRY *Multiple Choice* Alex is trying to install a *tert*-butyl group alpha to a carbonyl by adding *tert*-butyl chloride and trimethylsilyl triflate to his reaction, but he discovers that the reaction is low yielding. Which of the following reagents should he add to his reaction to improve the yield?

W) Trifluoroacetic acid
X) Pyridine
Y) Palladium (II) (read: *palladium two*) acetate
Z) Titanium (IV) (read: *titanium four*) chloride

ANSWER: Z) Titanium (IV) chloride

## BONUS

3) CHEMISTRY *Short Answer* When running a Suzuki reaction between an alkyl boronic acid and aryl iodide in the presence of a palladium (0) (read: *palladium zero*) catalyst, a student observes a lot of reduced aryl iodide instead of the desired product. By name or number, identify all of the following three changes which could reduce the amount of reduced aryl iodide formed:

1) Running the reaction with more equivalents of boronic acid
2) Running the reaction with more equivalents of aryl iodide
3) Switching to an aryl bromide over the aryl iodide

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

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## TOSS UP

4) EARTH AND SPACE *Multiple Choice* The fastest winds of a hurricane are found in which of the following locations?

W) Near the surface in the eye wall
X) Near the surface within the eye
Y) Aloft near the tropopause in the eye wall
Z) Aloft near the tropopause within the eye

ANSWER: W) Near the surface in the eye wall

## BONUS

4) EARTH AND SPACE *Multiple Choice* Breadcrust bombs are volcanic bombs with a cracked exterior. This is due to initial cooling of the surface followed by further expansion of the interior of the bomb. Which of the following factors is the cause of this expansion?

W) Continued gas exsolution after the surface cools
X) Ice wedging
Y) Reheating when buried by a lava or pyroclastic flow
Z) Columnar jointing

ANSWER: W) Continued gas exsolution after the surface cools

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## TOSS UP

5) PHYSICS *Multiple Choice* Unfortunately, the Earth has stopped orbiting the Sun. As a result, gravity will now pull it into the Sun, starting from rest at a distance of 1 AU. Which of the following is closest to the time it will take for the Earth to fall into the Sun in years?

W) 0.25
X) 0.5
Y) 1
Z) 2

ANSWER: W) 0.25

## BONUS

5) PHYSICS *Short Answer* Ana and Banana are flying in separate rocket ships, each at a constant velocity. In Ana's frame, two supernovae (*soo-per-NO-vee*) happen 3 years apart, separated by a distance of 9 lightyears. In Banana's frame, the two supernovae happen 7 years apart. In lightyears, what was the distance between the two supernovae in Banana's frame?

ANSWER: 11

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## TOSS UP

6) BIOLOGY *Short Answer* Aspirin is effective at reducing pain because it inhibits COX-2, which produces what group of local regulators that increase sensitivity to pain?

ANSWER: Prostaglandins

## BONUS

6) BIOLOGY *Multiple Choice* Which of the following is NOT true about the effects of salicylic acid?

W) In humans, salicylic acid inhibits the activity of COX-1, a cyclooxygenase
X) In plants, a volatile ester of salicylic acid can induce an immune response upon being taken up by the stomata
Y) In humans, salicylic acid is keratolytic and is used in skincare products
Z) In plants, salicylic acid directly induces the hypersensitive response

ANSWER: Z) In plants, salicylic acid directly induces the hypersensitive response

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## TOSS UP

7) MATH *Short Answer* Suppose that $f(x, y)$ is a smooth function with a saddle point at the origin. By name or number, identify all of the following statements which must be true of $f$ at the origin:

1) The gradient of $f$ is zero
2) The second derivatives of $f$ in $x$ and in $y$ have opposite signs
3) $f$ does not have a local maximum at the origin

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

## BONUS

7) MATH *Short Answer* What is the sum of all integer values of $x$ such that $x^3 + 8$ is the square of a prime?

ANSWER: 1

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## TOSS UP

8) CHEMISTRY *Multiple Choice* According to crystal field theory, which of the following $d$-orbitals would be at the highest energy in a trigonal bipyramidal complex?

