

2023 MIT Science Bowl High School Invitational

Round 5

TOSS UP

1) MATH *Short Answer* What is the smallest positive integer that is equivalent to $1/9$ (read: *one over nine*) mod 13?

ANSWER: 3

BONUS

1) MATH *Multiple Choice* The product of all prime numbers less than 100 is P . What is the remainder when P is divided by 60?

W) 20

X) 30

Y) 40

Z) 50

ANSWER: X) 30

TOSS UP

2) EARTH AND SPACE *Multiple Choice* At what height in kilometers in the atmosphere would ozone concentrations be expected to be the highest?

- W) 5
- X) 10
- Y) 15
- Z) 20

ANSWER: Z) 20

BONUS

2) EARTH AND SPACE *Short Answer* Order the following currents in the North Pacific Gyre (*jai-ur*) from fastest to slowest:

- 1) California current
- 2) North Equatorial Current
- 3) Kuroshio Current

ANSWER: 3, 2, 1

TOSS UP

3) ENERGY *Short Answer* Researchers at the Horvitz lab at MIT are using *C. elegans* to investigate how the expression of genes affects animal development. A focus of this lab is seeing how the activation of proteases leads to apoptosis at different stages of development. What is the name given to these proteases?

ANSWER: Caspases

BONUS

3) ENERGY *Multiple Choice* The Chen Lab at MIT is investigating the mechanisms governing host-pathogen interactions, which MHC proteins are highly involved in. Which of the following incorrectly matches cell type to MHC class?

- W) B-cells and MHC class II
- X) Dendritic cells and MHC class II
- Y) Erythrocytes and MHC class I
- Z) Hepatocytes and MHC class I

ANSWER: Y) Erythrocytes and MHC class I

TOSS UP

4) CHEMISTRY *Short Answer* To the nearest whole number, what is the pH of a 1 molar solution of a monoprotic acid with a pKa of 6?

ANSWER: 3

BONUS

4) CHEMISTRY *Short Answer* To the nearest integer, what is the pH of a 0.1 molar solution of sodium acetate, given that the pKa of acetic acid is approximately 5?

ANSWER: 9

TOSS UP

5) PHYSICS *Short Answer* Two linear polarizers are placed 45 degrees from each other, and unpolarized light is passed through the polarizers. By what factor does the intensity of the light change?

ANSWER: 1/4 (ACCEPT: 0.25)

BONUS

5) PHYSICS *Multiple Choice* An AC voltage source is connected in series to a capacitor and an inductor. Which of the following best describes how the impedences of the capacitor and inductor will change if the frequency of the voltage source is doubled?

- W) The impedences of the capacitor and inductor will both double
- X) The impedance of the capacitor will double, while the impedance of the inductor will halve
- Y) The impedance of the capacitor will halve, while the impedance of the inductor will double
- Z) The impedences of the capacitor and inductor will both halve

ANSWER: Y) The impedance of the capacitor will halve, while the impedance of the inductor will double

TOSS UP

6) BIOLOGY *Short Answer* At the end of the light-dependent reactions of photosynthesis, the electrons derived from the splitting of water are ultimately found in what molecule?

ANSWER: NADPH

BONUS

6) BIOLOGY *Short Answer* In which phylum would one find the Portuguese man o' war, which possesses nematocysts that kill its prey?

ANSWER: Cnidaria

TOSS UP

7) EARTH AND SPACE *Multiple Choice* Mauna Loa, the second largest volcano in the world, is located in Hawaii and would be classified as which of the following types of volcanoes?

- W) Shield
- X) Cinder cone
- Y) Composite
- Z) Complex

ANSWER: W) Shield

BONUS

7) EARTH AND SPACE *Short Answer* What line separates a floating ice shelf from the land-based ice sheet that feeds into it?

ANSWER: Grounding line

TOSS UP

8) CHEMISTRY *Multiple Choice* Which of the following gases deviates the most from the ideal gas law at low temperatures?

- W) Helium
- X) Methane
- Y) Ammonia
- Z) Neon

ANSWER: Y) Ammonia

BONUS

8) CHEMISTRY *Short Answer* How many normal modes of vibration does dinitrogen have?

