2021 MIT Science Bowl High School Invitational Round 9

TOSS UP

1) EARTH AND SPACE *Short Answer* Type 1A supernovae can be distinguished from other type 1 supernovae by an absorption line of the singly ionized form of what element at 635 nm?

ANSWER: Silicon

BONUS

1) EARTH AND SPACE *Multiple Choice* Which of the following events most closely coincides with the boundary between the Archean and Proterozoic Eras?

W) The formation of the first piece of continental crust
X) The first evidence of life
Y) The great oxygenation event
Z) The Cambrian Explosion

ANSWER: Y) The great oxygenation event

TOSS UP

2) ENERGY *Short Answer* The Engelhardt group at MIT is studying quantum gravity and black holes. One phenomenon they are investigating is the observation that all singularities are located within event horizons, known as what hypothesis?

ANSWER: Cosmic censorship hypothesis

BONUS

2) ENERGY *Short Answer* The Lee group at MIT is investigating the results of high energy proton-proton collisions, including the decay of the Higgs boson. One possible mode is the generation of a Z boson and what meson, consisting of a strange and antistrange quark?

ANSWER: Phi meson

TOSS UP

3) PHYSICS *Multiple Choice* In quantum mechanics, which of the following best describes the states which can be observed?

W) Hamiltonian state
X) Eigenstate
Y) Bogoliubov state (read: *bo-guh-LIU-buv*)
Z) Instantaneous collapse state

ANSWER: X) Eigenstate

BONUS

3) PHYSICS *Short Answer* A point charge of 10 coulombs is enclosed inside a cube with side length 1 meter. In terms of ε_0 (read: *epsilon naught*), what is the total electric flux through this cube?

ANSWER: $\frac{10 \text{ coloumbs}}{\varepsilon_0}$ (accept: $10/\varepsilon_0$)

TOSS UP

4) BIOLOGY *Multiple Choice* The cyclization of glutamine (*GLOO-tuh-meen*) produces what residue which is known as a helix breaker along with glycine?

W) Pyrrolysine (*PEE-ruh-ly-seen*)
X) Proline
Y) Selenocysteine (*se-le-no-SIS-teen*)
Z) Glutamic acid

ANSWER: X) proline

BONUS

4) BIOLOGY *Short Answer* Porphyrin (*POR-ferr-in*) rings are an important component of hemoglobin and cytochromes. In non-photosynthetic eukaryotes, what amino acid residue is the precursor of porphyrin?

ANSWER: Glycine

TOSS UP

5) CHEMISTRY *Short Answer* How many stereocenters does the linear form of glucose have?

ANSWER: 4

BONUS

5) CHEMISTRY *Short Answer* By name or number, identify all of the following three compounds which have prochiral sp^2 (read: *s p two*) carbons:

1) Acetone
2) 2-butanone
3) Cyclohexanone

ANSWER: 2 only

TOSS UP

6) MATH *Short Answer* A sequence of three numbers which starts with 6 is both an arithmetic and a geometric sequence. What is the last number in the sequence?

ANSWER: 6

BONUS

6) MATH *Multiple Choice* A cylinder's surface area is numerically equal to its volume. Which of the following is the largest integer value that can NOT be the radius of the cylinder?

W) 1
X) 2
Y) 3
Z) 4

ANSWER: X) 2

TOSS UP

7) MATH *Multiple Choice* In a normal distribution with a mean of 0 and standard deviation 1, which of the following z-scores most closely corresponds to a percentile of 70%?

W) 0.2
X) 0.5
Y) 1
Z) 1.5

ANSWER: X) 0.5

BONUS

7) MATH *Short Answer* What are all the real eigenvalues of the 3 by 3 matrix whose entries are all 1?

ANSWER: 0 and 3 (accept: 0, 0, and 3)

TOSS UP

8) EARTH AND SPACE *Short Answer* Three of the four Galilean moons of Jupiter are locked in a 1:2:4 orbital resonance. Which Galilean moon is NOT part of this resonance?

ANSWER: Callisto

BONUS

8) EARTH AND SPACE *Multiple Choice* Which of the following best characterizes the values of the density parameter, omega, that would imply an open universe?

W) Omega is greater than 0
X) Omega is greater than 1
Y) Omega is less than 0
Z) Omega is less than 1

ANSWER: Z) Omega is less than 1

TOSS UP

9) ENERGY *Multiple Choice* The Lehmann group at MIT studies RNA localization in Drosophila. mRNA localization to structures called germ granules is crucial to its translational activation, which would most likely be mediated by what structural component of mRNA?