W) $d_{x^2-y^2}$ (read: *d x squared minus y squared*)
X) $d_{z^2}$ (read: *d z squared*)
Y) $d_{xy}$ (read: *d-x-y*)
Z) $d_{yz}$ (read: *d-y-z*)

ANSWER: X) $d_{z^2}$

## BONUS

8) CHEMISTRY *Short Answer* Praseodymium is a lanthanide metal with symbol Pr and an approximate molar mass of 140 grams per mole. When a 420 milligram sample of praseodymium metal is burned in an oxygen rich atmosphere, it is converted completely into a mixed praseodymium oxide and its mass increases by 88 milligrams. Answer the following two questions about this compound:

1) What is the formula unit of this compound?
2) All the praseodymium in this oxide is in either the +3 or +4 oxidation state. How many praseodymium atoms per formula unit are in the +4 oxidation state?

ANSWER: 1) $Pr_6O_{11}$ 2) 4

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## TOSS UP

9) PHYSICS *Short Answer* Doubly ionized lithium consists of a lithium nucleus and a single electron. To the nearest ten electronvolts, what is the absolute value of the ground state energy of doubly ionized lithium?

ANSWER: 120

## BONUS

9) PHYSICS *Multiple Choice* A uniform 3 kilogram rod with a length of 4 meters lies on a frictionless table. A 3 kilogram ball moving at 5 meters per second perpendicular to the rod strikes the end of the rod and sticks to it inelastically. What is the angular velocity of the resulting system in radians per second?

W) 2/3
X) 1
Y) 1.5
Z) 2

ANSWER: Y) 1.5

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## TOSS UP

10) ENERGY *Short Answer* Researchers at MIT's Kavli Institute for Astrophysics and Space Research are searching for exoplanets by detecting periodic dips in the star's brightness as the planet transits across the face of the star. If the star happens to be rotating in the same direction as the planet's orbit, the beginning of the transit will show light of a higher wavelength than the end of the transit, due to Doppler shifts in the rotating photosphere of the star. What is the name of this effect?

ANSWER: Rossiter-McLaughlin effect

## BONUS

10) ENERGY *Short Answer* Researchers in MIT's Low Energy Electronic Systems group have discovered new ways to control light emissions from materials. They do this by changing the angle between two overlapping sheets of graphene. What is the general name of the study of how altering the angle between layers of materials can change their electrical properties?

ANSWER: Twistronics

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## TOSS UP

11) EARTH AND SPACE *Multiple Choice* Which of the following regions would have rocks with the highest strontium-87 to strontium-86 ratios?

W) Mid-Atlantic Ridge
X) Appalachian Mountains
Y) Upper asthenosphere
Z) Mantle transition zone

ANSWER: X) Appalachian Mountains

## BONUS

11) EARTH AND SPACE *Multiple Choice* Which of the following states of the North Atlantic Oscillation and Arctic Oscillation, respectively, likely brings the warmest winters to Northern Europe, given that the positive phase of both are associated with larger pressure differences?

W) Positive and positive
X) Positive and negative
Y) Negative and positive
Z) Negative and negative

ANSWER: W) Positive and positive

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## TOSS UP

12) BIOLOGY *Multiple Choice* In the lac operon, the cyclic AMP receptor protein is best classified as which of the following regulatory proteins?

W) Activator
X) Corepressor
Y) Enhancer
Z) Inducer

ANSWER: W) Activator

## BONUS

12) BIOLOGY *Short Answer* Though the start codon represents the first amino acid to be translated, the first start codon in the mRNA transcript is not always where translation begins. In eukaryotes, what conserved sequence of nucleotides contains the start codon and functions as the site of translation initiation?

ANSWER: Kozak sequence

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## TOSS UP

13) ENERGY *Short Answer* The Pentelute lab at MIT is synthesizing bioconjugated proteins to target superbugs. What group of high-yield, stereospecific organic reactions is the lab using to join small molecules to the proteins, an example of which is the reaction of an alkyne with an azide using copper (I) (read: *copper one*) catalysis?

ANSWER: Click chemistry

## BONUS

13) ENERGY *Short Answer* Researchers in the Kiessling group at MIT have been researching ways to control the length of carbohydrate polymers. In classical step-growth polymerization, what equation is used to model the degree of polymerization as a function of fractional monomer conversion?

