2024 MIT Science Bowl High School Invitational

Round 6

TOSS UP

1) PHYSICS *Multiple Choice* A satellite is in an elliptical orbit around Earth. A small, instantaneous impulse can be applied to the satellite in any direction and in any position along its orbit. What is the optimal impulse to maximize the period of the resulting orbit of the satellite?

W) At the perigee, along the velocity of the satellite
X) At the perigee, against the velocity of the satellite
Y) At the apogee, along the velocity of the satellite
Z) At the apogee, against the velocity of the satellite

ANSWER: W) At the perigee, along the velocity of the satellite

BONUS

1) PHYSICS *Multiple Choice* The molecules of an ideal gas in a closed container collide with the walls of the container at a frequency F. The gas then expands at constant pressure such that the temperature of the gas and the volume of the container both double. In terms of F, what is the new collision frequency of the ideal gas against the walls of the container?

W) $F/2$
X) $F/\sqrt{2}$
Y) $F\sqrt{2}$
Z) $2F$

ANSWER: X) $F/\sqrt{2}$

TOSS UP

2) EARTH AND SPACE *Multiple Choice* Which of the following objects would be most likely to display a titanium oxide line in its spectrum?

W) Wolf-Rayet star
X) Planetary nebula
Y) Red dwarf
Z) White dwarf

ANSWER: Y) Red dwarf

BONUS

2) EARTH AND SPACE *Short Answer* Rank the following three components of the ophiolite (read: *Oaf-ee-oh-light*) structure from bottom-most to top-most:

1) Pillow Lavas
2) Layered Peridotite (read: *Per-ih-doh-tight*)
3) Layered Gabbro

ANSWER: $2, 3, 1$

TOSS UP

3) ENERGY *Multiple Choice* Researchers in the Surendranath group at MIT are researching methods to reduce the carbon footprint of producing phosphorous. Which of the following allotropes of phosphorous were they producing, whose molecules are individual unlinked tetrahedra of phosphorous atoms?

W) Red phosphorous
X) Black phosphorous
Y) Violet phosphorous
Z) White phosphorous

ANSWER: Z) White phosphorous

BONUS

3) ENERGY *Multiple Choice* Researchers at the Laub Lab are studying proteobacterial classification. Which of the following subgroups is heliobacter in?

W) Alpha
X) Beta
Y) Delta
Z) Epsilon

ANSWER: Z) Epsilon

TOSS UP

4) CHEMISTRY *Short Answer* Rank the following three oxides by increasing basicity of the solution formed when added to water:

1) Aluminum oxide
2) Calcium oxide
3) Sulfur dioxide

ANSWER: 3, 1, 2

BONUS

4) CHEMISTRY *Short Answer* Glucose is known to commonly exist in both a straight-chain form and a ring form. The relationship between these two forms is best described as what special types of structural isomers that readily interconvert?

ANSWER: Tautomers

TOSS UP

5) BIOLOGY *Short Answer* Identify all of the following three species that have a true coelom (read: *ciel-uhm*):

1) Honey bee
2) Jellyfish
3) C. elegans.

ANSWER: 1 only

BONUS

5) BIOLOGY *Short Answer* Pompe's (read: *Pomp-s*) disease is almost always fatal before reproductive age and has a prevalence of roughly one in four hundred. Individuals are equally likely to be affected regardless of sex. Assuming short-term Hardy-Weinberg equilibrium and expressing your answer as a fraction in simplest form, what fraction of the population are heterozygotes?

ANSWER: 19/200

TOSS UP

6) MATH *Short Answer* To the nearest whole number, what is the harmonic mean of 1 and 2024?

ANSWER: 2

BONUS

6) MATH *Short Answer* Vigyan flips an unfair coin twice. Given that at least one coin was heads, the probability that both were heads is one-fifth. What is the probability that a single flip of his coin is heads?

ANSWER: $\frac{1}{3}$

TOSS UP

7) BIOLOGY *Multiple Choice* In which of the following sections of a kidney would you find the highest osmolarity (*OZ-mo-LARE-ity*)?

W) Proximal tubule of cortical nephron (*NEFF-ron*)
X) Loop of Henle (*HEN-lee*) of cortical nephron
Y) Proximal tubule of juxtaglomerular (*JUCKS-ta-glow-MAIR-yoo-ler*) nephron
Z) Loop of Henle of juxtaglomerular nephron

ANSWER: Z) Loop of Henle of juxtaglomerular nephron

BONUS

7) BIOLOGY *Short Answer* Variation in beak size between populations of Galapagos finches is an example of what phenomenon, where particular traits are more divergent in sympatric populations than in allopatric populations of the same species?

ANSWER: Character displacement

TOSS UP

8) CHEMISTRY *Multiple Choice* The central atom in the triiodide anion, I_3^- (*i three one minus*), exhibits which of the following types of electron geometry?

W) Linear
X) Tetrahedral
Y) Trigonal bypyramidal
Z) Octahedral

ANSWER: Y) Trigonal bipyramidal

BONUS

8) CHEMISTRY *Short Answer* While tin (IV)(read: *four*) chloride is stable at room temperature, lead (IV) chloride can only be stored at cryogenic temperatures. What effect, which describes the difficulty of ionizing s electrons of heavier main group elements, accounts for this observation?

