2020 MIT Science Bowl High School Invitational Round 7

TOSS UP

1) PHYSICS *Multiple Choice* Albert, with his incredibly deep desire to return to Boston, digs a perfectly straight tunnel through the Earth from Los Angeles to Boston. He then hops in the frictionless tunnel. Assuming the Earth is a uniform sphere, which of the following best describes his position versus time through the tunnel?

W) Sinusoidal
X) Parabolic
Y) Sawtooth
Z) Gaussian

ANSWER: W) Sinusoidal

BONUS

1) PHYSICS *Multiple Choice* Which of the following best describes the dependence of the strength of differential tidal forces between distant two bodies on the distance d between them?

W) Proportional to d
X) Inversely proportional to d squared
Y) Inversely proportional to d cubed
Z) Inversely proportional to d to the fourth

ANSWER: Y) Inversely proportional to d cubed

TOSS UP

2) CHEMISTRY *Multiple Choice* What is the average oxidation state of the iron ions in the iron oxide magnetite, with formula Fe_3O_4?

W) 2
X) 7/3
Y) 8/3
Z) 3

ANSWER: Y) 8/3

BONUS

2) CHEMISTRY *Short Answer* Given that ammonia has a K_b (read: *K B*) of 2×10^{-5}, when equal volumes of an 0.4 molar ammonia solution and 0.4 molar HCl solution are reacted, to one significant figure, what is the pH of the resulting solution?

ANSWER: 5

TOSS UP

3) EARTH AND SPACE *Multiple Choice* Which of the following gases has the lowest concentration in the average parcel of dry air?

W) Argon
X) Krypton
Y) Carbon monoxide
Z) Carbon dioxide

ANSWER: Y) Carbon monoxide

BONUS

3) EARTH AND SPACE *Short Answer* Yash is initially using a partial cover over his telescope aperture, which only allows light through a circular hole with a radius of 2 centimeters. He then takes the cover off so that he is observing with the whole aperture, which is circular with a diameter of 12 centimeters. By what factor does the light gathering power of his telescope increase when he takes off the cover?

ANSWER: 9

TOSS UP

4) BIOLOGY *Short Answer* What is the name of the specially modified chlorophyll molecule in Photosystem II (read: *photosystem two*) that is capable of oxidizing water?

ANSWER: P680 (accept: P680+)

BONUS

4) BIOLOGY *Short Answer* By name or number, identify all of the following four types of glycosidic linkages that may be found in starch.

1) 1-4 alpha (read: *one four alpha*)
2) 1-4 beta
3) 1-6 alpha
4) 1-6 beta

ANSWER: 1 and 3

TOSS UP

5) ENERGY *Multiple Choice* Researchers in the Littleton group at MIT are studying the synapses between neurons of Drosophila flies. Which of the following best describes how a chemical synapse operates?

W) Neurotransmitter is released from the presynaptic dendrite and binds to the postsynaptic axon
X) Calcium ions are released from the presynaptic dendrite and bind to the postsynaptic axon
Y) Neurotransmitter is released from the presynaptic axon and binds to the postsynaptic dendrite
Z) Calcium ions are released from the presynaptic axon and bind to the postsynaptic dendrite

ANSWER: Y) Neurotransmitter is released from the presynaptic axon and binds to the postsynaptic dendrite

BONUS

5) ENERGY *Short Answer* Researchers in the Littleton group at MIT specifically study the effects of mutations on neurons in Drosophila. By name or number, identify all of the following three mutations that would cause a gluatamatergic neuron to lose the ability to engage in long-term potentiation, but not excitatory transmission.

1) Loss-of-function mutation in AMPA receptor
2) Constitutive binding of Mg^{2+} to NMDA receptor
3) Loss of function mutation in the glutamate release pathway

ANSWER: 2 only

TOSS UP

6) MATH *Short Answer* Thomas has the option to buy green onions in bunches of 10 or 13. What is the maximum number of green onions he can NOT buy?

ANSWER: 107

BONUS

6) MATH *Multiple Choice* Which of the following points is a critical point of the function $f(x, y) = x^2 + y^2 + 3x + 6y$?

W) $(1, 2)$
X) $(-1, -2)$
Y) $(3/2, 3)$
Z) $(-3/2, -3)$

ANSWER: Z) $(-3/2, -3)$

TOSS UP

7) BIOLOGY *Multiple Choice* In which of the following types of species is the female generally showier than their male counterpart?

W) Monogamous
X) Polygynous (*poe-LIH-jih-niss*)
Y) Polyandrous (*paw-lee-AN-druss*)
Z) Promiscuous

ANSWER: Y) Polyandrous

BONUS

7) BIOLOGY *Short Answer* What specific part of the kidney releases the hormone renin?

