

2025 MIT Science Bowl High School Invitational

Round 5

TOSS-UP

1) BIOLOGY – *Multiple Choice* Which of the following states would lead to the highest expression of lac operon?

- W) High lactose, high glucose
- X) High lactose, low glucose
- Y) Low lactose, high glucose
- Z) Low lactose, low glucose

ANSWER: X) HIGH LACTOSE, LOW GLUCOSE

BONUS

1) BIOLOGY – *Short Answer* The statoliths (read: *stay-toe-liths*) that help plant roots sense gravity are specialized versions of what starch-storing plant organelle?

ANSWER: AMYLOPLAST (DO NOT ACCEPT: PLASTID)

TOSS-UP

2) ENERGY – *Short Answer* The Zhang Lab studied IscB’s (read: *Is-ck-B’s*), a family of proteins that cut bacterial DNA. IscB’s are the evolutionary ancestors of what protein widely used in CRISPR gene editing?

ANSWER: CAS9

BONUS

2) ENERGY – *Multiple Choice* Researchers in the Multicore Algorithms Group at MIT are studying the design of hashable data structures. After a list of prime numbers are added to a hash set, which of the following could not be the product of the hash set’s elements?

- W) 51
- X) 67
- Y) 70
- Z) 75

ANSWER: Z) 75

TOSS-UP

3) MATH – *Short Answer* In terms of a single trigonometric function, what is the simplest form of the trigonometric expression $\cot x \sin^2 x / \cos x$ (read: *quantity cotangent of x times quantity sine of x squared divided by quantity cosine of x*)?

ANSWER: $\sin x$

BONUS

3) MATH – *Short Answer* What is the remainder when the polynomial $2x^4 - 3x^3 + 5x - 9$ (read: *2 x to the power of 4 minus 3 x cubed plus 5 x minus 9*) is divided by the monomial $x - 2$?

ANSWER: 9

TOSS-UP

4) PHYSICS – *Short Answer* To the nearest radian per second, what is the angular frequency of a wave whose period is 6 seconds?

ANSWER: 1

BONUS

4) PHYSICS – *Short Answer* A spacecraft initially floating at rest suddenly explodes into two pieces with masses 200 and 400 kilograms, such that each piece receives an impulse of 1500 newton-seconds. After the explosion, what is the relative speed of the two pieces, in meters per second?

ANSWER: 11.25 (ACCEPT: 45/4)

TOSS-UP

5) CHEMISTRY – *Multiple Choice* A mystery gas effuses through a pinhole three times faster than water vapor at the same temperature. Which of the following could be the identity of the mystery gas?

- W) Hydrogen
- X) Helium
- Y) Carbon dioxide
- Z) Sulfur dioxide

ANSWER: W) HYDROGEN

BONUS

5) CHEMISTRY – *Multiple Choice* What is the average oxidation state of technetium in the polyoxotechnetate (read: *poly-oxo-tech-nuh-tate*) ion $Tc_{20}O_{68}^{4-}$ (read: *T-c 20 O 68 four minus*)?

- W) +6.4
- X) +6.6
- Y) +6.8
- Z) +7

ANSWER: X) +6.6

TOSS-UP

6) EARTH AND SPACE – *Multiple Choice* In which season of the Northern Hemisphere do atmospheric carbon dioxide concentrations typically peak?

- W) Winter
- X) Spring
- Y) Summer
- Z) Fall

ANSWER: X) SPRING

BONUS

6) EARTH AND SPACE – *Multiple Choice* If Earth abruptly stopped rotating, which of the following best describes how global atmospheric circulation patterns would most likely change?

- W) Intensified three-cell circulation due to stronger pressure gradients
- X) Weakened three-cell circulation due to weaker pressure gradients
- Y) Single cell per hemisphere with rising air at the equator and sinking at the poles
- Z) Single cell per hemisphere with rising air at the poles and sinking at the equator

ANSWER: Y) SINGLE CELL PER HEMISPHERE WITH RISING AIR AT THE EQUATOR AND SINKING AT THE POLES

TOSS-UP

7) PHYSICS – *Short Answer* A seesaw, 6 meters long, has beavers sitting on opposite ends with masses of 20 and 30 kilograms, respectively. In newton-meters and rounded to the nearest integer, what is the magnitude of the net torque exerted on the seesaw about its midpoint?

ANSWER: 294

BONUS

7) PHYSICS – *Short Answer* A solid and uniformly dense sphere has a mass of 10 kilograms and a radius of 3 meters. In kilogram meters squared, what is the moment of inertia of the sphere about an axis tangent to its surface?

ANSWER: 126

TOSS-UP

8) CHEMISTRY – *Multiple Choice* Which of the following quantum numbers could be equal to -1 for an electron occupying an atomic orbital?

- W) Principal
- X) Azimuthal
- Y) Magnetic
- Z) Spin

ANSWER: Y) MAGNETIC

BONUS

8) CHEMISTRY – *Short Answer* Rank the following three types of unit cells by increasing packing efficiency: 1) Body-centered cubic; 2) Simple cubic; 3) Hexagonal close packed.