ANSWER: 1

TOSS UP

9) ENERGY *Multiple Choice* Researchers in the Gilliard Lab at MIT are doping polycyclic aromatic hydrocarbons with boron to improve their energy storage. Which of the following vacant atomic orbitals in boron facilitates the observed improvements?

- W) *s*
- X) *p*
- Y) *d*
- Z) *f*

ANSWER: X) *p*

BONUS

9) ENERGY *Short Answer* Researchers in the Kulik group at MIT are using machine learning to study the structure of complex materials formed by the linking of metal clusters to organic ligands. What is the general name for this class of materials?

ANSWER: Metal organic frameworks (ACCEPT: MOFs)

TOSS UP

10) BIOLOGY *Short Answer* Which second messenger created by the activity of phospholipase C (*FOSS-foe-LIE-pase C*) diffuses into the cytoplasm and activates calcium ion channels in the ER?

ANSWER: IP3 (ACCEPT: Inositol trisphosphate, Inositol 1,4,5-trisphosphate)

BONUS

10) BIOLOGY *Multiple Choice* Which of the following is true about the lagging strand in DNA replication?

- W) It is synthesized in a 5' (read: *5 prime*) to 3' (read: *3 prime*) direction and is discontinuous
- X) It is synthesized in a 5' to 3' direction and is continuous
- Y) It is synthesized in a 3' to 5' direction and is discontinuous
- Z) It is synthesized in a 5' to 3' direction and is discontinuous

ANSWER: W) It is synthesized in a 5' to 3' direction and is discontinuous

TOSS UP

11) MATH *Short Answer* In a calculus class, 30 out of 36 students got an average of 72% on the exam. The rest of the students got an average of 78% on the exam. What is the average of the entire class?

ANSWER: 73

BONUS

11) MATH *Short Answer* The largest real root to the quadratic equation $x^2 - 20x = 2023$ (read: *x squared minus twenty x equals 2023*) can be written as $a + \sqrt{b}$ (read: *a plus the square root of b*) for positive integers a and b . What is the value of $a + b$ (read: *a plus b*)?

ANSWER: 2133

TOSS UP

12) PHYSICS *Short Answer* The proton consists of quarks bound together by the exchange of what virtual particles?

ANSWER: Gluons

BONUS

12) PHYSICS *Multiple Choice* Water is flowing through a pipe. The velocity of the water suddenly doubles while temperature remains the same. Which of the following values of the water must necessarily increase?

- W) Molar heat capacity
- X) Density
- Y) Reynolds number
- Z) Speed of sound

ANSWER: Y) Reynolds number

TOSS UP

13) BIOLOGY *Multiple Choice* What type of ecological dispersion pattern do starfish found in tide pools typically follow?

- W) Clumped
- X) Uniform
- Y) Radial
- Z) Random

ANSWER: W) Clumped

BONUS

13) BIOLOGY *Short Answer* Identify all of the following three descriptions that is a true difference between animal and plant development:

- 1) Plants primarily grow in height by elongation of cells while animals primarily grow by cell division,
- 2) Juvenile and adult forms can be found within one plant while animals grow from juvenile to adult forms,
- 3) Plants undergo determinate growth while animals undergo indeterminate growth.

ANSWER: 1 and 2

TOSS UP

14) MATH *Multiple Choice* Which of the following is always true of matrix multiplication?

- W) Commutative and associative
- X) Commutative but not associative
- Y) Associative but not commutative
- Z) Not Commutative and not associative

ANSWER: Y) Associative but not commutative

BONUS

14) MATH *Short Answer* How many non-congruent triangles are there with sides of integer length having at least one side of length 5 units and having no side longer than 5 units?

ANSWER: 9

TOSS UP

15) CHEMISTRY *Short Answer* At what point on the phase diagram of water are ice, liquid water, and water vapor in equilibrium inside a closed container?

ANSWER: Triple point

BONUS

15) CHEMISTRY *Multiple Choice* Which of the following acids is the strongest?

- W) Acetic acid
- X) Fluoroacetic acid
- Y) Difluoroacetic acid
- Z) Trifluoroacetic acid

ANSWER: Z) Trifluoroacetic acid

TOSS UP

16) EARTH AND SPACE *Short Answer* Order the following martian time periods from earliest to latest.

