

2024 MIT Science Bowl High School Invitational

Round 13

TOSS UP

1) MATH *Multiple Choice* The first five terms of the Fibonacci sequence are 1, 1, 2, 3, 5. For the next terms, each term is the sum of the previous two. Let the n -th term be the first term with 1 million digits. Which of the following is n to 1 significant figure?

- W) 5000
- X) 100,000
- Y) 5,000,000
- Z) 10^{1000} (read: *ten to the thousandth power*)

ANSWER: Y) 5,000,000

BONUS

1) MATH *Multiple Choice* Over which of the following binary operations on the positive integers is multiplication NOT distributive?

- W) Modulus
- X) Least common multiple
- Y) Bitwise exclusive or
- Z) Maximum

ANSWER: Y) Bitwise exclusive or

TOSS UP

2) BIOLOGY *Multiple Choice* In the most common form of hemolytic disease of the newborn, the Rh (read: *r-h*) factors of the mother's plasma and the newborn's red blood cells are incompatible. Which of the following best describes the Rh factors of the mother and father of a baby suffering from the disease, respectively?

- W) Negative, Negative
- X) Negative, Positive
- Y) Positive, Negative
- Z) Positive, Positive

ANSWER: X) Negative, Positive

VISUAL BONUS

2) BIOLOGY *Short Answer* Your next bonus is visual. Shown is an image of an MRI scan. Answer the following two questions about this image:

- 1) Arrow A highlights a loss in signal in the left side of what brain structure, which resulted in having the acute onset of right-sided weakness and right hemisensory loss as well as partial memory impairment?
- 2) Arrow B points to the accumulation of blood within a structure of the limbic system responsible for consolidation of short term memories. What is this structure?

ANSWER: 1) Thalamus; 2) Hippocampus

TOSS UP

3) EARTH AND SPACE *Multiple Choice* Variations in which of the following quantities do not define one of the three Milankovitch cycles?

- W) Eccentricity
- X) Obliquity
- Y) Precession
- Z) Libration

ANSWER: Z) Libration

BONUS

3) EARTH AND SPACE *Multiple Choice* According to Anderson fault theory, in which of the following types of fault is the intermediate principal stress directed into the ground?

- W) Normal fault
- X) Reverse fault
- Y) Thrust fault
- Z) Strike-slip fault

ANSWER: Z) Strike-slip fault

TOSS UP

4) ENERGY *Multiple Choice* MIT Scientists at the Broad institute are studying viruses belonging to the family Orthomyxoviridae. Which of the following viruses could they be studying?

- W) HIV
- X) Epstein barr virus
- Y) Ebolavirus
- Z) Influenzavirus

ANSWER: Z) Influenzavirus

VISUAL BONUS

4) ENERGY *Short Answer* Your next bonus is visual. Researchers at the Bell lab have been studying the minichromosome maintenance protein complex, or the MCM. Based on the provided diagram of the eukaryotic Mcm2-7 (*m-c-m-two-through-seven*) complex, answer the following two questions:

- 1) What class of motor proteins that separate DNA strands does Mcm2-7 belong to?
- 2) What does the ORC in the diagram stand for?

ANSWER: 1) Helicase; 2) Origin recognition complex

TOSS UP

5) CHEMISTRY *Multiple Choice* Caleb tests a solution for the presence of halide ions by adding silver nitrate and observing if a precipitate forms. However, he accidentally forgets to acidify the solution beforehand. Which of the following ions could produce a false positive for Caleb's test?

- W) Fluoride
- X) Sulfide
- Y) Perchlorate
- Z) Sulfate

ANSWER: X) Sulfide

VISUAL BONUS

5) CHEMISTRY *Short Answer* Your next bonus is visual. Shown in the image is the key step in a famous organic synthesis reaction. Answer the following two questions about this reaction:

- 1) The product of this reaction is a precursor to what notable hydrocarbon?
- 2) How many degrees of unsaturation does the product of this reaction have?

ANSWER: 1) Cubane; 2) 7

TOSS UP

6) PHYSICS *Short Answer* What physical constant allows the quantization of the classical action in the path integral of quantum mechanics?

ANSWER: Planck's Constant (ACCEPT: Reduced Planck's Constant, h , h -bar)

VISUAL BONUS

6) PHYSICS *Short Answer* Your next bonus is visual. Shown in the image is a semiconductor-based circuit component. Answer the following three questions about this component using the image as a reference:

- 1) What is the name of this component?
- 2) What is the name of the region labeled A?;
- 3) Do negative charge carriers pass from left to right or right to left through this circuit component?