ANSWER: 2, 1, 3

TOSS-UP

9) MATH – *Short Answer* Two vertices of a regular decagon are selected at random. What is the probability that the segment connecting them is not one of the sides of the decagon?

ANSWER: 7/9

BONUS

9) MATH – *Short Answer* How many four digit positive integers satisfy the property that the product of their digits is 2025?

ANSWER: 6

TOSS-UP

10) EARTH AND SPACE – *Multiple Choice* In which of the following rock types are subterranean rivers most commonly embedded?

- W) Limestone
- X) Sandstone
- Y) Granite
- Z) Shale

ANSWER: W) LIMESTONE

BONUS

10) EARTH AND SPACE – *Short Answer* Order the following three gems by increasing hardness on the Mohs hardness scale: 1) Topaz; 2) Diamond; 3) Pearls.

ANSWER: 3, 1, 2

TOSS-UP

11) BIOLOGY – *Short Answer* Plant cells do not lyse in a hypotonic environment due to the presence of what cellulose-containing structure?

ANSWER: CELL WALL

BONUS

11) BIOLOGY – *Multiple Choice* Which of the following DNA strands, if annealed with their complementary strand, would have the lowest melting point?

- W) TTAGAAT
- X) ACTCAGA
- Y) ACTACGT
- Z) GCGCCTT

ANSWER: W) TTAGAAT

TOSS-UP

12) ENERGY – *Short Answer* Scientists at the Whitehead Institute have been using fluorinated glucose to study brown fat as a potential use for starving cancer of glucose. What imaging technique did the scientists use to track radioactive fluorinated glucose throughout the body?

ANSWER: POSITRON EMISSION TOMOGRAPHY (ACCEPT: PET)

BONUS

12) ENERGY – *Short Answer* MIT scientists discovered both L and D forms of amino acids in samples recently collected by NASA from an asteroid. What type of isomerism relates the L and D forms of an amino acid?

ANSWER: ENANTIOMERISM (ACCEPT: STEREO, STEREOISOMERISM, OPTICAL, OPTICAL ISOMERISM , DO NOT ACCEPT: GEOMETRIC)

TOSS-UP

13) MATH – *Short Answer* Bronya has a weighted six-sided die, where the probability of rolling each face is proportional to the number on the face. What is the probability that Bronya rolls a one?

ANSWER: 1/21

BONUS

13) MATH – *Short Answer* The \log^* (read: *log star*) operation, often known as the binary iterated logarithm, is the number of times a base two logarithm must be applied to a number until it is less than or equal to 1. What is the smallest positive integer such that when the \log^* operation is applied, the result is 4?

ANSWER: 17

TOSS-UP

14) BIOLOGY – *Multiple Choice* Elk often live in groups, and the male is highly ornamented while the females are not highly ornamented. Knowing this, what kind of mating system do elk likely follow?

- W) Monogamy
- X) Polyandry
- Y) Polygyny (read: *puh-LIH-jih-nee*)
- Z) Promiscuity

ANSWER: Y) POLYGYNY (READ: PUH-LIH-JIH-NEE)

BONUS

14) BIOLOGY – *Multiple Choice* Which of the following processes is least likely to be disrupted by the introduction of a calcium chelator?

- W) Formation of a fertilization envelope in a zygote
- X) Action potential initiation in a sensory neuron
- Y) Long term potentiation in the brain
- Z) Peristalsis in the small intestine

ANSWER: X) ACTION POTENTIAL INITIATION IN A SENSORY NEURON

TOSS-UP

15) CHEMISTRY – *Multiple Choice* Which of the following molecules is nonpolar?

- W) Chlorine trifluoride
- X) Phosphorus trifluoride
- Y) Chlorine pentafluoride
- Z) Phosphorus pentafluoride

ANSWER: Z) PHOSPHORUS PENTAFLUORIDE

BONUS

15) CHEMISTRY – *Multiple Choice* Cations with which of the following properties will be hydrated by the most water molecules in aqueous solution?

- W) Small ionic radius and low charge
- X) Small ionic radius and high charge
- Y) Large ionic radius and low charge
- Z) Large ionic radius and high charge

ANSWER: X) SMALL IONIC RADIUS AND HIGH CHARGE

TOSS-UP

16) PHYSICS – *Multiple Choice* Which of the following configurations of quarks has the same net charge as a proton?

- W) 3 up quarks
- X) 2 up quarks and 1 down quark
- Y) 1 up quark and 2 down quarks
- Z) 3 down quarks

ANSWER: X) 2 UP QUARKS AND 1 DOWN QUARK

BONUS

16) PHYSICS – *Multiple Choice* Mingwen is moving toward a stationary loudspeaker, while Yufei remains stationary. If Yufei hears a constant pitch from the loudspeaker, which of the following statements must be true?

- W) Mingwen observes a higher amplitude sound wave than Yufei
- X) Mingwen observes a lower amplitude sound wave than Yufei
- Y) Mingwen observes a higher frequency sound wave than Yufei
- Z) Mingwen observes a lower frequency sound wave than Yufei

ANSWER: Y) MINGWEN OBSERVES A HIGHER FREQUENCY SOUND WAVE THAN YUFEI

TOSS-UP

17) EARTH AND SPACE – *Multiple Choice* Relative to a cluster's main sequence turnoff point, where on an H-R diagram are blue stragglers found?

