2021 MIT Science Bowl High School Invitational Round 13

TOSS UP

1) ENERGY *Short Answer* The Suess group at MIT is exploring iron sulfur clusters in cells. If an iron sulfur cluster has four iron atoms and four sulfur atoms with a net charge of +2, what is the expected spin state of the lower oxidation state iron species in the cluster?

ANSWER: 2

BONUS

1) ENERGY *Short Answer* The Suess group at MIT is exploring a redox active protein with four iron atoms and four sulfur atoms in a cubane structure. One of the irons is redox active and changes between iron III and iron II. By name or number, identify all of the statements which are true about this complex.

1) Increasing the number of hydrogen bonds to the sulfur atoms will increase the standard reduction potential of the cluster
2) All of the iron centers are high spin
3) Each iron is formally bonded to four sulfur atoms

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

TOSS UP

2) CHEMISTRY *Multiple Choice* Xavier is trying to convert a carboxylic acid to an acid chloride using oxalyl chloride with dichloromethane as a solvent. To accelerate the reaction, Xavier should add a drop of which of the following substances to his reaction flask?

W) N,N-dimethylformamide
X) water
Y) 4-dimethylaminopyridine
Z) tosylic acid

ANSWER: W) N,N-dimethylformamide

BONUS

2) CHEMISTRY *Short Answer* Zoe is trying to perform a Heck coupling between an aryl bromide and an olefin using 1 mole percent of palladium acetate and 2 mole percent of triphenylphosphine along with a slight excess of base. By name or number, identify all of the following three changes which would dramatically improve Zoe's yield:

1) Using 2 mole percent palladium acetate
2) Using 3 mole percent triphenylphosphine
3) Changing the palladium source to $Pd(dba)_2$

ANSWER: 2 and 3

TOSS UP

3) PHYSICS *Short Answer* Antiferromagnets have 0 net magnetization, regardless of the external field applied. What is the name of the temperature above which antiferromagnetic materials become paramagnetic due to thermal disorder?

ANSWER: Neel temperature (accept: Neel)

BONUS

3) PHYSICS *Short Answer* By name or number, identify all of the following five elements which are ferromagnetic:

1) Cobalt
2) Copper
3) Ruthenium
4) Dysprosium
5) Holmium

ANSWER: 1 and 4

TOSS UP

4) MATH *Short Answer* Two of the side lengths of a triangle are 50 units and 51 units. If the tangent of the angle measure between the two sides is 8/15, what is the area of the triangle?

ANSWER: 600

BONUS

4) MATH *Short Answer* To the nearest integer, what is the value of $2718^{2719}/2719^{2718}$ (read: *the fraction with numerator* 2718^{2719} *and denominator* 2719^{2718})?

ANSWER: 1000

TOSS UP

5) BIOLOGY *Multiple Choice* Actin molecules polymerize and depolymerize at both plus and minus ends. Which of the following statements correctly describes the rate of actin polymerization in the absence of a capping protein?

W) Polymerization occurs quickest at the plus end
X) Polymerization occurs quickest at the minus end
Y) Polymerization occurs equally quickly at the plus and minus ends
Z) Polymerization does not occur without capping proteins

ANSWER: W) Polymerization occurs quickest at the plus end

BONUS

5) BIOLOGY *Multiple Choice* In muscle cells, what molecule caps the minus end of actin filaments?

W) CapZ
X) Tropomodulin
Y) Tropomyosin
Z) CapA

ANSWER: X) Tropomodulin

TOSS UP

6) EARTH AND SPACE *Multiple Choice* The root-mean-square radial velocity of stars in one galaxy is 20 kilometers per second. In kilometers per second, which of the following is closest to the velocity dispersion of the stars in the galaxy?

W) 25
X) 35
Y) 45
Z) 60

ANSWER: X) 35

BONUS

6) EARTH AND SPACE *Short Answer* The concept of cosmological redshift is described by what metric which is based on the universe being isotropic and homogenous?

ANSWER: FLRW metric

TOSS UP

7) PHYSICS *Short Answer* What model of solids predicts that the heat capacity of a solid is proportional to the temperature cubed at low temperature by using phonons to describe atomic lattice vibrations?

ANSWER: Debye model

BONUS

7) PHYSICS *Short Answer* The dependence of electrical resistance with respect to temperature has multiple different contributions. One term with logarithmic dependence arises from what effect, which describes the interaction of magnetic impurities and conduction electron magnetic moments?

ANSWER: Kondo effect

TOSS UP

8) BIOLOGY *Short Answer* The mutations D10A and H840A affect which two domains in Streptococcus pyogenes (*STREP-toh-coc-cus py-AW-je-neez*) Cas9, respectively?

ANSWER: RuvC; HNH

BONUS

8) BIOLOGY *Short Answer* By name or number, identify all of the following three statements about KRAB (read: *CRAB*) domains that are true:

1) Transcription factors with a KRAB domain generally repress RNA polymerase activity
2) Transcription factors with a KRAB domain generally promote RNA polymerase activity
3) KRAB is often used alongside CRISPR technology to further modulate transcription

ANSWER: 1 and 3

TOSS UP

9) MATH *Short Answer* What is the dual polyhedron of a regular icosahedron?