ANSWER: 1) FET (ACCEPT: Field-effect transistor, MOSFET); 2) Depletion Region; 3) Left to right

TOSS UP

7) BIOLOGY *Short Answer* Order the following three structures in the eye by increasing number of cone cells per unit area:

- 1) Optic disc
- 2) Fovea
- 3) Outer macula

ANSWER: 1, 3, 2

BONUS

7) BIOLOGY *Short Answer* Cyan's rabbits are all heterozygous for four traits located very close to each other on the same chromosome. Of the sixteen possible genotypes for the rabbits' gametes, how many are most likely the result of exactly two crossing over events?

ANSWER: 6

TOSS UP

8) ENERGY *Multiple Choice* Researchers at the MIT Laboratory for Financial Engineering are studying pricing models, such as the Black-Scholes (*shoals*) model. In this model, the price of a commodity is a continuous stochastic variable whose value fluctuates according to geometric Brownian motion. Which of the following values cannot be modeled as a continuous stochastic variable?

- W) The average global temperature over the next century
- X) The winning number for the Powerball lottery
- Y) The distance between two water molecules in a glass of water
- Z) The widths of particles in a pile of sand

ANSWER: X) The winning number for the Powerball lottery

BONUS

8) ENERGY *Multiple Choice* Researchers in the Hong group at MIT are using solid-state nuclear magnetic resonance spectroscopy, or ssNMR, to analyze molecular structures. Which of the following best describes the difference between ssNMR and traditional NMR techniques?

- W) ssNMR yields information that would be lost due to molecular motion in solution
- X) ssNMR is effective on molecules that are too large for traditional NMR
- Y) ssNMR is not dependent on rapid rotation of the analyte, as traditional NMR requires
- Z) ssNMR requires significantly more sample preparation than traditional NMR

ANSWER: W) ssNMR yields information that would be lost due to molecular motion in solution

TOSS UP

9) CHEMISTRY *Multiple Choice* In the second step of the Favorskii rearrangement, the enolate formed by deprotonation of an alpha carbon attacks the other alpha carbon, which is attached to a leaving group. Which of the following reaction mechanisms best describes the second step of the Favorskii rearrangement?

- W) Electrophilic addition
- X) Nucleophilic addition
- Y) Electrophilic substitution
- Z) Nucleophilic substitution

ANSWER: Z) Nucleophilic substitution

VISUAL BONUS

9) CHEMISTRY *Short Answer* Your next bonus is visual. Shown in the image are representations of the Lennard-Jones potential for two sets of atoms. Answer the following two questions:

- 1) According to the Lennard-Jones model, the energy due to repulsive interactions between two atoms is dependent on what power of distance?
- 2) Would the minimum of the plot of the potential between two neutral argon atoms lie in region 1, 2, or 3?

ANSWER: 1) -12; 2) 3

TOSS UP

10) EARTH AND SPACE *Multiple Choice* Which of the following is responsible for the Mediterranean climate along the West Coast of the United States?

- W) A thermal low forms over Southern California in summer, bringing more rainfall due to the North American Monsoon
- X) The Pacific High moves North in summer redirecting northern storms and causing sinking air
- Y) The Pineapple Express, driven by the jet stream, brings moisture from the tropics in Summer
- Z) The Polar Jet Stream moves North in Summer, decreasing the formation rate of Mid Latitude Cyclones in the region

ANSWER: X) Pacific High moves North in summer redirecting northern storms and causing sinking air

VISUAL BONUS

10) EARTH AND SPACE *Short Answer* Your next bonus is visual. The diagram depicts the flow of gradient wind around a mid-latitude pressure system. Answer the following three questions.

- 1) What hemisphere is the pressure system located in?
- 2) Is the magnitude of the pressure gradient force acting on the red dot greater than, equal to, or less than the magnitude of the Coriolis force acting on the same region?
- 3) If this system were moved to the equator, what term would describe the flow of wind in which magnitude of the Coriolis force is approximately zero?

ANSWER: 1) Southern Hemisphere; 2) Greater than; 3) Cyclostrophic

TOSS UP

11) PHYSICS *Multiple Choice* Which of the following statements is true regarding fluid flow?

- W) Steady-state flow cannot be rotational
- X) Reynold's number is proportional to dynamic viscosity
- Y) Inertial effects dominate flow at low Reynolds numbers
- Z) For a laminar flow of constant rate, the pressure gradient is inversely proportional to area squared

ANSWER: Z) For a laminar flow of constant rate, the pressure gradient is inversely proportional to area squared

BONUS

11) PHYSICS *Multiple Choice* Which of the following pairs of measurements can be performed both simultaneously and without deviations from the original values according to quantum mechanics?