ANSWER: Inert pair effect (ACCEPT: Lazy pair effect)

TOSS UP

9) ENERGY *Multiple Choice* Researchers at MIT's Statistics and Data Science center applied the central limit theorem to model probability distributions that grow over time. For example, suppose every millisecond a point is drawn independently from a normal distribution and added to a list. Which of the following is not true about this process according to the central limit theorem?

W) The mean of a point drawn does not change over time
X) The variance of a point drawn does not change over time
Y) The mean of the list's average changes over time
Z) The variance of the list's average changes over time

ANSWER: Y) The mean of the list's average changes over time

BONUS

9) ENERGY *Short Answer* Researchers at MIT's Kulik Lab are using computational chemistry to design efficient syntheses of azetidines (*uh-ZET-ideens*), which contain four-membered heterocycles and are potential drug compounds. Another common example of a four-membered heterocycle is penicillin's beta-lactam ring, which is a cyclic form of what functional group?

ANSWER: Amide

TOSS UP

10) EARTH AND SPACE *Multiple Choice* Which of the following does NOT correctly pair a metamorphic rock with its protolith?

W) Marble, limestone
X) Soapstone, peridotite
Y) Slate, shale
Z) Quartzite, breccia (*BRECK-yuh*)

ANSWER: Z) Quartzite, breccia (*BRECK-yuh*)

BONUS

10) EARTH AND SPACE *Short Answer* Outgassing of water from Enceladus (read: *En-cell-ah-duh-s*) replenishes which ring of Saturn?

ANSWER: E

TOSS UP

11) MATH *Short Answer* The circumradius of a right triangle has length 5, and one of the legs of the triangle has length 6. What is the area of the triangle?

ANSWER: 24

BONUS

11) MATH *Short Answer* One of the roots of the cubic polynomial $x^3 + ax^2 + bx - 2$ (read: *x cubed plus a times x squared plus b times x minus 2*) is $-1 - \sqrt{2}$. If both a and b are integers, what is the value of a?

ANSWER: 4

TOSS UP

12) PHYSICS *Short Answer* In special relativity, transformations between reference frames are calculated via the Lorentz transformation. What similar transformation in classical mechanics provides a close approximation to Lorentzian relativity at non-relativistic speeds?

ANSWER: Gallilean

BONUS

12) PHYSICS *Short Answer* Identify all of the following three physical fields that are divergence-free:

1) Magnetic field
2) Electric field
3) Gravitational field of a point mass

ANSWER: 1 only

TOSS UP

13) BIOLOGY *Multiple Choice* Karon is trying to determine the viral load of different viruses infecting humans. Which of the following techniques would he use to quantify the viral load?

W) Sanger sequencing
X) Flow cytometry
Y) qPCR
Z) Western blot

ANSWER: Y) qPCR

BONUS

13) BIOLOGY *Multiple Choice* Damien is studying biosystematics, but he has some trouble classifying chordates. Which of the following statements is false concerning chordates?

W) All vertebrates are chordates
X) All gnathostomes are craniates
Y) All mammals are tetrapods
Z) All tetrapods are amniotes

ANSWER: Z) All tetrapods are amniotes

TOSS UP

14) CHEMISTRY *Short Answer* The rate of effusion of a gas is proportional to what power of its absolute temperature?

ANSWER: 0.5 (ACCEPT: One-half)

BONUS

14) CHEMISTRY *Multiple Choice* Which of the following gas-phase reactions is the least likely to occur in one step, without the formation of any intermediates?

W) $H_2 + 2\,ICl \longrightarrow I_2 + 2\,HCl$ (*H two plus two i C L yields two i two plus two H C L*)
X) $CH_3Br + OH^- \longrightarrow CH_3OH + Br^-$ (*C H three B R plus O H minus yields C H three O H plus B R minus*)
Y) $2\,NO \longrightarrow N_2O_2$ (*two N O yields N two O two*)
Z) $N_2O_4 \longrightarrow 2\,NO_2$ (*N two O four yields two N O two*)

ANSWER: W) $H_2 + 2\,ICl \longrightarrow I_2 + 2\,HCl$ (*H two plus two i c l yields two i two plus two h c L*)

TOSS UP

15) PHYSICS *Short Answer* A planet's density is a function of the distance r from the center of the planet. If the gravitational field has constant magnitude everywhere inside the planet, the density of the planet is proportional to r raised to what power?

ANSWER: -1

BONUS

15) PHYSICS *Multiple Choice* Which of the following experiments demonstrated the wave nature of electrons?

W) Franck Hertz experiment
X) Stern Gerlach experiment
Y) Davisson Germer experiment
Z) Elitzur Vaidman experiment (read: *Elee-tsur Vay-d-man*)

ANSWER: Y) Davisson Germer experiment

TOSS UP

16) ENERGY *Short Answer* Researchers in the Bartel Lab at MIT are researching microRNA. If the nitrogen bases of a group of nucleotides included 2 adenines, 2 guanines, 1 cytosine, and 1 uracil, how many different RNA sequences could be produced from permuting the 6 nucleotides?

