2025 MIT Science Bowl High School Invitational

Round 10

TOSS-UP

1) MATH – *Short Answer* Vector $\vec{a}$ (read: *a*) has magnitude 20 and vector $\vec{b}$ (read: *b*) has magnitude 25. If the magnitude of $\vec{a} \cdot \vec{b}$ (read: *a dot b*) is 400, what is the magnitude of $\vec{a} \times \vec{b}$ (read: *a cross b*)?

ANSWER: 300

BONUS

1) MATH – *Short Answer* The MIT Engineers and Harvard Crimsons are playing a best-of-seven series against each other, where the first team to win four games wins the series. If both teams have an equal probability of winning a game, what is the probability the MIT Engineers win the series in game 7?

ANSWER: 5/32

TOSS-UP

2) EARTH AND SPACE – *Multiple Choice* Which of the following best explains how atmospheric CO_2 interacts with oceanic buffering?

W) Dissolved CO_2 reacts with water to form acid and consumes carbonate
X) Dissolved CO_2 reacts with water to yield carbonate ions
Y) Dissolved CO_2 reacts with water to form carbonate, which consumes carbonic acid
Z) Dissolved CO_2 reacts with water to form carbonate, which further yields carbonic acid

ANSWER: W) DISSOLVED CO_2 REACTS WITH WATER TO FORM ACID AND CONSUMES CARBONATE

BONUS

2) EARTH AND SPACE – *Multiple Choice* Stephen is journeying to the center of the Earth, starting in the middle of Germany and digging down into the mantle. Which of the following best summarizes the rocks he will see, in order?

W) Granite, peridotite (read: *puh-RID-uh-tight*)
X) Granite, komatiite (read: *kuh-MAT-ee-ite*)
Y) Granite, basalt, peridotite
Z) Granite, basalt, komatiite

ANSWER: W) GRANITE, PERIDOTITE (READ: *PUH-RID-UH-TIGHT*)

TOSS-UP

3) ENERGY – *Short Answer* Mathematicians in the Sheffield Group searched for paths that pass through each of the vertices of a regular graph exactly once. What type of paths are these?

ANSWER: HAMILTONIAN PATHS (ACCEPT: HAMILTONIAN, HAMILTON PATHS, DO NOT ACCEPT: HAMILTONIAN CYCLES, CYCLES)

BONUS

3) ENERGY – *Short Answer* Scientists at the Reddien Lab in the Whitehead Institute are studying the delta notch pathway, which specifies how neuronal cells such as glia (read: *glee-ah*) differentiate. The delta notch pathway secretes factors that induce some of these glia to guide the axons for newly growing neurons. What kind of glia perform this function?

ANSWER: RADIAL

TOSS-UP

4) BIOLOGY – *Multiple Choice* Selena is hand-pollinating a carrot plant with self-incompatibility genotype S1S2. Successful fertilization would only be possible if carrots used which type of self-incompatibility and if the plant supplying the pollen had what self-incompatibility genotype, respectively?

W) Sporophytic, S1S2
X) Sporophytic, S2S3
Y) Gametophytic, S1S2
Z) Gametophytic, S2S3

ANSWER: Z) GAMETOPHYTIC, S2S3

BONUS

4) BIOLOGY – *Multiple Choice* Which of the following molecules would be most readily recognized by a macrophage?

W) Phosphatidylserine
X) Phosphatidylcholine
Y) Sphingomyelin
Z) Cholesterol

ANSWER: W) PHOSPHATIDYLSERINE

TOSS-UP

5) PHYSICS – *Multiple Choice* Charles is fleeing from Earth in a relativistic spaceship. From his perspective, he experiences a constant acceleration in his direction of motion in the absence of gravity. From the perspective of an observer on Earth, which of the following choices best describes Charles's speed and momentum over time, respectively?

W) Increases without bound, increases without bound
X) Increases without bound, approaches a finite value
Y) Approaches a finite value, increases without bound
Z) Approaches a finite value, approaches a finite value

ANSWER: Y) APPROACHES A FINITE VALUE, INCREASES WITHOUT BOUND

BONUS

5) PHYSICS – *Short Answer* A spin-1/2 particle's normalized wave function has an amplitude of $0.42 - 0.56i$ (read: *zero point four two minus zero point five six i*) in the spin-up state. What is the probability of the particle being measured in the spin-down state?

