2024 MIT Science Bowl High School Invitational

Round 9

TOSS UP

1) MATH *Short Answer* Let z equal $\sqrt{3} - i$ (read: *the square root of three minus i*). What is z^3 (read: *z cubed*)?

ANSWER: -8i (DO NOT ACCEPT: 8i)

BONUS

1) MATH *Short Answer* To the nearest hundredth, what is $\cos(\frac{1}{5})$ (read: *cosine of one fifth*)?

ANSWER: 0.98

2) ENERGY *Multiple Choice* Researchers at the Weissman lab are studying secretin secretion by S cells. These S cells are located in what organ of the digestive system?

 W) Pancreas
 X) Esophagus
 Y) Small Intestine
 Z) Gallbladder

ANSWER: Y) Small Intestine

BONUS

2) ENERGY *Short Answer* Researchers at MIT's Center for Bits and Atoms are researching nuclear spins. Identify all of the following three nuclei that can be studied via NMR spectroscopy:

 1) Carbon-12
 2) Carbon-13
 3) Nitrogen-14

ANSWER: 2 and 3

TOSS UP

3) PHYSICS *Short Answer* The electric field on the axis of an electric dipole is proportional to what power of the distance from the dipole?

ANSWER: -3

BONUS

3) PHYSICS *Short Answer* Adeline's coin of radius one centimeter is rolling without slipping on a flat surface and is traveling at two meters per second. Expressed as a decimal rounded to the nearest tenth, what is the speed of a point on the rim of the coin located one centimeter above the ground?

ANSWER: 2.8

TOSS UP

4) CHEMISTRY *Short Answer* The cation in Meerwein's salt, a common methylating agent, is an example of what type of chemical species where the oxygen atom carries a positive formal charge?

ANSWER: Oxonium (ACCEPT: Oxonium cation, Oxonium ion)

BONUS

4) CHEMISTRY *Short Answer* Titanium dioxide adopts a unit cell lattice with two distinct sets of side lengths at right angles. Which Bravais lattice corresponds to the unit cell of titanium dioxide?

ANSWER: Tetragonal

TOSS UP

5) EARTH AND SPACE *Multiple Choice* Which of the following best describes what occurs to the temperature, pressure, and percentage water of a rock during retrograde metamorphism?

  W) Increases, Increases, Decreases
  X) Increases, Increases, Increases
  Y) Decreases, Decreases, Decreases
  Z) Decreases, Decreases, Increases

ANSWER: Z) Decreases, Decreases, Increases

BONUS

5) EARTH AND SPACE *Short Answer* To the nearest hundred kilometers per second, if a galaxy's $H - \alpha$ emission lines are observed at 627 nanometers, what velocity is the galaxy moving if unredshifted $H - \alpha$ lines are 626 nanometers?

ANSWER: 500

TOSS UP

6) BIOLOGY *Short Answer* Sharks produce TMAO to avoid the deleterious effects of a particular nitrogenous product of protein catabolism. What is the common name for this nitrogenous compound?

ANSWER: Urea

BONUS

6) BIOLOGY *Short Answer* Identify all of the following three conditions which are directly related to an imbalance in thyroid hormone levels, as opposed to levels of other hormones:

1) Graves' disease
2) Myxedema
3) Addison's disease.

ANSWER: 1 and 2

TOSS UP

7) ENERGY *Short Answer* Researchers in the Kulik group at MIT are using generative artificial intelligence to predict the transition states of chemical reactions. One of these reactions is the endothermic rearrangement of a 5-membered aromatic ring into a 3-membered ring, which is predicted by their AI to have a transition state that also has a 3-membered ring. This prediction supports what hypothesis, stating that transition states of chemical reactions resemble the higher energy side of the reaction coordinate?

ANSWER: Hammond's Postulate (ACCEPT: Hammond-Leffler Postulate)

BONUS

7) ENERGY *Short Answer* Researchers at MIT's Statistics and Data Science center optimized classifying transport phenomena by their smoothness. What decision rule did the researchers likely use to reduce the worst possible risk of their classification algorithm?

ANSWER: Minimax

8) CHEMISTRY *Multiple Choice* Which of the following organic reagents can be used to selectively insert two hydroxyl groups onto the same face of a carbon carbon double bond?

  W) Meta chloro peroxy benzoic acid
  X) Osmium tetroxide
  Y) Mercuric acetate
  Z) Dilute acid

ANSWER: X) Osmium tetroxide

BONUS

8) CHEMISTRY *Short Answer* To one significant figure, what is the ratio of the Kc equilibrium constant to the Kp equilibrium constant for the combustion of methane at 300 kelvin and 1 bar of pressure to produce carbon dioxide and liquid water?

ANSWER: 600

TOSS UP

9) EARTH AND SPACE *Multiple Choice* Which of the following best describes the development of a future G type main sequence star when it exits the Hayashi track?