ANSWER: 180

BONUS

16) ENERGY *Multiple Choice* Researchers at MIT and Caltech's LIGO collaboration are estimating parameters of gravitaitonal-wave events using Monte Carlo methods. Which of the following is true about Monte Carlo methods?

W) They do not require a specific domain of possible inputs
X) They rely on repeated random sampling to obtain numerical results
Y) They can be used on chaotic events such as the three-body problem
Z) They are methods whose computational cost cannot be affected by parallel computing

ANSWER: X) They rely on repeated random sampling to obtain numerical results

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TOSS UP

17) EARTH AND SPACE *Multiple Choice* Which of the following classes of galaxies possesses the most tightly wrapped spiral arms?

W) S0
X) E0
Y) Sa
Z) SBc

ANSWER: Y) Sa

BONUS

17) EARTH AND SPACE *Multiple Choice* Tim is walking back to his dorm from a Christmas eve party, and observes that the phase of the moon is the third quarter. Which of the following is a possible date of the next solar eclipse?

W) December 31st
X) January 7th
Y) January 14th
Z) January 21st

ANSWER: W) December 31st

TOSS UP

18) MATH *Short Answer* If a corner of a fair six sided die is picked at random, what is the expected value of the sum on the three adjacent faces?

ANSWER: 21/2 (ACCEPT: 10.5)

BONUS

18) MATH *Short Answer* Ellie woke up late and is speeding to the airport. If she travels at 90 miles per hour, she will arrive ten minutes earlier than if she obeyed the speed limit of 80 miles per hour. In miles, how far away is the airport?

ANSWER: 120

TOSS UP

19) CHEMISTRY *Multiple Choice* For which of the following substances is the enthalpy of formation not zero?

W) Oxygen gas
X) Octasulfur solid
Y) Chlorine gas
Z) Bromine gas

ANSWER: Z) Bromine gas

BONUS

19) CHEMISTRY *Short Answer* The equilibrium constant for the reaction $H_2 + I_2 \longrightarrow 2\,HI$ (Read as: hydrogen gas plus iodine gas yields two hydrogen iodide gas) is 64 at 330 K. When 1 atmosphere of hydrogen iodide gas is injected into a sealed container and allowed to reach equilibrium, what is the partial pressure of hydrogen gas to one significant figure and in atmospheres?

ANSWER: 0.1

TOSS UP

20) PHYSICS *Short Answer* Jessica randomly chooses a meter-stick from a factory and measures its length to be 100 centimeters with an absolute error of 1 centimeter. If Jessica measures 100 meter-sticks from the factory and finds the length of a meter-stick by averaging her measurements, what is the new absolute error in Jessica's measurement?

ANSWER: 0.1

BONUS

20) PHYSICS *Short Answer* A 5 kilogram object is flung into the air and lands on the hood of a nearby car. If the maximal height of the object was 20 meters above the car's hood, and the car's hood stopped the object in 0.4 seconds, what was the average force exerted on the car's hood, in newtons and to one significant figure?

ANSWER: 300

TOSS UP

21) EARTH AND SPACE *Short Answer* Nor'easters are a class of cyclones whose formation has been enhanced by what major current?

ANSWER: Gulf Stream

BONUS

21) EARTH AND SPACE *Multiple Choice* Which of the following indicies would be the most appropriate to use in quantifying vegetation levels in a temperate rainforest?

W) RGB
X) CIR
Y) NDWI
Z) NDVI

ANSWER: Z) NDVI

TOSS UP

22) MATH *Multiple Choice* Which of the following pairs of coordinates and coordinate systems is equivalent to the cartesian coordinate point $(-2, 2, \sqrt{6})$?

W) Cylindrical, $(2, 3\pi/4, \sqrt{6})$
X) Cylindrical, $(2\sqrt{2}, \pi/4, \sqrt{6})$
Y) Spherical, $(\sqrt{14}, \pi/4, \pi/3)$
Z) Spherical, $(\sqrt{14}, 3\pi/4, \pi/3)$

ANSWER: Z) Spherical, $(\sqrt{14}, 3\pi/4, \pi/3)$

BONUS

22) MATH *Short Answer* A decimal number decreases by a hundred when it is treated as a number in base 9. What is the largest possible decimal number that satisfies this condition?

ANSWER: 558

TOSS UP

23) BIOLOGY *Multiple Choice* Which of the following statements is LEAST accurate concerning plants?

W) Tropical plants rarely have distinct growth rings
X) Monocot roots contain parenchyma at their center
Y) Eudicot stems have scattered vascular bundles
Z) Secondary phloem sloughs off over time

ANSWER: Y) Eudicot stems have scattered vascular bundles

BONUS

23) BIOLOGY *Short Answer* Identify all of the following three molecules that are likely less concentrated in the bundle-sheath cells than in the mesophyll cells of C4 plants: 1) Rubisco; 2) Carbon dioxide; 3) PEP carboxylase

ANSWER: 3 only