ANSWER: Dodecahedron (accept: regular dodecahedron)

BONUS

9) MATH *Short Answer* Evaluate $\int_{-\infty}^{\infty} e^{-(x^2+8x+9)}\,dx$

ANSWER: $\sqrt{\pi}e^7$

TOSS UP

10) EARTH AND SPACE *Short Answer* Lin-Shu density wave theory was proposed as a solution to what problem, which suggested that differential rotation of a galaxy would lead to dissolution of the spiral arms?

ANSWER: Winding problem

BONUS

10) EARTH AND SPACE *Multiple Choice* Which of the following types of volcanic eruptions occurs when seawater enters the magma chamber and causes a steam explosion?

W) Plinian (*PLI-nee-uhn*)
X) Phreatic (*free-A-tic*)
Y) Surtseyan (*SURT-see-yuhn*)
Z) Strombolian (*strom-BO-lee-uhn*)

ANSWER: Y) Surtseyan

TOSS UP

11) CHEMISTRY *Short Answer* Because of Jahn-Teller distortion, hexaaquacopper (II) (*HEX-a-a-qua-cop-per two*) exhibits tetragonal elongation. In such a complex, what is the highest energy d orbital?

ANSWER: $d_{x^2-y^2}$

BONUS

11) CHEMISTRY *Multiple Choice* Which of the following is true of the lowest-energy d-orbitals in the complex $[Cu(CN)_4]^{2-}$?

W) It is a singly degenerate d_{xy} orbital
X) It is a singly degenerate d_{z^2} orbital
Y) It is a set of doubly degenerate d_{xz} and d_{yz} orbitals
Z) It is a set of triply degenerate d_{xy}, d_{xz}, and d_{yz} orbitals

ANSWER: W) It is a singly degenerate d_{xy} orbital

TOSS UP

12) ENERGY *Short Answer* Researchers in the Kavli Institute at MIT have discovered 4 new exoplanets using the Transiting Exoplanet Survey Satellite. Although TESS relies on the transit method, the first exoplanets were discovered using what other method which involves measuring the shift in the wavelength of spectral lines emitted by a parent star?

ANSWER: Doppler radial velocity method

BONUS

12) ENERGY *Short Answer* The Liu group at MIT is researching string theory and its relationship with quantum gravity. String theory relies on how many spatial and temporal dimensions, respectively?

ANSWER: 9 spatial and 1 temporal

TOSS UP

13) MATH *Short Answer* What specific distribution describes the probability of k successes in n draws from a finite population without replacement?

ANSWER: Hypergeometric (do not accept: geometric)

BONUS

13) MATH *Short Answer* What is the value of the approximation of arctan(1) using the first three nonzero terms of the power series of arctan(x) centered at $x = 0$?

ANSWER: 13/15

TOSS UP

14) CHEMISTRY *Multiple Choice* Which of the following statements is NOT true about g-anisotropy in EPR (read: *E-P-R*) spectroscopy?

W) Any deviation from the g-factor of the free electron is due to spin-orbit coupling
X) For one single transition, the peak measured at the lower magnetic field corresponds to a lower g-tensor component in the corresponding dimension
Y) In the absence of hyperfine splitting, g-anisotropy accounts for different splitting patters in EPR spectroscopy
Z) Different g values for the three different components of a g-tensor resuts in a rhombic splitting pattern

ANSWER: X) For one single transition, the peak measured at the lower magnetic field corresponds to a lower g-tensor component in the corresponding dimension

BONUS

14) CHEMISTRY *Short Answer* By name or number, identify all of the following 3 species which would result in one isotropic peak in EPR spectroscopy:

1) $[Mn(H_2O)_6]_2^+$
2) $[Cr(H_2O)_6]_3^+$
3) $[Fe(H_2O)_6]_2^+$

ANSWER: 1 and 2

TOSS UP

15) ENERGY *Multiple Choice* Researchers at MIT's Mediated Matter group are currently studying ways to ameliorate the decrease in the global bee population. Bees are quite unique in that bees employ a haplo-diploid sex-determination system. Which of the following fractions gives the coefficient of relatedness between a female bee and her maternal aunt?

W) 1/8
X) 1/4
Y) 3/8
Z) 3/4

ANSWER: Y) 3/8

BONUS

15) ENERGY *Short Answer* Researchers at MIT's Bartel group are currently studying RNA regulation. What's the name of the complex in bacterial cells that's responsible for the degradation of RNA, typically mRNA?

ANSWER: Degradosome

TOSS UP

16) BIOLOGY *Multiple Choice* Which of the following statements is NOT true about plant nutrients?

W) Symptoms of iron deficiency usually appear first in older leaves.
X) Aluminum toxicity is a major problem for crops grown in acidic soil environments.
Y) Manganese deficiency directly affects the oxygen-evolving complex.
Z) Chlorosis is a general condition that can be caused by several types of nutrient deficiencies.

