2024 MIT Science Bowl High School Invitational

Round 4

TOSS UP

1) PHYSICS *Multiple Choice* A satellite moves periodically in a non-circular elliptical path around the Earth. At which points along the satellite's elliptical orbit is the magnitude of the force on the object minimized?

W) The endpoints of the major axis
X) The endpoints of the minor axis
Y) Apogee
Z) Perigee

ANSWER: Y) Apogee

BONUS

1) PHYSICS *Short Answer* A 50 kilogram astronaut in space launches a large 15 kilogram toy baby at 18 meters per second toward another astronaut. If the astronauts are initially at rest and separated by a distance of 30 meters, in meters, how far apart are they when the second astronaut receives the baby?

ANSWER: 39

TOSS UP

2) ENERGY *Short Answer* Researchers at the Roche lab have developed a biorobotic hybrid heart to act as a mitral (*mih-trahl*) valve simulator. In normal circulatory flow, blood that passes through the mitral valve enters what chamber of the heart?

ANSWER: Left ventricle

BONUS

2) ENERGY *Short Answer* MIT scientists at the Liu lab are using a modified cytosine deaminase (read: *de-ahm-in-ace*) base editor which can potentially correct hundreds of disease causing mutations in human somatic cells. Identify all of the following three diseases whose most common variant can be corrected by base editors:

1) Turner's syndrome
2) Sickle cell anemia
3) Down syndrome

ANSWER: 2 only

TOSS UP

3) MATH *Multiple Choice* Consider the statement "If n is a prime, then $2n + 1$ is prime." Which of the following values of n is a counterexample of this statement?

W) 3
X) 5
Y) 6
Z) 7

ANSWER: Z) 7

BONUS

3) MATH *Short Answer* At MIT Science Bowl, two thirds of teams have an alternate, and three quarters of teams are from Cambridge. What is the minimum fraction of teams at MIT Science Bowl that have an alternate and are from Cambridge?

ANSWER: $\frac{5}{12}$

TOSS UP

4) EARTH AND SPACE *Multiple Choice* Which of the following is the primary ore of titanium?

W) Galena
X) Pyrite
Y) Magnetite
Z) Ilmenite

ANSWER: Z) Ilmenite

BONUS

4) EARTH AND SPACE *Short Answer* Taking Hubble's constant to be 71 kilometers per second per megaparsec and giving your answer to two significant figures, what is the distance to a galaxy in megaparsecs that is observed to be receding from Earth at a velocity of 85 thousand kilometers per second?

ANSWER: 1200 (ACCEPT: $1.2 \cdot 10^3$)

TOSS UP

5) BIOLOGY *Short Answer* Sea otters in kelp forests are an example of what type of species that is crucial for the stability of an ecosystem?

ANSWER: Keystone species

BONUS

5) BIOLOGY *Short Answer* Order the following three steps in mammalian lipid digestion in chronological order:

1) Assembly of triglycerides into chylomicrons;
2) Entrance into circulatory system,
3) Emulsification by bile salts.

ANSWER: 3, 1, 2

TOSS UP

6) CHEMISTRY *Short Answer* The Sechenov equation allows for estimating the solubility of gases in solutions with a high ionic strength. Which gas law is the Sechenov equation an extension of?

ANSWER: Henry's Law

BONUS

6) CHEMISTRY *Multiple Choice* Upon doping, the polymer polyacetylene is highly electrically conductive. This property is best attributed to the delocalization of electrons throughout which type of molecular orbital?

W) Sigma
X) Pi
Y) Delta
Z) Phi

ANSWER: X) Pi

TOSS UP

7) BIOLOGY *Multiple Choice* Which of the following biogeochemical cycles does NOT involve the atmosphere as a significant reservoir of nutrients?

W) Water cycle
X) Carbon cycle
Y) Nitrogen cycle
Z) Phosphorus cycle

ANSWER: Z) Phosphorus cycle

BONUS

7) BIOLOGY *Short Answer* While bicarbonate ions are produced easily from carbon dioxide and water in red blood cells, it does not happen as readily in the blood. This is due to the presence of what enzyme in red blood cells?

ANSWER: Carbonic anhydrase

TOSS UP

8) ENERGY *Short Answer* Researchers from the Wang Lab at the Broad Institute developed a computational method called CAST for searching across spatial omics samples at a single-cell level. CAST models the relationships between each pair of cells as edges in what discrete mathematical structures?