ANSWER: 0.51 (ACCEPT: 51%)

TOSS-UP

6) CHEMISTRY – *Multiple Choice* Which of the following hydrocarbons must contain a pi bond?

W) C_3H_4 (read: *C three H four*)
X) C_5H_8
Y) C_5H_{10}
Z) C_6H_{10}

ANSWER: W) C_3H_4 (READ: *C THREE H FOUR*)

BONUS

6) CHEMISTRY – *Multiple Choice* Which of the following reagents should be added to cyclohexene to produce an optically active diol as the major product?

W) Acidified peroxy acid
X) Catalytic osmium tetroxide
Y) Basified potassium permanganate
Z) Ozone with dimethyl sulfide

ANSWER: W) ACIDIFIED PEROXY ACID

TOSS-UP

7) MATH – *Multiple Choice* The cone $z = \sqrt{x^2 + y^2}$ (read: *z equals the square root of the quantity x squared plus y squared*) is intersected by the plane $z = 2x - 1$. Which of the following best describes the curve of intersection?

W) Hyperbola
X) Parabola
Y) Ellipse
Z) Degenerate

ANSWER: W) HYPERBOLA

BONUS

7) MATH – *Short Answer* If x is a positive real number such that $x + 1/x = 5$ (read: *x plus quantity one over x equals five*), evaluate $(x - 1/x)^2$ (read: *open parentheses x minus quantity one over x close parentheses squared*).

ANSWER: 21

TOSS-UP

8) PHYSICS – *Multiple Choice* A cord is wrapped around a vertical pulley, and masses of 3 kilograms and 6 kilograms are suspended from either side. The masses are then allowed to fall. Which of the following is closest to the tension in the cord in Newtons?

W) 30
X) 40
Y) 60
Z) 90

ANSWER: X) 40

BONUS

8) PHYSICS – *Multiple Choice* Olivia releases the bob of a 1 meter-long pendulum from an angle of 90 degrees from the vertical. In seconds, which of the following is closest to its resulting period?

W) 1
X) 1.7
Y) 2
Z) 2.4

ANSWER: Z) 2.4

TOSS-UP

9) BIOLOGY – *Short Answer* Dr. Julius has come across a shocking patient who requires an immediate blood transfusion. The patient has the Bombay phenotype, meaning she possesses no antigens on her red blood cells. Identify all of the following four blood types that would be able to safely give her a transfusion: 1) A; 2) B; 3) O; 4) AB.

ANSWER: NONE

BONUS

9) BIOLOGY – *Multiple Choice* Which of the following structures do NOT contain phosphodiester bonds?

W) active Ras (read: *rahs*)
X) p53
Y) ribosome
Z) spliceosome

ANSWER: X) P53

TOSS-UP

10) ENERGY – *Multiple Choice* Researchers at the Institute for Medical Engineering and Science tested the limits of vision-language models. Vision-language models process captions to images using which of the following types of embeddings?

W) scalar
X) vector
Y) matrix
Z) function

ANSWER: X) VECTOR

BONUS

10) ENERGY – *Short Answer* Researchers at CSAIL's Complexity Theory group are studying randomized algorithms. Which class of randomized algorithms use random sampling to approximate numerical solutions for otherwise intractable problems?

ANSWER: MONTE CARLO

TOSS-UP

11) EARTH AND SPACE – *Multiple Choice* Jerry is in Florida and the weather report says a late afternoon thunderstorm is highly likely. However, at noon, Jerry only sees short, isolated clouds in the sky. What general type of cloud best describes what Jerry likely sees?

W) Nimbostratus
X) Cumulus
Y) Altocumulus
Z) Cirrocumulus

ANSWER: X) CUMULUS

BONUS

11) EARTH AND SPACE – *Multiple Choice* Which of the following best describes the cause of the 1980 eruption of Mount St. Helens?

W) An earthquake triggered a landslide which triggered the eruption
X) Glacial movements triggered a landslide which triggered the eruption
Y) Small phreatic eruptions triggered glacial melting which triggered the eruption
Z) An earthquake triggered magmatic outgassing which triggered the eruption

ANSWER: W) AN EARTHQUAKE TRIGGERED A LANDSLIDE WHICH TRIGGERED THE ERUPTION

TOSS-UP

12) CHEMISTRY – *Short Answer* The energy of the hydrogen atom's sole electron is proportional to its principal quantum number raised to what power?