ANSWER: W) Symptoms of iron deficiency usually appear first in older leaves

BONUS

16) BIOLOGY *Short Answer* In some cells infected with Rhizhobia (*rhy-ZOH-bee-a*), what pink pigment protein buffers oxygen concentration to allow both cellular respiration and nitrogenase activity to occur?

ANSWER: Leghemoglobin

TOSS UP

17) PHYSICS *Multiple Choice* A spaceship with a 650-nanometer light is launched in a straight line so that it passes 100 meters from an observer at closest approach. It travels at a speed of $12c/13$. What is the wavelength of the light that the observer will measure when the spaceship is at its closest approach?

W) 250 nanometers
X) 600 nanometers
Y) 1560 nanometers
Z) 1690 nanometers

ANSWER: Z) 1690 nanometers

BONUS

17) PHYSICS *Short Answer* An ideal parallel plate capacitor with circular plates of radius 1 millimeter is charged rapidly, so that the electric field increases from 0 to 9 volts per meter in 10^{-16} seconds. In teslas and in scientific notation to one significant figure, calculate the magnitude of the magnetic field around the edge of the area between the parallel plates.

ANSWER: 5×10^{-4}

TOSS UP

18) EARTH AND SPACE *Multiple Choice* Recrystallization of which of the following minerals would lead to the formation of smaller numbers of large grains as opposed to large numbers of small grains in porphyritic rocks?

W) Biotite
X) Muscovite
Y) Quartz
Z) Andalusite

ANSWER: Z) Andalusite

BONUS

18) EARTH AND SPACE *Short Answer* What is the name of the large scale shock waves found in the Sun's corona that are often described as a kind of solar "tsunami"?

ANSWER: Moreton wave

TOSS UP

19) EARTH AND SPACE *Short Answer* What is the name given to the type of scattering which produces the Sunyaev-Zeldovich (*SU-nee-ev ZEL-do-vich*) effect?

ANSWER: Inverse Compton Scattering

BONUS

19) EARTH AND SPACE *Short Answer* What layer of the ionosphere splits into two layers, one containing molecular ions and the other containing atomic oxygen, during the day and recombines into one layer during the night?

ANSWER: F layer (accept: Appleton-Barnett Layer)

TOSS UP

20) MATH *Short Answer* What is the name of the statement that there is no set with cardinality strictly between that of the integers and the real numbers?

ANSWER: Continuum hypothesis

BONUS

20) MATH *Short Answer* Suppose that more than half of all n-digit integers contain the digit 7. What is the smallest possible value of the positive integer n?

ANSWER: 7

TOSS UP

21) CHEMISTRY *Multiple Choice* Which of the following statements best explains why the 2p sigma bonding orbitals in dinitrogen are higher in energy than the 2p pi bonding orbitals?

W) Nitrogen's p orbitals are relatively diffuse which allows for effective pi bonding interactions
X) The small size of nitrogen causes the sigma bonding set to rise in energy due to electrostatics
Y) The p orbital sigma bonding set interacts with the s orbital sigma bonding set which causes further mixing
Z) The shape of p orbitals makes them favor pi bonding

ANSWER: Y) The p orbital sigma bonding set interacts with the s orbital sigma bonding set which causes further mixing.

BONUS

21) CHEMISTRY *Short Answer* By name or number, identify all of the following three statements which are true of the diatomic compound BF:

1) The B-F bond length is shorter than the C-O bond length in CO
2) BF is a better sigma donor than CO
3) BF is a better pi acceptor than CO

ANSWER: 2 and 3

TOSS UP

22) BIOLOGY *Multiple Choice* In which conformation of DNA do the hydrogen bonds occur relatively perpendicular to the central axis?

W) A-DNA
X) B-DNA
Y) C-DNA
Z) Z-DNA

ANSWER: X) B-DNA

BONUS

22) BIOLOGY *Multiple Choice* In a male mammalian cell undergoing meiosis, which of the following prophase I stages typically takes the longest to complete and is also when crossing over occurs?

W) Leptotene
X) Zygotene
Y) Pachytene (*PAH-kuh-teen*)
Z) Diplotene

ANSWER: Y) Pachytene

TOSS UP

23) PHYSICS *Multiple Choice* Which of the following causes leads to the most error in the ionization energy approximation given by Koopman's theorem?

W) Koopman's theorem fails to account for atomic fine structure
X) Koopman's theorem fails to account for the different electronegativities of atoms
Y) Koopman's theorem fails to account for the energy change due to spin-orbit coupling
Z) Koopman's theorem fails to account for the change in the wavefunction after an electron is removed

ANSWER: Z) Koopman's theorem fails to account for the change in the wavefunction after an electron is removed.

BONUS

23) PHYSICS *Short Answer* By name or number, identify all of the following three statements that explain why quantum dots sometimes do not continuously emit light despite continous excitation:

1) Energy can be released through the emission of Auger electrons instead of photons
2) Empty nonbonding orbitals at quantum dot surfaces can serve as sinks for the energy and prevent emission
3) The distribution of exciton energies is such that not all decays will lead to emission in the visible spectrum

ANSWER: 1 and 2