ANSWER: Graphs (DO NOT ACCEPT: Trees)

BONUS

8) ENERGY *Short Answer* Researchers at MIT in the Román Lab are developing a process to recycle what complex phenolic polymer from tree bark into a component of jet fuel?

ANSWER: Lignin

TOSS UP

9) MATH *Short Answer* In a quiz taken by 100 students, the first, second, and third questions were correctly answered by 70, 60, and 50 students respectively. Given only this information, what is the maximum number of students that could have answered all three questions correctly?

ANSWER: 50

BONUS

9) MATH *Short Answer* Given that the roots of the cubic polynomial (read: *slowly*) $x^3 + 2x + 1$ (read: *x cubed plus 2 times x plus 1*) are distinct, what is the sum of the reciprocals of the roots?

ANSWER: -2

TOSS UP

10) PHYSICS *Multiple Choice* A gas has a constant-pressure heat capacity approximately equal to $2.5R$, where R is the ideal gas constant. Which of the following could be the identity of the gas?

W) Hydrogen
X) Helium
Y) Oxygen
Z) Carbon dioxide

ANSWER: X) Helium

BONUS

10) PHYSICS *Short Answer* Identify all of the following three statements that are true about displacement current:

1) The displacement and conduction currents share the same units
2) The displacement current is proportional to the time derivative of the electric field
3) A constant displacement current can produce a magnetic field

ANSWER: All

TOSS UP

11) CHEMISTRY *Multiple Choice* Which of the following best justifies the difference in the first ionization energies of beryllium and boron?

W) Beryllium has a lower first ionization energy than boron because the half-filled 2s orbital is very stable
X) Beryllium has a lower first ionization energy than boron because 2s electrons are lower in energy than 2p electrons
Y) Boron has a lower first ionization energy than beryllium because the half-filled 2p orbital is very stable
Z) Boron has a lower first ionization energy than beryllium because 2s electrons are lower in energy than 2p electrons

ANSWER: Z) Boron has a lower first ionization energy than beryllium because 2s electrons are lower in energy than 2p electrons

BONUS

11) CHEMISTRY *Short Answer* Identify all of the following three actions that would lower the pH of a buffer made by mixing equal volumes of 1 molar ammonia and 0.5 molar hydrochloric acid:

1) Diluting the solution by a factor of 10
2) Adding solid ammonium chloride to the solution
3) Adding solid potassium chloride to the solution

ANSWER: 2 only

TOSS UP

12) EARTH AND SPACE *Short Answer* What phenomenon is responsible for generating Earth's magnetic field?

ANSWER: Dynamo effect

BONUS

12) EARTH AND SPACE *Short Answer* Identify all of the following three shoreline features that are best classified as erosional:

1) Spit
2) Sea Stack
3) Baymouth Bar

ANSWER: 2 only

TOSS UP

13) PHYSICS *Multiple Choice* Ethan is riding on a carousel at constant speed. In which direction does the time derivative of his acceleration point?

W) Towards the center of the carousel
X) Away from the center of the carousel
Y) In his direction of motion
Z) Opposite his direction of motion

ANSWER: Z) Opposite his direction of motion

BONUS

13) PHYSICS *Multiple Choice* A particle moves in a uniform circular orbit in three dimensional space. What is the locus of all points such that the magnitude of the angular momentum of the particle with respect to these points is constant?

W) Point
X) Line
Y) Flat circle
Z) Entire space

ANSWER: X) Line

TOSS UP

14) CHEMISTRY *Short Answer* For the reaction $2\,NO_2 \longrightarrow N_2O_4$ (read: *N O two yields N two O four*), the rate constant of the forward reaction is 180 M-1s-1(read: *inverse molar seconds*) while the rate constant of the reverse reaction is 12 s-1(read: *inverse seconds*). What is the equilibrium constant of the reaction?

ANSWER: 15

BONUS

14) CHEMISTRY *Short Answer* In coordination chemistry, polydentate ligands often exhibit far greater affinity for metal ions due to the chelation effect. What thermodynamic quantity is significantly more positive for the formation of a chelated complex compared to a complex formed with monodentate ligands?

ANSWER: Entropy

TOSS UP

15) MATH *Short Answer* A triangle has 3 points with x-coordinates 1, 10 and 100 respectively. What is the x-coordinate of the center of mass of this triangle?

ANSWER: 37

BONUS

15) MATH *Short Answer* In a science bowl tournament with five different schools and two teams from each school, how many ways are there to split teams into two indistinguishable divisions such that no division has two teams from the same school?

ANSWER: 16

TOSS UP

16) EARTH AND SPACE *Short Answer* Type Ia (*one A*) supernovae often result from what event, which is the violent reignition of thermonuclear fusion in a cooling white dwarf?

