

2024 MIT Science Bowl High School Invitational

Round 10

TOSS UP

1) EARTH AND SPACE *Short Answer* Identify all of the following THREE factors that would favor the formation of a whaleback over a traditional roche moutonnée:

- 1) Higher glacial velocity
- 2) Lower glacial thickness
- 3) Higher bedrock porosity

ANSWER: None

BONUS

1) EARTH AND SPACE *Multiple Choice* Which of the following statements is NOT true regarding Karst Topography?

- W) Stalactites often display soda straw structure
- X) The Ghyben-Herzberg (*GAI-ben HERZ-berg*) equation relates cavern size to water table depth
- Y) Tower karst structures are often composed of limestone
- Z) Oxidation of sulfides in karst regions may create gypsum

ANSWER: X) The Ghyben-Herzberg equation relates cavern size to water table depth

TOSS UP

2) PHYSICS *Multiple Choice* Lightbulb L2 and L3 are placed in parallel, and the result is placed in series with lightbulb L1 and a voltage source. All three lightbulbs are identical. Which of the following best describes the result if L3 is removed?

- W) Both L1 and L2 get brighter
- X) L1 gets brighter and L2 gets dimmer
- Y) L1 gets dimmer and L2 gets brighter
- Z) Both L1 and L2 get dimmer

ANSWER: Y) L1 gets dimmer and L2 gets brighter

BONUS

2) PHYSICS *Short Answer* Steph is pouring milk onto the ground at a constant rate of five kilograms per second. The milk exits at a distance of 80 centimeters above the floor and has an initial velocity of three meters per second directed horizontally. Expressed in Newtons and rounded to the nearest integer, find the magnitude of the force that the milk stream exerts on the ground, neglecting air resistance and assuming that its collision with the ground only cancels out the vertical component of the milk's velocity.

ANSWER: 20

TOSS UP

3) MATH *Short Answer* Alice runs $1m/s$ (read: *one meter per second*) faster than Bob. In a 2000 meter race, Alice finishes the race just as Bob starts his fifth lap of the 400 meter track. How many seconds did Alice take to finish the race? Assume Alice and Bob run at constant speeds.

ANSWER: 400 (ACCEPT: 400s, 6min 40s)

BONUS

3) MATH *Short Answer* To the nearest degree, what is the arctangent of 2 plus the arctangent of 3?

ANSWER: 135

TOSS UP

4) BIOLOGY *Multiple Choice* Which of the following is NOT a reason why DNA is generally used for long-term storage of genetic information rather than RNA?

- W) RNA introduces errors when it catalyzes its own replication
- X) Products of cytosine deamination are indistinguishable from regular uracil
- Y) Ribose contains reactive 2' (*two prime*) hydroxyl groups
- Z) Wobble base pairing stabilizes RNA mutations

ANSWER: W) RNA introduces errors when it catalyzes its own replication

BONUS

4) BIOLOGY *Short Answer* Identify all of the following three statements that accurately match a form of DNA repair with one of its characteristics:

- 1) Base excision: fixes damage from ultraviolet radiation;
- 2) Nucleotide excision: removes hypoxanthine (*hi-poe-ZAN-theen*) and uracil (*your-ah-sill*);
- 3) Homologous recombination: can repair double-stranded breaks.

ANSWER: 3 only

TOSS UP

5) ENERGY *Multiple Choice* Researchers at the Gehring Lab recently discovered genetic imprinting mechanisms in water lilies, which are commonly classified as basal angiosperms. Which of the following characteristics of water lilies distinguishes them from non-basal angiosperms?

- W) Their roots are lined with filamentous hairs
- X) Some of their cells are multinucleate
- Y) They lack a vascular cambium
- Z) They possess a modified tissue called aerenchyma (*air-ren-kai-ma*)

ANSWER: Y) They lack a vascular cambium

BONUS

5) ENERGY *Short Answer* MIT Scientists at the White Lab are using various methods to sequence the primary structure of proteins. Identify all of the following three methods that are able to accomplish this:

- 1) ATAC-Seq
- 2) MALDI-TOF
- 3) Tandem MS

ANSWER: 2 and 3

TOSS UP

6) CHEMISTRY *Multiple Choice* Which of the following molecules is the least polar?