ANSWER: Juxtaglomerular apparatus

TOSS UP

8) EARTH AND SPACE *Short Answer* By name or number, arrange the following metamorphic rocks in order of increasing metamorphic grade.

1) Slate
2) Migmatite (*MIG-muh-tight*)
3) Gneiss (*NAIS*)
4) Phyllite (*FIE-lait*)

ANSWER: 1, 4, 3, 2

BONUS

8) EARTH AND SPACE *Short Answer* By name or number, identify all of the following three statements that are true of the Bowen's reaction series.

1) Minerals with higher crystallization temperatures tend to weather more easily
2) Plagioclase (*PLAY-jee-uh-klayz*) feldspar is the primary constituent of the continuous branch
3) Granite would be expected to have a larger proportion of minerals with high crystallization temperatures

ANSWER: 1 and 2

TOSS UP

9) ENERGY *Multiple Choice* Researchers in the Fakhri group at MIT are studying applications of theoretical physics to biological processes. Recently, they have shown that topological defects in starfish oocyte membranes are similar to the dynamics of vortices in Bose-Einstein Condensates. Which of the following atoms can form a Bose-Einstein Condensate?

W) Helium-4
X) Neon-21
Y) Sodium-22
Z) Lithium-8

ANSWER: W) Helium-4

BONUS

9) ENERGY *Multiple Choice* Researchers at the MIT-Harvard Center for Ultracold atoms are studying interactions between photons in a quantum nonlinear medium. They have shown that due to atomic interactions, photons in this medium aquire an effective mass. Which of the following correctly describes the result of this effective mass?

W) Photons in the medium now give off Cherenkov radiation
X) Photons in the medium no longer travel at the speed of light
Y) Photons in the medium no longer obey the conservation of momentum
Z) Photons in the medium behave identically to photons in a vacuum

ANSWER: X) Photons in the medium no longer travel at the speed of light

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TOSS UP

10) MATH *Short Answer* A train carries a certain number of passengers. At its first stop, 35% of the passengers leave the train. At the second stop, 24 passengers get off the train. At the third and final stop, all remaining passengers get off the train. The number of passengers who left at the third stop happened to be equal to the number of passengers who left at the first stop. How many passengers were originally on the train?

ANSWER: 80

BONUS

10) MATH *Short Answer* What is the range of the following function defined over all real numbers? $f(x) = (\cos(x) + 2)/(x^2 + 2)$. Give your answer in interval notation.

ANSWER: $(0, 3/2]$

TOSS UP

11) CHEMISTRY *Multiple Choice* Which of the following compounds is most reactive toward a unimolecular nucleophilic substitution reaction mechanism?

W) Methyl iodide
X) Ethyl iodide
Y) Isopropyl iodide
Z) Tert-butyl iodide

ANSWER: Z) Tert-butyl iodide

BONUS

11) CHEMISTRY *Short Answer* What is the formal charge on the nitrogen atom in the most stable Lewis structure of the thiocyanate ion?

ANSWER: -1

TOSS UP

12) PHYSICS *Short Answer* Which rule of thermodynamics gives an approximation to the molar specific heat capacity of certain elemental solids and states that their specific heat capacities are inversely proportional to their molar masses?

ANSWER: Dulong-Petit

BONUS

12) PHYSICS *Short Answer* By name or number, identify which of Maxwell's equations that would have to change if magnetic monopoles were discovered:

1) Gauss's law of electricity
2) Gauss's law of magnetism
3) Faraday's law
4) Ampere's law

ANSWER: 2 and 3

TOSS UP

13) CHEMISTRY *Short Answer* Sodium chloride, NaCl, crystallizes in a face-centered cubic lattice of chloride ions, with the sodium ions occupying the holes in between the chloride ions. How many Cl^- ions are in contact with any single Na^+ ion?

ANSWER: 6

BONUS

13) CHEMISTRY *Multiple Choice* Which of the following compounds has the longest wavelength absorbance maximum?

W) 1,2-pentadiene
X) 1,3-pentadiene
Y) 2,3-pentadiene
Z) 1,4-pentadiene

ANSWER: X) 1,3-pentadiene

TOSS UP

14) MATH *Short Answer* What is the slope of a line with y-intercept of 3 that goes through the point $(4, 1)$ (read: *4 comma 1*)?

ANSWER: $-1/2$

BONUS

14) MATH *Multiple Choice* You are told that a cubic function has an inflection point at the point $(4, 8)$. How many more points on the graph of the function would you need to be given to completely determine the cubic?

W) 0
X) 1
Y) 2
Z) 3

ANSWER: Y) 2

TOSS UP

15) BIOLOGY *Multiple Choice* Which of the following animals would exhibit a pulmocutaneous (*pull-moe-kyoo-TAY-nee-uss*) circuit?