  W) It develops a radiative zone in its envelope
  X) It develops a convective zone in its envelope
  Y) It develops a radiative zone in its core
  Z) It develops a convective zone in its core

ANSWER: Y) It develops a radiative zone in its core

BONUS

9) EARTH AND SPACE *Short Answer* What mechanism describes how small scale changes in the temperature gradient across the equatorial Pacific Ocean can magnify to cause El Nino and La Nina events?

ANSWER: Bjernkes (*b-YERK-ness*) Feedback

TOSS UP

10) BIOLOGY *Multiple Choice* Which of the following best describes the shapes of the oxygen saturation curves for hemoglobin and myoglobin, respectively?

  W) Hyperbolic, hyperbolic
  X) Hyperbolic, sigmoidal
  Y) Sigmoidal, hyperbolic
  Z) Sigmoidal, sigmoidal

ANSWER: Y) Sigmoidal, hyperbolic

BONUS

10) BIOLOGY *Short Answer* A recessive Z-linked trait in pigeons is exhibited by 20 percent of females. Assuming Hardy-Weinberg equilibrium and balanced sex ratio, what is the probability that a randomly selected, phenotypically normal male pigeon is a carrier of the trait, expressed as a fraction in simplified form?

ANSWER: 1/3

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11) PHYSICS *Multiple Choice* Ethan is fleeing from Earth at 0.8c to avoid AP Music Theory sight-singing practice. If Phoebe is standing on Earth and using a metronome ticking at 100 beats per minute, what tempo does Ethan observe, in beats per minute and rounded to the nearest integer?

W) 60
X) 80
Y) 125
Z) 167

ANSWER: W) 60

BONUS

11) PHYSICS *Short Answer* Flora and Kian have coherent light sources of intensities 7 Watts per square meter and 6 Watts per square meter, respectively. If the phase difference of their light sources is 60 degrees, find the intensity of the resulting light when they combine their sources, rounded to the nearest integer and expressed in Watts per square meter.

ANSWER: 11

TOSS UP

12) MATH *Multiple Choice* Which of the following choices is not necessarily true for the nth roots of unity for all n greater than or equal to 2?

  W) The nth roots of unity have a sum of zero
  X) The nth roots of unity have a product of one
  Y) The real parts of the nth roots of unity have a sum of zero
  Z) The imaginary parts of the nth roots of unity have a product of zero

ANSWER: X) The nth roots have a product of one

BONUS

12) MATH *Short Answer* In Timlandia, two-thirds of the population always tell the truth, while the remaining one-third always lie. Emmy asks four inhabitants of Timlandia whether it is snowing currently, and three of them say yes. What is the probability that it is snowing, given that Emmy's prior is that it is equally likely to snow or not snow in Timlandia?

ANSWER: 4/5

13) EARTH AND SPACE *Multiple Choice* Which of the following is responsible for the formation of downdrafts in thunderstorms?

  W) Entrainment (*en-train-ment*) of dry air causes evaporation, cooling air
  X) Entrainment of dry air causes condensation, cooling air
  Y) Entrainment of moist air causes evaporation, cooling air
  Z) Entrainment of moist air causes condensation, cooling air

ANSWER: W) Entrainment (*en-train-ment*) of dry air causes evaporation, cooling air

BONUS

13) EARTH AND SPACE *Multiple Choice* Assuming the dry and moist adiabatic lapse rates of an air parcel are 10 and 6 degrees Celsius per kilometer, respectively, which of the following values for the environmental lapse rate would create absolutely stable conditions?

  W) 5 Degrees Celsius per kilometer
  X) 7 Degrees Celsius per kilometer
  Y) 9 Degrees Celsius per kilometer
  Z) 11 Degrees Celsius per kilometer

ANSWER: W) 5 Degrees Celsius per kilometer

14) MATH *Multiple Choice* A random variable is attained by flipping ten thousand fair coins and counting the number of heads. Assume the result of each coin is uniform and independent. Which of the following is the standard deviation of this random variable?

W) 10
X) 50
Y) 100
Z) 500

ANSWER: X) 50

BONUS

14) MATH *Short Answer* An equilaterial triangle is inscribed inside a regular hexagon with side length 1. What is the ratio of the minimum possible area of the triangle to the maximum possible area?

ANSWER: 3/4

TOSS UP

15) PHYSICS *Short Answer* In the vicinity of atomic nuclei, high energy photons are able to undergo what process to produce new leptons and their corresponding antiparticles?

ANSWER: Pair Production

BONUS

15) PHYSICS *Short Answer* The virial theorem holds true for quantum systems such as a neutral hydrogen atom. If the expected energy of the bound-state in a hydrogen atom is -13.6 electron-volts, what is the expected potential energy of the bound-state?

ANSWER: -27.2

TOSS UP

16) ENERGY *Short Answer* Scientists at MIT and Caltech's LIGO collaboration used new lasers and mirrors to vastly improve their gravitational wave measurements. These instruments are part of what general technique used by LIGO to measure gravitational waves?

ANSWER: Interferometry

BONUS

16) ENERGY *Short Answer* Astronomers from MIT's Kavli Institute are studying the instability caused by quantized oscillations of electron density in plasmas to better understand stellar conditions. What instability in stars are the scientists seeking to replicate?