- W) Ammonia
- X) Nitrogen trifluoride
- Y) Nitrogen trichloride
- Z) Nitrogen tribromide

ANSWER: X) Nitrogen trifluoride

BONUS

6) CHEMISTRY *Short Answer* The lead-acid battery used in cars today utilizes the reaction $Pb + PbO_2 + 2 H_2SO_4 \longrightarrow 2 PbSO_4 + 2 H_2O$ (*P B plus P B O two plus two H two S O four yields two P B S O four plus two H two O*). Identify all of the following three statements that are true as the battery discharges:

- 1) The voltage of the cell decreases
- 2) The density of the electrolyte decreases
- 3) The mass of at least one of the electrodes decreases

ANSWER: 1 and 2

TOSS UP

7) ENERGY *Short Answer* Researchers at MIT's Kulik Lab are using computational chemistry to design efficient organic syntheses from alkenes (*al-KEENs*) and imines (*ih-meen-s*) that have been hydroxylated at their nitrogen atom. What specific functional group are these imines an example of?

ANSWER: Oximes

BONUS

7) ENERGY *Multiple Choice* Researchers at MIT's Schwarzman College of Computing are studying algorithmic complexity in quantum computing. A function with one parameter n performs an operation with $\theta(n^2)$ (read: *big theta n squared*) time complexity and then makes two recursive calls to itself, each with parameters of $n/2$, unless n is less than 1, at which point it stops. What is the overall big theta time complexity of the function?

- W) n^2
- X) $n^2 \log n$
- Y) n^3
- Z) $n^3 \log n$

ANSWER: W) n^2

TOSS UP

8) CHEMISTRY *Multiple Choice* Which of the following types of electronic transition produces electromagnetic radiation without conserving spin?

- W) Atomic fluorescence
- X) Vacuum fluorescence
- Y) Persistent phosphorescence
- Z) Triplet phosphorescence

ANSWER: Z) Triplet phosphorescence

BONUS

8) CHEMISTRY *Multiple Choice* Alec performs a thin-layer chromatography experiment using silica gel as the stationary phase, and a 90 to 10 mixture of hexanes and ethyl acetate as the mobile phase. Which of the following compounds would be expected to have the highest retention factor in this experiment?

- W) Phenol
- X) Benzyl alcohol
- Y) Benzaldehyde
- Z) Benzoic acid

ANSWER: Y) Benzaldehyde

TOSS UP

9) BIOLOGY *Multiple Choice* The lengthening and narrowing of the primitive streak over the course of chick gastrulation occurs primarily due to which of the following morphogenetic movements?

- W) Invagination
- X) Ingression
- Y) Involution
- Z) Convergent extension

ANSWER: Z) Convergent extension

BONUS

9) BIOLOGY *Short Answer* Damian is practicing blood smear analysis of birds and he notices interesting things about their blood cells. Identify all of the following three things that he would notice:

- 1) They have enucleated erythrocytes (*eh-ry-throw-sites*)
- 2) They have biconcave erythrocytes
- 3) They have B cells.

ANSWER: 3 only

TOSS UP

10) EARTH AND SPACE *Multiple Choice* Which of the following is indicative of planetary formation around a star?

- W) Stellar flare activity
- X) Gaps in the circumstellar disk
- Y) Metal lines in the star's spectrum
- Z) Rapid star rotation

ANSWER: X) Gaps in the circumstellar disk

BONUS

10) EARTH AND SPACE *Short Answer* Identify all of the following three quantities that could be used for the vertical axis of a HR diagram:

- 1) Magnitude
- 2) Color
- 3) Luminosity

ANSWER: 1 and 3

TOSS UP

11) MATH *Short Answer* There are 168 primes below the number 1000. How many of them are one less than a perfect square?

ANSWER: 1

BONUS

11) MATH *Short Answer* If $f'(x) = |2x - 4|$ (read: *f prime of x equals the absolute value of open parentheses 2 x minus 4 close parentheses*), then what is the value of $f(3) - f(-3)$ (read: *f of 3 minus f of negative 3*)?

ANSWER: 26

TOSS UP

12) PHYSICS *Multiple Choice* A turtle is sitting 2 meters away from a convex lens that has a focal length of 3 meters. Which of the following best describes the image of the turtle?