- W) Measuring the spin of a fermion along the x and y axes
- X) Measuring spin along a common axis for each particle in an entangled pair
- Y) Measuring the momentum and position of a particle
- Z) Measuring the energy and lifetime of a resonance state

ANSWER: X) Measuring spin along a common axis for each particle in an entangled pair

TOSS UP

12) MATH *Multiple Choice* Ricky shuffles a deck of 52 cards and starts drawing cards from the top. How many kings would he expect to draw before he draws his first ace?

- W) $3/5$
- X) $3/4$
- Y) $4/5$
- Z) 1

ANSWER: Y) $4/5$

BONUS

12) MATH *Short Answer* Evie scored a 90 on her calculus final, which is one standard deviation above the class mean of 80. The final is broken into two equally weighted parts A and B so that the sum of the scores on both parts is the final score. If her score on Part A had a z-score of 1 and her score on Part B a z-score of $1/2$, what is the standard deviation of the class's scores on Part B, assuming both parts to be normally distributed?

ANSWER: 8

TOSS UP

13) EARTH AND SPACE *Multiple Choice* The Gunn-Peterson trough and the Lyman-alpha forest observed in the spectra of some distant quasars are evidence that the universe has undergone which of the following processes?

- W) Inflation
- X) Recombination
- Y) Reionization
- Z) Baryogenesis

ANSWER: Y) Reionization

BONUS

13) EARTH AND SPACE *Multiple Choice* Which of the following describes the Chapman cycle?

- W) High energy ultraviolet light initiates an oxygen radical reaction, forming ozone that absorbs low energy ultraviolet light
- X) Low energy ultraviolet light initiates an oxygen radical reaction, forming ozone that absorbs high energy ultraviolet light
- Y) High energy ultraviolet light initiates a water vapor radical reaction, forming ozone that absorbs low energy ultraviolet light
- Z) Low energy ultraviolet light initiates a water vapor radical reaction, forming ozone that absorbs low energy ultraviolet light

ANSWER: W) High energy ultraviolet light initiates an oxygen radical reaction, forming ozone that absorbs low energy ultraviolet light

TOSS UP

14) PHYSICS *Multiple Choice* Which of the following is an example of a system that experiences secular changes?

- W) Orbit of a satellite
- X) Vibrations of a double pendulum
- Y) Oscillations of an underdamped harmonic oscillator
- Z) Homogenization of a mixed medium

ANSWER: W) Orbit of a satellite

BONUS

14) PHYSICS *Short Answer* The unstable isotope thorium-232 decays via a series of alpha and beta-minus emissions into the stable isotope lead-208. If the atomic numbers of lead and thorium are 82 and 90, respectively, how many total decay steps are involved in this decay chain?

ANSWER: 10

TOSS UP

15) BIOLOGY *Multiple Choice* Which of the following biotechnological techniques cannot be used to distinguish proteins based on their size?

- W) Gel filtration chromatography
- X) SDS-PAGE
- Y) Circular dichroism
- Z) Density centrifugation

ANSWER: Y) Circular dichroism

VISUAL BONUS

15) BIOLOGY *Short Answer* Your next bonus is visual. The image provided shows a pedigree tracing the inheritance of a completely penetrant X-linked recessive trait amongst a family. Answer the following two questions regarding the pedigree:

- 1) What is the coefficient of relatedness between the individual in the third generation and her mother?
- 2) What is the probability that the person marked with a question mark exhibits the trait, given that they are female?

ANSWER: 1) 0.75; 2) 0.5

TOSS UP

16) CHEMISTRY *Short Answer* Saddle points on the potential energy surface of a chemical reaction correspond to what locally maximal energy states?

ANSWER: Transition States

BONUS

16) CHEMISTRY *Multiple Choice* What is the first mechanistic step in S_N1CB hydration of the complex ion penta-amine chlorido cobalt (III) by aqueous base?

- W) Dissociation of amine ligand
- X) Dissociation of chloride ligand
- Y) Association of hydroxide ligand
- Z) Deprotonation of amine ligand

ANSWER: Z) Deprotonation of amine ligand

TOSS UP

17) ENERGY *Short Answer* Researchers at the Condensed Matter Theory Group at MIT are studying high-temperature superconductivity. The minimum critical temperature for a superconductor to be considered as high-temperature is the boiling point of what element?