W) Mammals
X) Reptiles
Y) Birds
Z) Amphibians

ANSWER: Z) Amphibians

BONUS

15) BIOLOGY *Short Answer* Given two parents that are heterozygous in 4 genes that follow a dominant-recessive inheritance pattern, what is the probability that the resulting child will be homozygous dominant for at least one trait?

ANSWER: 175/256

TOSS UP

16) ENERGY *Short Answer* Researchers in the Johnson group at MIT are focusing on polymer chemistry, with applications in hydrogel chemistry and energy production. Many of the polymers produced by this group involve multiple types of monomers, chained together. What are these polymers with different monomers known as?

ANSWER: Copolymers

BONUS

16) ENERGY *Short Answer* Researchers in the Cao group at MIT have been trying to develop mathematical models to describe colloidal suspensions for several years. What term is used to describe the random motion of particles suspended in a medium?

ANSWER: Brownian motion

TOSS UP

17) PHYSICS *Multiple Choice* Which of the following particles does NOT have a spin of 1?

W) Gluon
X) Z boson
Y) Photon
Z) Graviton

ANSWER: Z) Graviton

BONUS

17) PHYSICS *Short Answer* Tyler is performing an experiment in which he increases the temperature of an ideal gas from -23 degrees Celsius to 87 degrees Celsius. By what factor does the root-mean-square speed of the molecules in the gas change?

ANSWER: 1.2 (accept: 6/5)

TOSS UP

18) EARTH AND SPACE *Short Answer* Order the following three minerals from lowest to highest crystallization temperatures:

1) Olivine (*AW-luh-veen*)
2) Muscovite (*MUH-skuh-vait*)
3) Biotite

ANSWER: 2, 3, 1

BONUS

18) EARTH AND SPACE *Short Answer* What term describes the twin nebulae that often surround a newborn star that glows as a result of gas from bipolar flows?

ANSWER: Herbig-Haro object

TOSS UP

19) BIOLOGY *Multiple Choice* What type of survivorship curve do most fish exhibit?

W) Type I
X) Type II
Y) Type III
Z) Type IV

ANSWER: Y) Type III

BONUS

19) BIOLOGY *Short Answer* By name or number, identify all of the following four methods that can transform a proto-oncogene into an oncogene.

1) Amplification of the proto-oncogene
2) Translocation of the proto-oncogene
3) Point mutation in the promoter of a proto-oncogene
4) Point mutation in the enhancer of a proto-oncogene

ANSWER: 1, 2, 3, 4 (accept: all)

TOSS UP

20) CHEMISTRY *Multiple Choice* Which of the following metals has the lowest density?

W) Lithium
X) Beryllium
Y) Sodium
Z) Magnesium

ANSWER: W) Lithium

BONUS

20) CHEMISTRY *Short Answer* To one significant figure, how many grams of sodium hydroxide are required to titrate 12.6 grams of nitric acid?

ANSWER: 8

TOSS UP

21) PHYSICS *Multiple Choice* A rigid body is in static equilibrium with 1/5 of its volume above the surface of the liquid in which it is submerged. Which of the following is equal to the ratio of the density of the liquid to that of the rigid body?

W) 1/5
X) 5
Y) 4/5
Z) 5/4

ANSWER: Z) 5/4

BONUS

21) PHYSICS *Short Answer* A large ball of mass 100 kilograms is dropped from rest in Earth's gravitational field. Air resistance on the ball is known to be proportional to the square of its speed, with a constant coefficient of 1.25 kilograms per meter. Calculate the terminal speed of the ball, to the nearest meter per second.

ANSWER: 28

TOSS UP

22) EARTH AND SPACE *Short Answer* What is the brightest star in the constellation Auriga?

ANSWER: Capella

BONUS

22) EARTH AND SPACE *Short Answer* By name or number, identify all of the following three types of tectonic activity that can be observed bordering the Juan de Fuca plate:

1) Divergent
2) Convergent
3) Transform

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

TOSS UP

23) MATH *Short Answer* A spherical ice cream scoop of radius r is put in an ice cream cone of radius r. In terms of r, what is the smallest height the cone can be to make sure the ice cream, even if fully melted, does not overflow? You may assume the density of the ice cream is the same in solid and liquid states.

ANSWER: $4r$

BONUS

23) MATH *Multiple Choice* If a sphere of radius r was dropped into a cone of radius r and height $6r$, what is the percentage of the volume of the sphere that is in the cone?

W) Between 30% and 40%
X) Between 40% and 50%
Y) Exactly 50%
Z) Between 50% and 60%

ANSWER: X) Between 40% and 50%
