2020 MIT Science Bowl High School Invitational
Round 13

TOSS UP

1) EARTH AND SPACE *Short Answer* By name or number, identify all of the following four plates which border the Pacific plate:

    1) North American plate
    2) Nazca plate
    3) Philippine plate
    4) Scotia plate

ANSWER: 1, 2, 3

BONUS

1) EARTH AND SPACE *Short Answer* By name or number, arrange the following four events in the post-main sequence evolution of a star like the Sun in chronological order, from earliest to latest:

    1) Helium flash
    2) Asymptotic giant branch
    3) Red giant branch
    4) Horizontal branch

ANSWER: 3, 1, 4, 2

TOSS UP

2) MATH *Multiple Choice* Which of the following vectors gives the direction of steepest change on a surface in 3 dimensions, defined by $z = f(x, y)$?

W) Curvature
X) Gradient
Y) Flux
Z) Normal

ANSWER: X) Gradient

BONUS

2) MATH *Short Answer* A positive integer is called fibbish if each digit, after the leftmost two, is at least the sum of the two digits to the left of it. What is the largest fibbish number?

ANSWER: 10112369

TOSS UP

3) BIOLOGY *Multiple Choice* Mangrove trees, which often reside in tidal swamps, exhibit what kind of root?

  W) Buttress roots
  X) Strangling aerial roots
  Y) Storage roots
  Z) Pneumatophores (*noo-MAT-oh-fores*)

ANSWER: Z) Pneumatophores

BONUS

3) BIOLOGY *Short Answer* The ABC model of flower development describes the development of floral organs in relation to various classes of homeotic (*home-ee-AW-tick*) genes. In addition to the ABC type genes are the D and E type genes, which are said to play a role in ovule and verticil (*VERT-uh-sull*) development. One such D type gene is floral binding protein 7, or FBP7. What specific gene family do FBP7 and many other floral organ identity genes belong to?

ANSWER: MADS-box

TOSS UP

4) ENERGY *Multiple Choice* Researchers at the MIT Francis Bitter Magnet Laboratory are utilizing state-of-the-art nuclear magnetic resonance (NMR) spectrometers to characterize and study different molecules and their interactions. Which of the following nuclei could not be studied by a typical NMR spectrometer?

  W) Hydrogen-2
  X) Carbon-12
  Y) Nitrogen-14
  Z) Phosphorus-31

ANSWER: X) Carbon-12

BONUS

4) ENERGY *Short Answer* Researchers in the Dinca group at MIT are synthesizing redox active metal organic frameworks (MOF) which can activate small molecules such as oxygen and nitrogen. To characterize these MOFs, researchers are employing a variety of spectroscopic techniques. Order the following three spectroscopic techniques in increasing energy of light used in the technique:

  1) Moessbauer
  2) NMR
  3) EPR

ANSWER: 2, 3, 1

5) PHYSICS *Multiple Choice* Which of the following constants represents the coupling strength of the electromagnetic force?

  W) Fine structure constant
  X) Planck's reduced constant
  Y) Yukawa coupling constant
  Z) Von Klitzing constant

ANSWER: W) Fine structure constant

BONUS

5) PHYSICS *Multiple Choice* A spaceship is emitting a signal of frequency f in its own rest frame. As it flies by you, at near the speed of light, which of the following best describes the frequency when you see the spaceship at its closest approach?

  W) Greater than f
  X) Less than f
  Y) Equal to f
  Z) Relation to f depends on f

ANSWER: X) Less than f

TOSS UP

6) CHEMISTRY *Multiple Choice* Which of the following best describes the cause of gold's distinctive color?