ANSWER: -2

BONUS

12) CHEMISTRY – *Multiple Choice* A 1 mole sample decays with a rate constant of 0.1 inverse seconds. How much of the sample has decayed after 30 seconds?

W) 75%
X) 90%
Y) 95%
Z) 99%

ANSWER: Y) 95%

TOSS-UP

13) PHYSICS – *Multiple Choice* The speed at which water exits a water fountain is proportional to the gauge pressure of the water stream raised to what power?

W) -1
X) -1/2
Y) 1/2
Z) 1

ANSWER: Y) 1/2

BONUS

13) PHYSICS – *Short Answer* A right square pyramid with a base of width 20 centimeters and a height of 10 centimeters is held with its apex pointing directly downwards and completely filled with 20 Newtons of an ideal fluid. In Newtons and rounded to one significant figure, what is the magnitude of the force on each lateral face of the pyramid?

ANSWER: 7

TOSS-UP

14) CHEMISTRY – *Multiple Choice* Which of the following is the highest occupied molecular orbital of the hydroxyl radical?

W) Nonbonding orbital on oxygen
X) Sigma bonding orbital
Y) Sigma antibonding orbital
Z) Pi bonding orbital

ANSWER: W) NONBONDING ORBITAL ON OXYGEN

BONUS

14) CHEMISTRY – *Multiple Choice* In which of the following solvents would hydrofluoric acid have the highest pKa?

W) Pyridine
X) Glacial acetic acid
Y) Water
Z) Ethanol

ANSWER: X) GLACIAL ACETIC ACID

TOSS-UP

15) BIOLOGY – *Short Answer* Rank the following three cell membranes in increasing permeability to water: 1) Collecting duct cell exposed to ADH; 2) Myelin sheath of neuron; 3) Erythryocyte membrane.

ANSWER: 2, 3, 1

BONUS

15) BIOLOGY – *Short Answer* Sean is forcing Aryan to write biology questions and traps him inside a room at a high altitude. While Aryan adapts to these conditions, identify all of the following three changes that would occur: 1) Increased hematocrit; 2) Increased 2,3 BPG concentration in erythrocytes; 3) Increased erythropoetin (read: *eh-rith-roh-POY-tin*) secretion.

ANSWER: ALL

TOSS-UP

16) MATH – *Multiple Choice* Ethan has a set containing the first ten positive integers and computes the least common multiple of this set. He adds a number n to this set, and finds that the least common multiple of the new set is greater. Which of the following could be the value of n?

W) 14
X) 16
Y) 18
Z) 20

ANSWER: X) 16

BONUS

16) MATH – *Short Answer* Donald has 0 clams and a fair coin. He begins flipping the coin. Every time the coin lands heads, he gains a clam. Every time the coin lands tails, his clams triple. What is the expected number of clams he has after 5 turns?

ANSWER: 15.5

TOSS-UP

17) ENERGY – *Multiple Choice* The Quantum Measurement Group is using X-ray absorption spectroscopy, or XAS, to study lanthanide-based materials. The wavelength of the hard X-rays used in XAS is closest to which of the following length scales?

W) Length of a viral capsid
X) Radius of a hydrogen atom
Y) Diameter of a proton
Z) Thickness of a human hair

ANSWER: X) RADIUS OF A HYDROGEN ATOM

BONUS

17) ENERGY – *Short Answer* The Gilliard Group is using NMR spectroscopy to follow the synthesis of heterocycles. Identify all of the following three heteroatomic nuclei that are NMR-active: 1) Boron-11; 2) Nitrogen-14; 3) Nitrogen-15.

ANSWER: ALL

TOSS-UP

18) EARTH AND SPACE – *Short Answer* In the cores of some extremely massive stars, absorption of gamma rays by atomic nuclei may lead to pair production, which rapidly reduces the radiation pressure of the star. What type of supernova, which leaves behind no remnant, is formed as a result?

ANSWER: PAIR-INSTABILITY

BONUS

18) EARTH AND SPACE – *Short Answer* Identify all of the following three compounds that have been detected on Titan: 1) Methane; 2) Ethane; 3) Propane

ANSWER: ALL

TOSS-UP

19) ENERGY – *Multiple Choice* The Oliver Group recently studied the strong localization of electrons in a qubit array. According to electronic band theory, what type of material is this qubit array?