ANSWER: Carothers equation

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## TOSS UP

14) BIOLOGY *Short Answer* By name or number, identify all of the following four blood components that are present in the buffy coat after blood centrifugation:

1) Plasma
2) White blood cells
3) Red blood cells
4) Platelets

ANSWER: 2 and 4

## BONUS

14) BIOLOGY *Multiple Choice* By name or number, rank the following three forms of hemoglobin by increasing affinity for oxygen:

1) R state
2) T state
3) Fetal hemoglobin

ANSWER: 2, 1, 3

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## TOSS UP

15) MATH *Multiple Choice* Let $ABCD$ be a unit square. Point $E$ lies on $AB$ and $F$ lies on $BC$ such that $EF$ is parallel to $AC$. If $EF$ has length $1/3$, what is the area of the pentagon $AEFCD$?

W) $2/3$
X) $8/9$
Y) $17/18$
Z) $35/36$

ANSWER: Z) $35/36$

## BONUS

15) MATH *Short Answer* Regular hexagons of side length 1 are used to tessellate the plane, forming an infinite grid. $A$ and $B$ are two different vertices on this grid. What are the four smallest possible values for the distance between $A$ and $B$?

ANSWER: $1, \sqrt{3}, 2, \sqrt{7}$

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## TOSS UP

16) CHEMISTRY *Multiple Choice* A compound has three peaks in its mass spectrum with relative intensities of 50%, 100%, and 50%. Which of the following could be the identity of the compound?

W) A monochlorinated hydrocarbon
X) A monobrominated hydrocarbon
Y) A dichlorinated hydrocarbon
Z) A dibrominated hydrocarbon

ANSWER: Z) A dibrominated hydrocarbon

## BONUS

16) CHEMISTRY *Multiple Choice* Which of the following statements best explains why an *N*-heterocyclic carbene (NHC) ligand was chosen for the Grubbs generation II (read: *two*) catalyst?

W) A sigma-donating NHC ligand accelerates the rate of phosphine (*FAWS-feen*) dissociation
X) A pi-donating NHC ligand accelerates the rate of phosphine (*FAWS-feen*) dissociation
Y) A sigma-donating NHC ligand accelerates the rate of alkene coordination
Z) A pi-donating NHC ligand accelerates the rate of alkene coordination

ANSWER: W) A sigma-donating NHC ligand accelerates the rate of phosphine dissociation

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## TOSS UP

17) EARTH AND SPACE *Multiple Choice* Which of the following statements about astrospheres is true?

W) Astrospheres form from the stellar wind of a single massive star
X) The heliosphere is an example of an astrosphere
Y) Stellar-wind bubbles are created as astrospheres combine
Z) Stellar-wind bubbles have a 2-shock structure

ANSWER: Z) Stellar-wind bubbles have a 2-shock structure

## BONUS

17) EARTH AND SPACE *Multiple Choice* During a transit, a rapidly rotating star being observed appears to be slightly redshifted then blueshifted. Which of the following statements best explains this observation?

W) The star has an exoplanet with a retrograde orbit
X) The star has an exoplanet with a prograde orbit
Y) The star is actually a binary system
Z) The star's axis of rotation is wobbling rapidly

ANSWER: W) The star has an exoplanet with a retrograde orbit

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## TOSS UP

18) PHYSICS *Multiple Choice* Diatomic hydrogen can be modeled as two spherical protons with nonzero mass connected by a massless rod, where the length of the rod is much larger than the radii of the spheres. The equipartition theorem predicts that, on average, the thermal energy of rotation is the same for all three axes. However, only rotation about the two axes perpendicular to the rod is typically observed. Which of the following statements is the best explanation for this phenomenon?

W) The moment of inertia about the rod is much smaller, so the energy scale is comparatively small and difficult to observe
X) Protons are better modeled as point masses, so rotation about the rod has no effect
Y) The moment of inertia about the rod is much smaller, and quantization of angular momentum causes the lowest nonzero rotational energy level to be much larger than the thermal energy
Z) Rotation about the rod is much harder to observe experimentally due to the comparatively small size of the protons

ANSWER: Y) The moment of inertia about the rod is much smaller, and quantization of angular momentum causes the lowest nonzero rotational energy level to be much larger than the thermal energy

## BONUS

18) PHYSICS *Short Answer* A certain alloy becomes superconducting at low temperatures and is placed in a variable magnetic field. As the external magnetic field is increased from zero, there is first a critical field above which the Meissner effect no longer holds completely but the resistivity is still zero. Then, at a much higher magnetic field, there is another critical field above which all superconductivity disappears. What is the term for this type of superconductor?