- W) Virtual and upright
- X) Virtual and inverted
- Y) Real and upright
- Z) Real and inverted

ANSWER: W) Virtual and upright

BONUS

12) PHYSICS *Short Answer* Alice and Bob are crossing a river that is 50 meters wide starting from the same location. The river flows at a speed of 10 meters per second in the direction parallel to its banks. Alice can travel at a speed of 18 meters per second in still water. Bob can only travel at a speed of 8 meters per second in still water. In meters, what is the final displacement between Alice and Bob if both minimize their displacement parallel to the river?

ANSWER: 37.5

TOSS UP

13) ENERGY *Multiple Choice* Researchers at MIT are studying the fractional quantum Hall effect, which expands the classical Hall effect to mesoscopic length scales. Which of the following statements is NOT true about the classical Hall effect?

- W) The Hall voltage is directly proportional to the strength of the applied magnetic field
- X) A Hall effect sensor can not differentiate between n-type and p-type semiconductors
- Y) The Hall voltage pushes charge carriers perpendicular to the magnetic field
- Z) Current carrying electrons and holes are deflected to opposite sides of the plate

ANSWER: X) A Hall effect sensor can not differentiate between n-type and p-type semiconductors

BONUS

13) ENERGY *Multiple Choice* Researchers in MIT's Condensed Matter Theory Group are studying how the number of particles affects thermodynamics of an exotic system. What related variable is the thermodynamic conjugate of the number of particles?

- W) Enthalpy
- X) Entropy
- Y) Chemical potential
- Z) Volume

ANSWER: Y) Chemical potential

TOSS UP

14) PHYSICS *Short Answer* A ray of light passing through air is incident upon a fluid at an angle of 45 degrees to the vertical. If the ray of light is refracted through the fluid at an angle of 30 degrees to the vertical, then to one significant figure, what is the ratio of the speed of light in the fluid to the speed of light in air?

ANSWER: 0.7

BONUS

14) PHYSICS *Multiple Choice* An underdamped harmonic oscillator has a time constant of one second. Which of the following, in seconds, is closest to the amount of time it will take for the oscillations of the system to reach 0.1% of their initial amplitude?

- W) 1
- X) 10
- Y) 100
- Z) 1000

ANSWER: X) 10

TOSS UP

15) EARTH AND SPACE *Multiple Choice* Which of the following sets of conditions would lead to the worst air pollution in a city?

- W) Thermal inversion, weak winds aloft
- X) Thermal inversion, strong winds aloft
- Y) Normal thermal conditions, weak winds aloft
- Z) Normal thermal conditions, strong winds aloft

ANSWER: W) Thermal inversion, weak winds aloft

BONUS

15) EARTH AND SPACE *Short Answer* Identify all of the following three statements that are reasons why retrograde metamorphism is less commonly observed than prograde metamorphism:

- 1) Metamorphic reactions are kinetically unfavorable at lower temperatures
- 2) Devolatilization (*de-vo-la-tih-lih-ZAY-shun*) during prior reactions removes components necessary for the formation of hydrous minerals
- 3) Devolatilization during prior reactions removes fluids that facilitate diffusion

ANSWER: All

TOSS UP

16) BIOLOGY *Multiple Choice* Which of the following is accurate regarding miRNA?

- W) They are transcribed from centromeric (*cent-ro-mare-ic*) DNA
- X) They are at least several hundred base pairs in length
- Y) They are always exogenous (*ex-oh-jen-us*)
- Z) They do not require perfect mRNA matches

ANSWER: Z) They do not require perfect mRNA matches

BONUS

16) BIOLOGY *Short Answer* Order the following three phyla of Archaeplastids from most to least inclusive:

- 1) Plantae
- 2) Streptophyta
- 3) Viridaeplantae

ANSWER: 3, 2, 1

TOSS UP

17) CHEMISTRY *Short Answer* Some commercial refrigerators operate on the Hampson-Linde cycle, which uses regenerative cooling to liquefy gases. What effect is exploited in the Hampson-Linde cycle, in which a temperature change accompanies the expansion of a gas?