W) 5' (*five prime*) cap
X) 5' UTR
Y) 3' UTR
Z) Poly-A tail

ANSWER: Y) 3' UTR

BONUS

9) ENERGY *Short Answer* The Lehmann group also researches the inheritance of the mitochondrial genome. In evolutionary genetics, what is the term for the process in which mutations accumulate in the absence of robust recombination mechanisms, such as in the mitochondria?

ANSWER: Muller's ratchet

TOSS UP

10) PHYSICS *Multiple Choice* A gas expands from an initial volume to a final volume, what process uses the least amount of work?

W) Reversible isobaric expansion
X) Reversible isothermal expansion
Y) Irreversible isothermal expansion
Z) Reversible adiabatic expansion

ANSWER: Z) Reversible adiabatic expansion

BONUS

10) PHYSICS *Multiple Choice* Which of the following best describes a vector in Minkowski space that lies inside of the light cone?

W) Timelike
X) Spacelike
Y) Lightlike
Z) Null

ANSWER: W) Timelike

TOSS UP

11) CHEMISTRY *Multiple Choice* 10 grams of which of the following substances would result in the greatest freezing point depression in aqueous solution?

W) Ethanol
X) Sodium chloride
Y) Hydrogen chloride
Z) Magnesium chloride

ANSWER: Y) Hydrogen chloride

BONUS

11) CHEMISTRY *Multiple Choice* Which of the following aqueous solutions will have the largest ionic strength?

W) 1 molar potassium chloride solution
X) 0.75 molar calcium chloride solution
Y) 0.5 molar aluminum chloride solution
Z) 0.25 molar titanium four chloride solution

ANSWER: Y) 0.5 molar aluminum chloride solution

TOSS UP

12) BIOLOGY *Multiple Choice* In an interrupted mating experiment, conjugation between an Hfr bacterial cell and an F- bacterial cell is allowed to occur for a limited time. What are the most probable resulting strains of the two cells, respectively?

W) Hfr and F-
X) Hfr and F+
Y) Hfr and Hfr
Z) F+ and F-

ANSWER: W) Hfr and F-

BONUS

12) BIOLOGY *Short Answer* By name or number, identify all of the following three statements that are true of non-Mendelian inheritance patterns:

1) Maternal effect genes can be controlled by mRNA products in the developing oocyte
2) Variegated coat patterns in mammalian fur almost always occurs in hemizygous individuals
3) Erasure of one parental allele during genomic imprinting occurs in both somatic and germ-line cells

ANSWER: 1 only

TOSS UP

13) BIOLOGY *Multiple Choice* By name or number, order the following three steps in a Western blot in order of occurence:

1) Blocking with milk
2) Incubation with secondary antibody
3) Ponceau (*PON-soh*) stain

ANSWER: 3, 1, 2

BONUS

13) BIOLOGY *Multiple Choice* SHERLOCK is a diagnostic test for COVID-19 which uses CRISPR-Cas13 to screen for COVID-related macromolecules. Which of the following macromolecules does CRISPR-Cas13 act on?

W) DNA
X) RNA
Y) Proteins
Z) Carbohydrates

ANSWER: X) RNA

TOSS UP

14) PHYSICS *Multiple Choice* To study computationally difficult problems, which of the following techniques computes the electronic distribution, rather than computing a wave function?

W) Hartree Fock
X) Density Functional Theory
Y) Moller-Plesset perturbation theory
Z) Configuration interaction

ANSWER: X) Density Functional Theory

BONUS

14) PHYSICS *Short Answer* By name or number, identify all of the following three changes that would increase the distance between the first and second peaks in a double slit experiment:

1) Increasing the wavelength of the light
2) Increasing the distance from the slits to the screen
3) Increasing the distance between the slits

ANSWER: 1 and 2

TOSS UP

15) EARTH AND SPACE *Short Answer* In Earth's atmosphere, what force is balanced by the gravitational force to maintain hydrostatic equilibrium?

ANSWER: Pressure-gradient force

BONUS

15) EARTH AND SPACE *Multiple Choice* Plutinos are Kuiper belt objects which share which of the following orbital resonances with Neptune?