  W) The surface of gold forms a passivation layer, which has a gold tilt
  X) Impurities within gold metal causes metal chloride complexes to form, which have a gold hue
  Y) Relativistic effects within gold shifts the wavelength of absorption into the blue region, resulting in a gold color
  Z) Electron tunneling distorts the energy levels within the gold, causing the appearance of new absorption bands

ANSWER: Y) Relativistic effects within gold shifts the wavelength of absorption into the blue region, resulting in a gold color

BONUS

6) CHEMISTRY *Short Answer* Cyclobutadiene has been found to form a stable complex with an iron tricarbonyl fragment. The four-carbon ring in this complex has been found to have aromatic properties. Answer the following two questions about this complex:

  1) Using a combination of L, X, and Z, what is the covalent bond classification of the cyclobutadiene ligand in this complex?
  2) What is the formal number of pi electrons in the cyclobutadiene ring in the complex?

ANSWER: 1) LX_2; 2) 6

7) BIOLOGY *Short Answer* In humans, what is the enzyme that converts carbon dioxide to bicarbonate and hydrogen ions?

ANSWER: Carbonic anhydrase

BONUS

7) BIOLOGY *Short Answer* By name or number, identify all of the following statements that are true about 2,3-BPG (read: *2 3 B P G*) binding to hemoglobin.

1) 2,3-BPG stabilizes the T state
2) 2,3-BPG decreases binding affinity for hemoglobin to oxygen
3) Fetal hemoglobin exihibits high affinity for 2,3-BPG

ANSWER: 1 and 2

TOSS UP

8) PHYSICS *Short Answer* By name or number, indicate all of the following three statements that are true of the Einstein model of a solid:

1) It matches the Dulong-Petit prediction at high temperatures
2) At low temperatures, it predicts heat capacity proportional to temperature cubed
3) It models atoms as independent quantum harmonic oscillators

ANSWER: 1 and 3

BONUS

8) PHYSICS *Short Answer* By number, indicate all of the following which are true regarding the theory of solids:

1) The Debye model predicts that as temperature approaches 0 heat capacities scale as temperature cubed
2) The Einstein model treats each atom as a quantum harmonic oscillator
3) Vibrations within the solid can be modeled as pseudoparticles called phonons

ANSWER: 1, 2, 3 (accept: all)

TOSS UP

9) MATH *Short Answer* The sum of the first N positive perfect seventh powers can be written as a polynomial expression in N. When this polynomial is written in standard polynomial form, what is its leading term?

ANSWER: $N^8/8$ (accept: $\frac{1}{8}N^8$)

BONUS

9) MATH *Short Answer* Find to one significant figure the area of a regular 1,000,000-sided polygon with side length 1. Express your answer in scientific notation.

ANSWER: 8×10^{10}

TOSS UP

10) ENERGY *Multiple Choice* Researchers at the MIT Department of Mathematics have conducted investigations into high-dimensional sphere packing, which aims to find the densest possible packing of congruent spheres in n-dimensional Euclidean space. The kissing number of a unit sphere is defined as the maximum number of unit spheres that can be placed tangent to the original so that no two overlap. What is the kissing number of a unit sphere in 3-dimensional space?

  W) 2
  X) 6
  Y) 12
  Z) 20

ANSWER: Y) 12

BONUS

10) ENERGY *Multiple Choice* Researchers at the MIT Mathematics Department have been focusing on the problem of determining which numbers can be represented as the sum of three cubes, yielding the recent discovery of an expression of 42 as the sum of three cubes, one of which is negative. Which of the following numbers cannot be written as the sum of three cubes?

  W) 5
  X) 7
  Y) 9
  Z) 11

ANSWER: W) 5

TOSS UP

11) CHEMISTRY *Multiple Choice* Using hard-soft acid base theory, describe both the alpha-carbon and oxygen in an enolate.

W) Carbon is a hard base, while oxygen is a hard base
X) Carbon is a hard base, while oxygen is a soft base
Y) Carbon is a soft base, while oxygen is a hard base
Z) Carbon is a soft base, while oxygen is a soft base

ANSWER: Y) Carbon is a soft base, while oxygen is a hard base

BONUS

11) CHEMISTRY *Short Answer* By name or number, arrange the following three species in order of increasing CH coupling in Carbon-13-NMR.

1) Acetylene
2) Ethylene
3) Ethane

ANSWER: 3, 2, 1

TOSS UP

12) EARTH AND SPACE *Multiple Choice* Which of the following estuary types is characterized by low river flow and net seaward movement of water at all depths?