- W) Up and to the left
- X) Up and to the right
- Y) Down and to the left
- Z) Down and to the right

ANSWER: W) UP AND TO THE LEFT

BONUS

17) EARTH AND SPACE – *Short Answer* Order the following three energy densities by the time at which they began to dominate the universe's expansion history, from earliest to latest: 1) Dark energy; 2) Matter; 3) Radiation.

ANSWER: 3, 2, 1

TOSS-UP

18) ENERGY – *Multiple Choice* Astronomers at the Kavli Institute observed an ancient lonely quasar. Where would a quasar be found?

- W) Outer edge of a planetary ring system
- X) Arm of a spiral galaxy
- Y) Remnant of a gamma ray burst
- Z) Bright core of a galaxy

ANSWER: Z) BRIGHT CORE OF A GALAXY

BONUS

18) ENERGY – *Multiple Choice* The Freedman Lab synthesized a strongly correlated spin glass with completely aligned electron spin domains. What type of magnetism does this spin glass exhibit?

- W) Paramagnetism
- X) Diamagnetism
- Y) Ferromagnetism
- Z) Anti-ferromagnetism

ANSWER: Y) FERROMAGNETISM

TOSS-UP

19) MATH – *Multiple Choice* Which of the following 3D shapes represents the locus of all points equidistant from a line?

- W) Cylinder
- X) Sphere
- Y) Ellipsoid
- Z) Paraboloid

ANSWER: W) CYLINDER

BONUS

19) MATH – *Short Answer* What percentage of 45 is equal to 65% of 18?

ANSWER: 26

TOSS-UP

20) PHYSICS – *Short Answer* When a sound wave is emanated isotropically from a point source, the intensity of the wave is linearly proportional to what power of the distance from the point source?

ANSWER: -2

BONUS

20) PHYSICS – *Short Answer* Mario travels along the x -axis. His momentum $p(t)$ (read: p of t) can be modeled as a function of time, where $p(t) = -2t^3 + 9t^2 - 12t + 1$ (read: p of t equals negative two t cubed plus nine t squared minus twelve t plus one). At what time t is the net force experienced by Mario most positive?

ANSWER: 3/2 (ACCEPT: 1.5)

TOSS-UP

21) CHEMISTRY – *Short Answer* How many sigma bonds are formed in one molecule of ethane?

ANSWER: 7

BONUS

21) CHEMISTRY – *Short Answer* Identify all of the following three rotational symmetries that are present in a ground-state benzene molecule: 1) Two-fold; 2) Three-fold; 3) Four-fold.

ANSWER: 1 AND 2

TOSS-UP

22) ENERGY – *Multiple Choice* Economists at MIT routinely use linear regression to model datasets. Which of the following coefficients of determination describes a linear regression model with the best goodness of fit?

- W) -0.1
- X) 0.2
- Y) 0.5
- Z) 0.8

ANSWER: Z) 0.8

BONUS

22) ENERGY – *Multiple Choice* Physicists at the MIT-Harvard Center for Ultracold Atoms cooled lithium-6 atoms to nanokelvin temperatures so they could observe frictionless resonance in what resulting state of matter?

- W) Plasma
- X) Superfluid
- Y) Ferromagnet
- Z) Bose-Einstein Condensate

ANSWER: X) SUPERFLUID

TOSS-UP

23) BIOLOGY – *Short Answer* Golden Gate and Gibson assembly both use what class of bacterial enzymes to cleave DNA fragments for plasmid assembly?

ANSWER: RESTRICTION ENZYME

BONUS

23) BIOLOGY – *Short Answer* Identify all of the following three vitamins that would be excreted in urine in significant amounts: 1) Thiamine; 2) Niacin; 3) Ascorbic acid.

ANSWER: ALL

TOSS-UP

24) EARTH AND SPACE – *Short Answer* Identify all of the following three anomalies that were caused by giant impacts: 1) Mars' crust is thinner in the northern than southern hemisphere; 2) Mercury has a disproportionately large iron core; 3) Uranus has a high obliquity to the ecliptic.

ANSWER: ALL

BONUS

24) EARTH AND SPACE – *Short Answer* Order the following three regions in order of increasing aggregate mass: 1) The asteroid belt; 2) The Kuiper belt; 3) The Oort cloud.

ANSWER: 1, 2, 3

TOSS-UP

25) PHYSICS – *Short Answer* Madeline is traveling at a constant 30 meters per second when she passes a cop car at rest. At that instant, the cop begins accelerating in pursuit at 5 meters per second squared. In seconds, how long will the cop take to catch up to Madeline?

ANSWER: 12

BONUS

25) PHYSICS – *Short Answer* Using scientific notation to one significant figure and in Joules, what is the energy of an object with a rest mass of 1 kilogram?

ANSWER: 9×10^{16} (READ: NINE TIMES TEN TO THE SIXTEENTH POWER)