W) 2:1
X) 3:2
Y) 5:2
Z) 3:1

ANSWER: X) 3:2

TOSS UP

16) CHEMISTRY *Short Answer* Azobisisobutyronitrile (*AY-zoh-bis-eye-so-bew-TEE-ro-NY-trile*) is a radical initiator which releases what molecule to generate two tertiary radicals upon heating?

ANSWER: Nitrogen

BONUS

16) CHEMISTRY *Short Answer* By name or number, order the following three radicals in order of increasing stability:

1) Methyl radical
2) Tertbutyl radical
3) Hydroxyl radical

ANSWER: 3, 1, 2

TOSS UP

17) MATH *Short Answer* A rhombus has a side length of 20, and contains an angle measuring 60 degrees. What is the length of the longest diagonal of the rhombus?

ANSWER: $20\sqrt{3}$

BONUS

17) MATH *Short Answer* The population standard deviation of a set of 10 data points is 5. What is the sample standard deviation of the set?

ANSWER: $5\sqrt{10}/3$

TOSS UP

18) ENERGY *Short Answer* Researchers in the Movassaghi group at MIT are studying diketopiperazine rings in potential anticancer products. They have found that n to pi star interactions in the ring's disulfide bond greatly reduce its capability of being reduced. When a disulfide bond is reduced, what functional group is produced as a result?

ANSWER: Thiol

BONUS

18) ENERGY *Short Answer* Researchers in the Dinca group at MIT are studying the use of porous catalysts to selectively dimerize ethylene into 1-butene. How many different alkene isomers exist with the same chemical formula as 1-butene?

ANSWER: 4

TOSS UP

19) BIOLOGY *Multiple Choice* Rho-dependent termination is an example of a process occurring in which of the following fundamental processes:

W) DNA replication
X) Transcription
Y) RNA splicing
Z) Translation

ANSWER: X) Transcription

BONUS

19) BIOLOGY *Multiple Choice* Consider 5 genes A-E with dominant and recessive alleles for each individual gene. Assuming a homozygous dominant parent is crossed with a homozygous recessive parent and independent assortment, which of the following gives the probability of second generation offspring exhibiting 3 dominant and 2 recessive phenotypes, assuming the first generation is self-crossed?

W) 113/512
X) 235/1024
Y) 135/512
Z) 150/512

ANSWER: Y) 135/512

TOSS UP

20) EARTH AND SPACE *Multiple Choice* Which of the following is the lowest grade metamorphic mineral?

W) Sillimanite
X) Garnet
Y) Chlorite
Z) Staurolite

ANSWER: Y) Chlorite

BONUS

20) EARTH AND SPACE *Multiple Choice* According to the Eddington Approximation, which of the following is closest to the optical depth of the photosphere?

W) 1/4
X) 1/3
Y) 2/3
Z) 3/4

ANSWER: Y) 2/3

TOSS UP

21) CHEMISTRY *Multiple Choice* Which of the following molecules has the lowest boiling point?

W) Methanol
X) Diethyl ether
Y) Acetone
Z) Water

ANSWER: X) Diethyl ether

BONUS

21) CHEMISTRY *Multiple Choice* Which of the following is true regarding optical isomerism of complexes with achiral ligands?

W) Linear complexes display optical isomerism when both ligands differ
X) Tetrahedral complexes never display optical isomerism
Y) Square planar complexes display optical isomerism when all ligands are different
Z) Octahedral complexes with three bidentate ligands will display optical isomerism

ANSWER: Z) Octahedral complexes with three bidentate ligands will display optical isomerism

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TOSS UP

22) MATH *Multiple Choice* Which of the following probability distributions is positively skewed?

W) Uniform
X) Bernoulli
Y) Normal
Z) Poisson

ANSWER: Z) Poisson

BONUS

22) MATH *Short Answer* Find the integral from 0 to π of $x\cos(x)dx$.

ANSWER: -2

TOSS UP

23) PHYSICS *Short Answer* What is the Young's Modulus of a rod of length 3 meters if it shrinks by 1.5 centimeters lengthwise under a pressure of 30 pascals?

ANSWER: 60,000 pascals

BONUS

23) PHYSICS *Short Answer* A tetrahedron is constructed using resistors, such that each edge is composed of a 4-ohm resistor. If two vertices are chosen as the terminals of the resistor, what is the equivalent resistance of this construct, in ohms?

ANSWER: 2 ohms