- 1) Amazonian
- 2) Noachian (*no-ache-ian*)
- 3) Hesperian

ANSWER: 2,3,1

BONUS

16) EARTH AND SPACE *Multiple Choice* What is the smallest constellation by area assigned by the International Astronomical Union on the celestial sphere?

- W) Crux
- X) Ursa Major
- Y) Gemini
- Z) Ursa Minor

ANSWER: W) Crux

TOSS UP

17) PHYSICS *Short Answer* A carnot refrigerator connects two thermal reservoirs of temperatures 350 kelvin and 250 kelvin. If 50 joules of work are expended, what is the maximum energy, in joules, that the refrigerator can extract from the cold reservoir?

ANSWER: 125 joules

BONUS

17) PHYSICS *Multiple Choice* In joules per mole kelvin, which of the following values is closest to the molar specific heat of copper metal at room temperature?

- W) 3
- X) 8
- Y) 15
- Z) 25

ANSWER: Z) 25

TOSS UP

18) ENERGY *Multiple Choice* Researchers in the Oliver group at MIT are studying the effects of tunneling on quantum computers. Which of the following best describes the relationship between the probability of quantum tunneling through a tall potential barrier and the width of the barrier?

- W) Linear
- X) Quadratic
- Y) Logarithmic
- Z) Exponential

ANSWER: Z) Exponential

BONUS

18) ENERGY *Short Answer* Researchers in the Taylor group at MIT are studying relativistic interactions between particles. Identify all of the following 3 quantities that are relativistically invariant:

- 1) Charge
- 2) Electric field strength
- 3) Magnetic field strength

ANSWER: 1 only

TOSS UP

19) MATH *Short Answer* A triangle has side lengths that are all prime numbers and its perimeter is prime as well. What is the smallest possible perimeter of the triangle?

ANSWER: 7

BONUS

19) MATH *Short Answer* Maisy chooses 2 different integers without replacement from 1 through 20 inclusive at random. What is the probability that both numbers are prime?

ANSWER: 14/95

TOSS UP

20) BIOLOGY *Multiple Choice* On Mount Jonah, the range of a particular pine tree species initially extends from the tree line to the base of the mountain. Over time, a new tree species outcompetes the pine until its range only encompasses the higher altitudes of the mountain. Assuming constant environmental conditions across time, which of the following statements is true regarding the original pine?

- W) Its fundamental niche is smaller than its realized niche
- X) Its fundamental niche is larger than its realized niche
- Y) Its fundamental niche and its realized niche are the same
- Z) No meaningful conclusion about its fundamental and realized niches can be drawn

ANSWER: X) Its fundamental niche is larger than its realized niche

BONUS

20) BIOLOGY *Short Answer* Identify all of the following four statements that are true of protostome development:

- 1) The blastopore develops into the mouth.
- 2) All protostomes lack a coelom.
- 3) Protostomes display radial cleavage.
- 4) Starfish are examples of protostomes.

ANSWER: 1 only

TOSS UP

21) CHEMISTRY *Short Answer* What is the equilibrium constant for the reaction of hydronium with hydroxide to form two molecules of water?

ANSWER: 10^{14}

BONUS

21) CHEMISTRY *Short Answer* What is the ratio of the energy released by a photon undergoing a transition from $n = 4$ to $n = 1$ versus $n = 5$ to $n = 1$ in a hydrogen atom?

ANSWER: 125/128

TOSS UP

22) PHYSICS *Short Answer* An airplane is traveling through air at twice the speed of sound. What is the angle, in degrees, that the pressure wave of the airplane makes with the airplanes path?

ANSWER: 30 degrees

BONUS

22) PHYSICS *Short Answer* A box is sitting on a horizontal table inside a car. The car is driving at 10 meters per second in a circle of radius 20 meters. To one significant figure, what is the minimum coefficient of static friction between the box and the table, so that the box does not slip on the table?

ANSWER: 0.5

TOSS UP

23) EARTH AND SPACE *Short Answer* Identify all of the following three exoplanet detection techniques that will have a bias toward gas giants compared to terrestrial planets:

- 1) Radial velocity
- 2) Transit photometry
- 3) Direct imaging

ANSWER: 3, 2, 1

BONUS

23) EARTH AND SPACE *Short Answer* An observer on Earth's surface sees an annular solar eclipse. What region of the moon's shadow is the observer currently in?

ANSWER: Antumbra