W) Semimetal
X) Semiconductor
Y) Insulator
Z) Superconductor

ANSWER: Y) INSULATOR

BONUS

19) ENERGY – *Short Answer* Material scientists at MIT are using machine learning to predict the alkaline dissolution rates of quartz polymorphs. Identify all of the following three minerals that the scientists could be studying: 1) Aragonite; 2) Rutile; 3) Stishovite.

ANSWER: 3 ONLY

TOSS-UP

20) EARTH AND SPACE – *Multiple Choice* The solar cycle primarily results from magnetic field variations caused by what phenomenon?

W) The Sun's magnetic axis precesses around its rotational axis
X) Convective cells in the Sun's interior periodically reverse direction
Y) The Sun's corona acquires an induced magnetic field to oppose existing field lines
Z) The Sun's equator rotates faster than its poles

ANSWER: Z) THE SUN'S EQUATOR ROTATES FASTER THAN ITS POLES

BONUS

20) EARTH AND SPACE – *Short Answer* A 10 solar mass black hole lies between Earth and a star 100 kiloparsecs away. Rank the following possible distances of the black hole from Earth by increasing maximum brightness of the star due to gravitational lensing: 1) 10 kiloparsecs; 2) 50 kiloparsecs; 3) 80 kiloparsecs.

ANSWER: 1, 3, 2

TOSS-UP

21) CHEMISTRY – *Multiple Choice* Which of the following molecules can act as a hydrogen bond acceptor but not as a hydrogen bond donor?

W) Water
X) Ammonia
Y) Dimethyl ether
Z) Methane

ANSWER: Y) DIMETHYL ETHER

BONUS

21) CHEMISTRY – *Short Answer* Rank the following three cycloalkanes in order of increasing ring strain: 1) Cyclobutane, 2) Cyclohexane, 3) Cycloheptane.

ANSWER: 2, 3, 1

TOSS-UP

22) MATH – *Short Answer* When evaluated at $x = 0$, what is the derivative with respect to x of $e^x(\sin x + \cos x)$ (read: *e to the power of x times open parantheses sin of x plus cosine of x close parantheses*)?

ANSWER: 2

BONUS

22) MATH – *Short Answer* Phoebe draws a triangle of area 10. She then draws a second triangle with two of the same side lengths, but with one side doubled in length. Identify all of the following three values that could be the area of her second triangle: 1) 5; 2) 10; 3) 15.

ANSWER: ALL

TOSS-UP

23) PHYSICS – *Multiple Choice* Adeline is riding a sled and slides down a frictionless incline, starting at some initial velocity. When plotted on a graph, which of the following pairs of variables would result in a straight line?

W) The square root of displacement and time
X) Velocity squared and displacement
Y) Displacement and the square root of time
Z) Velocity squared and time

ANSWER: X) VELOCITY SQUARED AND DISPLACEMENT

BONUS

23) PHYSICS – *Short Answer* Steve maintains a 3000-watt fire in his tiny, well-insulated house during a frigid zero-degree celsius night outside. Steve's walls only lose heat through a single rectangular window with an area of 1 square meter and thickness of 2 centimeters. If the thermal conductivity of glass is 5 watts per meter Kelvin, then to the nearest degree Celsius, what is the temperature inside Steve's house?

ANSWER: 12

TOSS-UP

24) BIOLOGY – *Multiple Choice* To help determine the identity of several classes of pathogens, Selena labels each with a fluorescent molecule that binds to sulfur. Which of the following classes of pathogens would most likely have the lowest amount of fluorescence?

W) Bacteria
X) Virus
Y) Viroid
Z) Prion

ANSWER: Y) VIROID

BONUS

24) BIOLOGY – *Multiple Choice* Caleb is eating a cherry and thinking about the polymer that makes the pit so tough. If he wanted to find more of this polymer in his bean plant, which of the following locations should he try?

W) Phloem
X) Petiole
Y) Root nodule
Z) Apical meristem

ANSWER: Y) ROOT NODULE

TOSS-UP

25) CHEMISTRY – *Multiple Choice* Which of the following transition metal cations has the most unpaired electrons in its ground state?

W) Iron two plus
X) Iron three plus
Y) Copper one plus
Z) Copper two plus

ANSWER: X) IRON THREE PLUS

BONUS

25) CHEMISTRY – *Short Answer* Identify all of the following three chemical reactions that are exothermic: 1) Decomposition of water vapor into hydrogen and oxygen; 2) Conversion of diamond to graphite; 3) Synthesis of glucose from water and carbon dioxide.

ANSWER: 2 ONLY