  W) Salt wedge
  X) Partially mixed
  Y) Well-mixed
  Z) Fjord-type

ANSWER: Y) Well-mixed

BONUS

12) EARTH AND SPACE *Short Answer* By name or number, indicate all of the following three statements that are true of white dwarfs:

  1) Heat is carried by electron conduction near the center of a white dwarf
  2) The interior of a white dwarf is close to isothermal
  3) The electrons in a white dwarf with mass near the Chandrasekhar limit are relativistic

ANSWER: 1, 2, 3 (accept: all)

---

13) MATH *Multiple Choice* A point P is chosen uniformly at random on a circle of radius 1. A point Q is then chosen uniformly at random from the interior of the circle. Which of the following is closest to the probability that the distance PQ is at most 1?

  W) 20%
  X) 40%
  Y) 60%
  Z) 80%

ANSWER: X) 40%

13) MATH *Short Answer* How many primitive 20th roots of unity are there?

ANSWER: 8

---

14) PHYSICS *Short Answer* A rocket travels at speed $0.8c$. What is the ratio of its kinetic energy to its rest energy?

ANSWER: 2/3

14) PHYSICS *Short Answer* Andrew is trying to ice skate through a circular loop-de-loop with radius 2 meters. If there is no frictional energy loss in this loop, what is the minimum speed, in meters per second to the nearest integer, that Andrew needs at the beginning of the loop to clear it?

ANSWER: 10 meters per second

TOSS UP

15) CHEMISTRY *Short Answer* What is the degeneracy of the 4th energy level of the rigid rotator model?

ANSWER: 7

BONUS

15) CHEMISTRY *Short Answer* By name or number, identify all of the following three statements which are true regarding photoredox catalysis:

1) Conformationally rigid complexes function as faster photoredox catalysts
2) Rose-Bengal is a commonly used, polyhalogenated organic photoredox catalyst
3) Amines are commonly used co-oxidizing agents, returning the photoredox catalyst to its original oxidation state

ANSWER: 1 and 2

TOSS UP

16) BIOLOGY *Multiple Choice* Which of the following types of fungi does NOT have coenocytic (*SEE-no-sit-ic*) hyphae (*HI-fae*)?

  W) Chytrids (*KYE-tridz*)
  X) Bread molds
  Y) Mycorrhizhae (*MY-koe-rye-zay*)
  Z) Club fungi

ANSWER: Z) Club fungi

BONUS

16) BIOLOGY *Multiple Choice* Which of the following types of filaments is the cross-linking protein plectin NOT able to bundle to intermediate filaments?

  W) Microtubules
  X) Actin
  Y) Tropomyosin
  Z) Myosin II

ANSWER: Y) Tropomyosin

TOSS UP

17) EARTH AND SPACE *Short Answer* By name or number, order the following four components of a standard ophiolite complex from top to bottom.

  1) Pillow lava
  2) Sheeted dikes
  3) Layered gabbro
  4) Peridotite deposits

ANSWER: 4, 3, 2, 1

BONUS

17) EARTH AND SPACE *Multiple Choice* Which of the following gives the best definition for stellar opacity for a certain material?

 W) The fraction of photons passing through which are absorbed or scattered
 X) The change in visual apparent magnitude as a result of light passing through
 Y) The cross-sectional area of absorption and scattering of light passing through, per unit mass
 Z) The inverse of the mean free path of light passing through

ANSWER: Y) The cross-sectional area of light absorption and scattering of light passing through, per unit mass

TOSS UP

18) ENERGY *Multiple Choice* Researchers in the Swager group at MIT have been using Janus emulsions for the detection of Listeria pathogens. These Janus emulsions are composed of two optically distinct phases within one droplet, and one phase is conjugated to an antibody. Which of the following best describes how the optics of the system evolve when Listeria is added?