ANSWER: Joule-Thomson effect (ACCEPT: Joule-Kelvin effect, throttling)

BONUS

17) CHEMISTRY *Multiple Choice* In crystal field theory, complexes may be considered high-spin or low-spin depending on the order of orbital filling. However, low-spin tetrahedral complexes are rarely observed. Which of the following best explains why?

- W) Ligands coordinated to a tetrahedral center are spaced too far apart for efficient electron pairing
- X) In tetrahedral complexes, the field splitting parameter is too small to outweigh electron-electron repulsion within orbitals
- Y) Low-spin tetrahedral complexes are unstable and rapidly dimerize to form hexavalent centers
- Z) Strong field ligands that would produce low-spin complexes can only form square planar structures

ANSWER: X) In tetrahedral complexes, the field splitting parameter is too small to outweigh electron-electron repulsion within orbitals

TOSS UP

18) MATH *Short Answer* A sequence starts with 1, and each subsequent term is the sum of all previous terms. What is the eighth term of this sequence?

ANSWER: 64

BONUS

18) MATH *Multiple Choice* Points A and B are distance 6 apart. The locus of points P such that the sum of distances PA and PB is 10 traces a shape. What is the area of this shape?

- W) 5π
- X) 10π
- Y) 15π
- Z) 20π

ANSWER: Z) 20π

TOSS UP

19) CHEMISTRY *Multiple Choice* Which of the following combinations of signs represents the change of enthalpy and change of entropy, respectively, for the Diels-Alder (*deelz-ahl-der*) reaction, a ring-forming reaction usually performed at cold temperatures?

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

ANSWER: Z) Negative, Negative

BONUS

19) CHEMISTRY *Short Answer* Identify all of the following three statements that are true about metals in solid-state chemistry:

- 1) The valence and conduction bands of a metal overlap
- 2) The resistance of a metal increases with temperature
- 3) The residual entropy of a metallic crystal approaches zero

ANSWER: 1 and 2

TOSS UP

20) EARTH AND SPACE *Multiple Choice* Which of the following areas of the Milky Way galaxy contains the youngest stars?

- W) Halo
- X) Bulge
- Y) Spiral arms
- Z) Galactic disk

ANSWER: Y) Spiral arms

BONUS

20) EARTH AND SPACE *Multiple Choice* The Roche limit of a spherical satellite is often approximated by assuming the satellite is a rigid body. Which of the following best describes this approximation's error and its primary source?

- W) This is an overestimate primarily because structural deformation of the satellite is ignored
- X) This is an overestimate primarily because internal rotational forces of the satellite are ignored
- Y) This is an underestimate primarily because structural deformation of the satellite is ignored
- Z) This is an underestimate primarily because internal rotational forces of the satellite are ignored

ANSWER: Y) This is an underestimate primarily because structural deformation of the satellite is ignored

TOSS UP

21) PHYSICS *Short Answer* What term describes the shortest path between two events that generalizes the concept of straight lines to curved spacetimes in general relativity?

ANSWER: Geodesic

BONUS

21) PHYSICS *Short Answer* A yoyo can be modeled as a solid cylinder with a massless string wrapped around it. If it is dropped from rest at a height of 1.2 meters and the string doesn't slip, to the nearest meter per second, what is the linear velocity of the yoyo right before it hits the ground?

ANSWER: 4

TOSS UP

22) BIOLOGY *Short Answer* In addition to serving as the substance released to attract mycorrhizal (*my-co-rye-zul*) associations, which group of plant hormones, whose secretion is promoted by auxin, is responsible for inhibiting axillary bud growth?

ANSWER: Strigolactones (*stree-go-lac-tones*)

BONUS

22) BIOLOGY *Short Answer* Identify all of the following three types of coated vesicles involved in transport away from the Golgi apparatus:

- 1) Clathrin-coated
- 2) COP I (read: *COP one*)
- 3) COP II (read: *COP two*)

ANSWER: 1 and 2

TOSS UP

23) MATH *Short Answer* In base 7, the five digit number $2024x$ (read: *two zero two four x*) is a multiple of 8. What is the value of the digit x ?

ANSWER: 0

BONUS

23) MATH *Multiple Choice* If n is a positive integer, which of the following cannot be a possible value of the totient of n ?

- W) 42
- X) 46
- Y) 50
- Z) 54

ANSWER: Y) 50