ANSWER: Type II

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## TOSS UP

19) MATH *Short Answer* By name or number, identify all of the following three measurements that are always sufficient to determine the circumradius of a triangle:

1) The measure of two specific angles and the length of a specific side
2) The measure of one specific angle and the length of two specific sides
3) The lengths of any three sides

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

## BONUS

19) MATH *Short Answer* How many ways are there to color the cells of a $3 \times 3$ (read: *three by three*) square grid each red or blue such that no two blue cells touch along an edge or corner?

ANSWER: 33

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## TOSS UP

20) BIOLOGY *Short Answer* What term describes the seeming impossibility of proteins randomly folding in seconds due to an astronomical number of possible conformations?

ANSWER: Levinthal's paradox

## BONUS

20) BIOLOGY *Short Answer* By name or number, identify all of the following events that occur when light hits rhodopsin in a rod cell:

1) Transducin (*trans-DOO-sin*) activates phosphodiesterase (*foss-pho-die-ess-terase*)
2) The rod cell membrane potential depolarizes
3) Intracellular concentration of GMP (read: *G-M-P*) increases

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

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## TOSS UP

21) CHEMISTRY *Multiple Choice* Which of the following statements about singlet carbenes is true?

W) The HOMO (read: *HO-mo*) of the carbene is a sigma donor, and the LUMO (read: *LOO-mo*) is a sigma acceptor
X) The HOMO (read: *HO-mo*) of the carbene is a sigma donor, and the LUMO (read: *LOO-mo*) is a pi acceptor
Y) The HOMO (read: *HO-mo*) of the carbene is a pi donor, and the LUMO (read: *LOO-mo*) is a sigma acceptor
Z) The HOMO (read: *HO-mo*) of the carbene is a pi donor, and the LUMO (read: *LOO-mo*) is a pi acceptor

ANSWER: X) The HOMO of the carbene is a sigma donor, and the LUMO is a pi acceptor.

## BONUS

21) CHEMISTRY *Multiple Choice* The band gap of graphene can be approximated by calculating graphene as a square potential well. If the highest occupied molecular orbital of a sample of graphene can be represented by the pair of quantum numbers 80 and 60, which of the following is closest to the number of carbon atoms in the sample of graphene?

W) 8,000
X) 16,000
Y) 24,000
Z) 32,000

ANSWER: X) 16,000

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## TOSS UP

22) PHYSICS *Short Answer* By name or number, identify all of the following three changes which would sharpen the resonance peak of a damped, driven harmonic oscillator:

1) Decreasing the damping
2) Increasing the mass
3) Decreasing the spring constant

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

## BONUS

22) PHYSICS *Short Answer* Water has a surface tension of approximately $10^{-2}$ newtons per meter. The Eotvos number is a dimensionless quantity characterizing the ratio of the significance of gravity to that of surface tension in a specific situation, and surface tension appears in the formula raised to the $-1$. To the nearest power of 10, what is the Eotvos number of a spherical water droplet near the surface of Earth with a radius of 1 millimeter?

ANSWER: 1 (ACCEPT: $10^0$)

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## TOSS UP

23) EARTH AND SPACE *Multiple Choice* Which of the following best describes the process that creates the plateau observed in Type II-P (read: *type two-P*) supernovae?

W) The hydrogen envelope is ionized then slowly recombines
X) The radioactive decay of cobalt-56 reionizes the hydrogen envelope
Y) Neutrinos produced during the supernova ionizes the hydrogen envelope
Z) The recollapse of the hydrogen envelope into the star releases energy

ANSWER: W) The hydrogen envelope is ionized then slowly recombines

## BONUS

23) EARTH AND SPACE *Multiple Choice* Which of the following statements best explains why the Hydra cluster's ionized calcium lines are visible?

W) Limb darkening causes other lines in the visual spectrum to dim
X) The Wilson-Bappu effect causes calcium emission lines to strengthen
Y) Ultraviolet wavelengths are redshifted due to Hydra's distance from the earth
Z) Calcium lines are more easily ionized due to electron instability in the cluster

ANSWER: Y) Ultraviolet wavelengths are redshifted due to Hydra's distance from the earth

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