W) Originally, both phases are visible, but only one is visible after Listeria addition
X) Originally, only one phase is visible, but both are visible after Listeria addition
Y) Originally, both phases are visible, but the orientation of these phases flips after Listeria addition
Z) Originally, only one phase is visible, but only the other phase is visible after Listeria addition

ANSWER: X) Originally, only one phase is visible, but both are visible after Listeria addition

BONUS

18) ENERGY *Short Answer* Researchers in the Bawendi group at MIT are focusing on quantum dots as next generation fluorescent dyes. Answer the following questions about quantum dots:

1) The energy levels of a quantum dot are proportional to what power of the radius?
2) Quantum dots can be generated by many techniques, including one technique where the pattern is imprinted on a thin surface using light, and then etched. What is this technique known as?

ANSWER: 1) -2; 2) Photolithography

TOSS UP

19) CHEMISTRY *Short Answer* What effect in extended solids analogous to Jahn-Teller distortion states that partially filled bands tend to distort to form one filled band and one empty band?

ANSWER: Peierls distortion

BONUS

19) CHEMISTRY *Short Answer* By name or number, identify all of the following three statements that are true about hyperconjugation in the tertbutyl radical:

1) An increase in carbon-carbon bond order is observed
2) The unpaired electron is slightly delocalized across the other three carbon atoms
3) The unpaired electron is stabilized by hyperconjugation

ANSWER: 1 and 2

TOSS UP

20) PHYSICS *Multiple Choice* Which of the following statements about the hydrogen atom is true, ignoring fine structure?

  W) L squared and H constitute a complete set of commuting observables
  X) Only a finite number of bound states exist
  Y) Muonic hydrogen has the same energy levels as ordinary hydrogen
  Z) The ground state radial wavefunction is an exponential

ANSWER: Z) The ground state radial wavefunction is an exponential

BONUS

20) PHYSICS *Short Answer* By name or number, identify all of the following four properties of a free particle that can be simultaneously measured with position to an arbitrary degree of accuracy:

  1) Linear momentum
  2) Spin angular momentum
  3) Total energy
  4) z-component of angular momentum

ANSWER: 2 only

TOSS UP

21) MATH *Short Answer* The Banach-Tarski (*buh-NAAK TAR-ski*) Paradox is a theorem stating that a sphere can be divided into finitely many pieces that can be rearranged to form two spheres of the same size. What somewhat controversial postulate commonly used in set theory is required to prove this theorem?

ANSWER: Axiom of Choice (accept: Choice, Well-Ordering Principle)

BONUS

21) MATH *Short Answer* By name or number, identify which of the following three posterior inference methods yield unbiased samples in all cases.

1) Variational inference
2) Gibbs sampling
3) Hamiltonian Monte Carlo

ANSWER: 2 and 3

22) BIOLOGY *Short Answer* Capsaicin (*cap-SAY-sin*), found in chili peppers, can lead to pain by causing the release of what peptide?

ANSWER: Substance P

BONUS

22) BIOLOGY *Short Answer* By name or number, identify all of the following statements related to linking numbers that are true.

1) The specific linking difference is calculated with respect to the specific length of the DNA molecule being analyzed
2) Linking number is calculated as the difference between its writhe and twist components
3) The superhelical density in cellular DNA is typically around -0.06
4) The writhe component of linking number may be interpreted as the measure of the coiling of the DNA helix axis

ANSWER: 3 and 4

TOSS UP

23) EARTH AND SPACE *Multiple Choice* The Sunyaev-Zel'dovich (*soon-YAW-ev zel-DO-vich*) effect, which is used by cosmologists to study the cosmic microwave background in galaxy clusters, is a result of which of the following physical phenomena?

  W) Relativistic Doppler effect
  X) Bremsstrahlung (*BREMZ-struh-lung*)
  Y) Cold dark matter
  Z) Inverse Compton scattering

ANSWER: Z) Inverse Compton scattering

BONUS

23) EARTH AND SPACE *Short Answer* By name or number, identify all of the following three statements that are true about the solar atmosphere:

  1) Granules are caused by convection within the photosphere
  2) The optical depth of the photosphere is much less than one
  3) The pink color of the chromosphere is produced by Balmer emission lines

ANSWER: 1 and 3