ANSWER: Carbon Deflagration (ACCEPT: Carbon Detonation)

BONUS

16) EARTH AND SPACE *Multiple Choice* Which of the following best describes sea breezes?

W) Land is cooled more during the night leading to surface air moving towards the sea
X) Land is cooled more during the night leading to surface air moving towards the land
Y) Land is heated more during the day leading to surface air moving towards the sea
Z) Land is heated more during the day leading to surface air moving towards the land

ANSWER: Z) Land is heated more during the day leading to surface air moving towards the land

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TOSS UP

17) BIOLOGY *Short Answer* A plant's root pressure may force water from the xylem to outside the leaf, which results in what phenomenon?

ANSWER: Guttation

BONUS

17) BIOLOGY *Short Answer* An initial population of 16 wolves enters an area with abundant space and resources. After one year, the population of wolves is 28. After a second year, the population of wolves is 49. What is the annual per capita rate of increase for this population?

ANSWER: 0.75 (ACCEPT: 75%)

TOSS UP

18) ENERGY *Short Answer* Researchers at MIT's Computational Turbulence Group are developing simulations for fluid dynamics. What regions in fluids consist of flow revolving about a common axis?

ANSWER: Vortices (ACCEPT: Vortex)

BONUS

18) ENERGY *Short Answer* Material scientists at MIT are studying the short-range order of complex systems, such as alloys. Identify all of the following three systems that display short-range order:

1) Water molecules in ice
2) Water molecules in liquid water
3) Water molecules in water vapor

ANSWER: 1 and 2

TOSS UP

19) MATH *Short Answer* How many distinct prime factors does 20! (read: *twenty factorial*) have?

ANSWER: 8

BONUS

19) MATH *Short Answer* A ball bounces on level ground such that its maximum height for any bounce is 20% less than that of the previous bounce. If the ball is dropped from a height of 5 feet, in feet, what is the total distance traveled by the ball as time goes to infinity?

ANSWER: 45

TOSS UP

20) BIOLOGY *Multiple Choice* Which of the following animals undergoes meroblastic cleavage?

W) Earthworms
X) Frogs
Y) Starfish
Z) Birds

ANSWER: Z) Birds

BONUS

20) BIOLOGY *Multiple Choice* Flap endonuclease 1 is involved in trimming short nucleotide "flaps" left over primarily during what process, in which DNA polymerase delta creates these "flaps" when displacing primers laid by DNA primase?

W) Transcription
X) Translation
Y) DNA replication
Z) Non-homologous end-joining

ANSWER: Y) DNA replication

TOSS UP

21) CHEMISTRY *Multiple Choice* Given that the molecular mass of isopropanol is approximately 60, which of the following is closest to the molecular mass of diisopropyl ether, formed by the condensation of two molecules of isopropanol?

W) 84
X) 102
Y) 120
Z) 138

ANSWER: X) 102

BONUS

21) CHEMISTRY *Short Answer* Ammonia is produced in the Haber process through the balanced reaction $N_2 + 3\,H_2 \longrightarrow 2\,NH_3$ (read: *N two plus three H two yields two N H three*), which has a change in enthalpy of -92 kilojoules per mole. Given that the forward reaction has an activation energy of 30 kilojoules per mole, what is the activation energy of the reverse reaction in kilojoules per mole?

ANSWER: 122

TOSS UP

22) PHYSICS *Multiple Choice* A rod is suspended from the ceiling with two massless ropes, with one hanging vertically at each end, each with tension T. The left rope suddenly breaks, causing the rod to fall. Immediately after the break, what is the tension in the right rope?

W) Less than T
X) T
Y) Between T and $2T$
Z) $2T$

ANSWER: Y) Between T and $2T$

BONUS

22) PHYSICS *Short Answer* A circuit consists of a 12 volt battery connected to two resistors in series. If one resistor dissipates 15 watts and the other dissipates 21 watts, what is the current, in amperes, across the battery?

ANSWER: 3

TOSS UP

23) EARTH AND SPACE *Short Answer* Identify all of the following three factors which promote jet stream formation at the boundaries of convection cells:

1) High pressure gradient between convection cells
2) High wind speed at tropopause
3) Geostrophic balance of coriolis force and pressure gradient force

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

BONUS

23) EARTH AND SPACE *Short Answer* Rank the following three spectral classes by increasing strength of Balmer lines:

1) K
2) B
3) O

ANSWER: 1, 3, 2