ANSWER: Jean instability (ACCEPT: Jean)

TOSS UP

17) CHEMISTRY *Multiple Choice* Dissolving one gram of which of the following compounds in one kilogram of water would lead to the solution with the highest boiling point?

 W) Sodium chloride
 X) Magnesium chloride
 Y) Calcium chloride
 Z) Aluminum chloride

ANSWER: W) Sodium chloride

BONUS

17) CHEMISTRY *Multiple Choice* Selenocysteine is a rare alpha-amino acid with a free selenol group on its side chain, while cysteine has a free thiol group and methionine has a methylated thiol group on their respective side chains. Which of the following reactions would produce the highest yield of selenocysteine?

 W) Treating cysteine with hydrogen selenide
 X) Treating methionine with hydrogen selenide
 Y) Treating cysteine with sodium hydroselenide
 Z) Treating methionine with sodium hydroselenide

ANSWER: Z) Treating methionine with sodium hydroselenide

TOSS UP

18) BIOLOGY *Multiple Choice* Gluconeogenesis (*GLUE-co-nee-oh-jen-uh-sis*) shares many of its enzymes with glycolysis, as many of the reactions they catalyze are easily reversible. Which of the following enzymes is NOT part of the gluconeogenesis pathway?

  W) Enolase
  X) Phosphoglycerate (*FOS-fo-gli-ser-ate*) mutase
  Y) Phosphofructokinase (*FOS-fo-fruc-toe-kine-ace*)
  Z) Glyceraldehyde (*GLI-ser-al-dee-hide*) phosphate dehydrogenase

ANSWER: Y) Phosphofructokinase (*FOS-fo-fruc-toe-kine-ace*)

BONUS

18) BIOLOGY *Short Answer* Identify all of the following three choices that are advantages of bicarbonate over phosphate as a buffer in the human bloodstream:

  1) It is more abundant
  2) Its pKa is closer to physiological pH
  3) It is coupled to the respiratory system

ANSWER: 1 and 3

TOSS UP

19) CHEMISTRY *Multiple Choice* Gideon has just recrystallized his organic product from aqueous solution and would like to isolate the newly formed crystals. Which of the following apparatuses would be best suited for this purpose?

  W) Chromatography column
  X) Separatory funnel
  Y) Buchner (*bew-kner*) funnel
  Z) Dean-Stark trap

ANSWER: Y) Buchner (*bew-kner*) funnel

BONUS

19) CHEMISTRY *Multiple Choice* Which of the following is closest to the average phosphorus-fluorine bond order in the molecule phosphorus trifluorodichloride (*tri-fluoro-di-chloride*)?

  W) 0.5
  X) 0.67
  Y) 0.83
  Z) 1

ANSWER: X) 0.67

TOSS UP

20) EARTH AND SPACE *Multiple Choice* At which of the following endpoints of a QAPF diagram would you not expect to find feldspathoids?

  W) Q
  X) A
  Y) P
  Z) F

ANSWER: W) Q

BONUS

20) EARTH AND SPACE *Short Answer* Order the following THREE index fossil clades in order of DECREASING age of last known extant species:

  1) Graptolites (*GRAP-toh-lites*)
  2) Multituberculate Teeth (*Multi-too-ber-cyoo-lates*)
  3) Ammonites (*Am-mo-nites*)

ANSWER: 3, 2, 1

TOSS UP

21) BIOLOGY *Multiple Choice* Which of the following animals is INCORRECTLY matched with the excretory system it uses?

  W) Flatworms and flame bulbs
  X) Mollusc larvae and metanephridia (*meh-ta-ne-fri-dee-a*)
  Y) Grasshoppers and Malpighian (*mal-fih-jee-an*) tubules
  Z) Mice and kidneys

ANSWER: X) Mollusc larvae and metanephridia

BONUS

21) BIOLOGY *Short Answer* The robotics team at a particular high school dumps sulfuric acid into the soil. Identify all of the following three nutrients that surrounding plants would absorb at increased rates:

  1) Aluminum
  2) Iron
  3) Phosphate

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

TOSS UP

22) PHYSICS *Short Answer* Magnetically sensitive dyes are used in spectral imaging because they produce split spectral lines in the presence of a magnetic field. What effect is responsible for this phenomenon?

ANSWER: Zeeman

BONUS

22) PHYSICS *Short Answer* Andrew stands in between two speakers playing in phase but doesn't hear anything. If Andrew is 30 meters away from speaker A and 70 meters away from speaker B, in meters, what is the maximum possible wavelength of the sound coming from the speakers?

ANSWER: 80

TOSS UP

23) MATH *Short Answer* What is the sum of the cubes of -1 through 9, inclusive?

ANSWER: 2024

BONUS

23) MATH *Short Answer* Vigyan writes the sequence 1, 2, 2, 3, 3, 3, and so on, in which every positive integer k appears k times. Find the limit as n approaches infinity of the nth term of this sequence divided by the square root of n.

ANSWER: $\sqrt{2}$