ANSWER: Nitrogen

VISUAL BONUS

17) ENERGY *Short Answer* Your next bonus is visual. Shown in the image is an example of a learning model researchers at CSAIL are working on. Answer the following two questions about this model using the image:

- 1) What type of machine learning model is shown?
- 2) While the input appears as a matrix, formally the input to this model is what type of multilinear map?

ANSWER: 1) Convolutional Neural Network; 2) Tensor (ACCEPT: 1) CNN, Neural Network)

TOSS UP

18) MATH *Short Answer* An algorithm with one positive integer input n has runtime $O(n^2)$ (read: *O n squared*) in big O notation. Identify all of the following three statements that could be true.

- 1) The runtime decreases as n increases when n is less than a hundred
- 2) The runtime goes to a constant as n goes to infinity
- 3) Whenever n increases by 1, the runtime doubles

ANSWER: 1 and 2

BONUS

18) MATH *Short Answer* Find the limit as x goes to infinity of the expression $-x^2 + x\sqrt{1+x^2}$ (read: *negative x squared plus x times the square root of the quantity one plus x squared*).

ANSWER: 0.5 (ACCEPT: $\frac{1}{2}$)

TOSS UP

19) EARTH AND SPACE *Multiple Choice* Which of the following types of cloud distribution would an Earth-like planet tidally locked around a star have?

- W) One large cloud facing the star
- X) One large cloud antipodal to the star
- Y) Scattered clouds facing the star
- Z) Scattered clouds antipodal to the star

ANSWER: W) One large cloud facing the star

BONUS

19) EARTH AND SPACE *Short Answer* Rank the following three circulation types in order of increasing rossby (*ROSS-bee*) number:

- 1) Cyclostrophic (*cyclo-strof-fik*) circulation in a tornado
- 2) Cyclonic circulation in a mid latitude cyclone
- 3) Large scale equatorial winds flowing across isobars

ANSWER: 2, 3, 1

TOSS UP

20) PHYSICS *Short Answer* Helium-II is a phase of helium that flows with no measurable viscosity. What state of matter does helium-II behave as?

ANSWER: Superfluid

BONUS

20) PHYSICS *Short Answer* The probability of a particle being in the excited state of a thermal two-state system is 20%. If the temperature of the system is doubled without changing the energy of each state, then to the nearest 5%, what is the new probability of a particle being in the excited state of the system?

ANSWER: 35%

TOSS UP

21) MATH *Short Answer* In acute triangle ABC with orthocenter H and circumcenter O, angle HAC is 30 degrees. What is the measure of angle OAB?

ANSWER: 30

VISUAL BONUS

21) MATH *Short Answer* Your next bonus is visual. The diagram depicts a fractal-like object composed of infinitely many rectangles such that the largest rectangle has a width of 1 unit and height of 0.5 units. Each rectangle has half the width and half the height of the previous rectangle, and every rectangle has an edge on the right side of the figure. Answer the following two questions regarding this fractal:

- 1) What is the perimeter of the figure?
- 2) What is the area of the figure?

ANSWER: 1) 5, 2) 2/3

TOSS UP

22) BIOLOGY *Short Answer* Floral genes AGAMOUS (*AAH-guh-mous*) and DEFICIENS (*duh-FE-shuns*) which have homeotic (*home-EE-ought-ic*) functions comparable to animal HOX (*hawks*) genes, are part of which gene family, named for a characteristic highly conserved sequence motif both genes contain?

ANSWER: MADS-BOX

BONUS

22) BIOLOGY *Short Answer* Identify all of the following three groups of insects that undergo incomplete metamorphosis:

- 1) Orthopterans
- 2) Hymenopterans
- 3) Dipterans

ANSWER: 1 only

TOSS UP

23) CHEMISTRY *Short Answer* When buckminsterfullerene is singly ionized, the icosahedral symmetry of the caged structure is broken. What effect is responsible for this electronic distortion?

ANSWER: Jahn-Teller

BONUS

23) CHEMISTRY *Multiple Choice* Which of the following best explains the source of the vibrant color produced when starch is added to a solution of iodine?

- W) Iodine accepts electrons from starch into a sigma star orbital
- X) Iodine accepts electrons from starch into a pi star orbital
- Y) Starch accepts electrons from iodine into a sigma star orbital
- Z) Starch accepts electrons from iodine into a pi star orbital

ANSWER: W) Iodine accepts electrons from starch into a sigma star orbital