

2023 MIT Science Bowl High School Invitational

Round 7

TOSS UP

1) PHYSICS *Short Answer* Hollow spheres A and B are constructed with the same uniform surface density, but sphere A has twice the radius of sphere B. What is the ratio of the moment of inertia about the central axis of sphere A to that of sphere B?

ANSWER: 16

BONUS

1) PHYSICS *Multiple Choice* Two identical trains start at the same location on Earth and have the same speed, with the first train traveling east and the second train traveling west. Which of the following statements best describes the apparent weights of the two trains?

- W) The first train has a higher apparent weight than the second train
- X) The first train has a lower apparent weight than the second train
- Y) Both trains have the same apparent weight
- Z) The relationship between the apparent weights of the trains depends on which hemisphere they are in

ANSWER: X) The first train has a lower apparent weight than the second train

TOSS UP

2) CHEMISTRY *Short Answer* Identify all of the following 3 variables which remain constant during any single step in the Carnot cycle for an ideal gas:

- 1) Internal energy
- 2) Volume
- 3) Entropy

ANSWER: 1 and 3

BONUS

2) CHEMISTRY *Short Answer* Order the following three cations by increasing wavelength of the color produced by their flame tests:

- 1) Li^+
- 2) Na^+
- 3) K^+

ANSWER: 3, 2, 1

TOSS UP

3) ENERGY *Multiple Choice* Scientists at the Chen Lab at MIT are studying African Swine Fever Virus genome in hopes of developing an mRNA vaccine for the disease. Because the genome is so short, they can do restriction fragment length polymorphism analysis of different strains of the virus. To visualize the DNA in this process, which of the following compounds are they likely using?

- W) Coomassie Blue
- X) Sodium Dodecyl Sulfate
- Y) Ethidium Bromide
- Z) Eosin

ANSWER: Y) Ethidium Bromide

BONUS

3) ENERGY *Multiple Choice* MIT Scientists at the Edgerton Lab have been studying certain viral causes of Burkitt's lymphoma and mononucleosis. What family of viruses were they likely studying?

- W) Papillomaviridae (*PAP-ill-oh-ma-veer-ih-day*)
- X) Retroviridae
- Y) Poxviridae
- Z) Herpesviridae

ANSWER: Z) Herpesviridae

TOSS UP

4) BIOLOGY *Short Answer* The synergids (*SIN-er-jids*) in the ovule of a flowering plant each contain 11 chromosomes. How many chromosomes will the mature endosperm contain?

ANSWER: 33

BONUS

4) BIOLOGY *Short Answer* Identify all of the following three statements that are true regarding mimicry:

- 1) Batesian (*bait-s-ian*) mimicry involves a harmless species mimicking a harmful one
- 2) Mullerian mimicry is positively frequency dependent
- 3) Batesian mimicry is positively frequency dependent

ANSWER: 1 and 2

TOSS UP

5) EARTH AND SPACE *Multiple Choice* A squall line is most closely associated with what type of front?

- W) Cold
- X) Warm
- Y) Occluded
- Z) Stationary

ANSWER: W) Cold

BONUS

5) EARTH AND SPACE *Short Answer* Order the following three mid-ocean ridges from fastest to slowest spreading:

- 1) East Pacific Rise
- 2) Mid-Atlantic Ridge
- 3) Juan de Fuca Ridge

ANSWER: 1, 3, 2

TOSS UP

6) MATH *Multiple Choice* Three of the side lengths of a quadrilateral are 3, 4, and 5. How many possible integer side lengths are there for the fourth side?

- W) 10
- X) 11
- Y) 12
- Z) 13

ANSWER: X) 11

BONUS

6) MATH *Short Answer* The vector $(a, a^2, 2)$ (read: *a comma a squared comma two*) is orthogonal to the vector $(a, a^2, -3)$ (read: *a comma a squared comma negative three*). What is the largest possible real value of a ?

ANSWER: $\sqrt{2}$

TOSS UP

7) EARTH AND SPACE *Multiple Choice* As rain falls from a thunderstorm, it often cools down the surrounding air. What best explains this phenomenon?

- W) Condensation of raindrops absorbs latent heat
- X) Evaporation of raindrops absorbs latent heat
- Y) Rain from thunderstorms tend to be cool and absorb sensible heat
- Z) Water radiates heat more efficiently than air

ANSWER: X) Evaporation of raindrops absorbs latent heat

BONUS

7) EARTH AND SPACE *Short Answer* When organic matter is squeezed, it may become coal. In certain circumstances, the organic matter leaves behind what type of fossil that leaves behind a dark outline of the compressed matter?

ANSWER: Carbon Film (ACCEPT: Carbonaceous film, carbonized film)

TOSS UP

8) PHYSICS *Short Answer* A small mass is attached to one end of a massless spring with rest length zero, while the other end of the spring is attached to a fixed ceiling so that the spring hangs vertically. The equilibrium length of the spring is proportional to what power of the spring's resonant frequency?

ANSWER: -2

BONUS

8) PHYSICS *Short Answer* Let $f(v) = v^2 e^{-v^2}$ (read: *v squared times e to the negative v squared*), which represents the general shape of the velocity distribution of a gas in a container. If a small hole is poked in the side of the container and the gas is allowed to escape, the velocity profile of the escaping gas can be represented by $f(v)$ multiplied by v to what power?

ANSWER: 1

TOSS UP

9) ENERGY *Multiple Choice* Researchers in the Bawendi group at MIT are studying methods to precisely synthesize quantum dots. Which of the following quantum models best describes a quantum dot?

- W) 2-dimensional particle in a box
- X) 3-dimensional particle in a box
- Y) Rigid rotor
- Z) Quantum harmonic oscillator

ANSWER: X) 3-dimensional particle in a box

BONUS

9) ENERGY *Short Answer* Researchers in the Willard group at MIT are researching the dynamics of excited electrons trapped in conjugated molecular systems. Which of the following three materials are examples of conjugated molecular systems?

- 1) Graphene
- 2) Polystyrene
- 3) Polyaniline

ANSWER: 1 and 3

TOSS UP

10) MATH *Short Answer* For what value of a are the vectors $a\hat{i} + 2\hat{j} - 9\hat{k}$ (read: *a i hat plus two j hat minus nine k hat*) and $3\hat{i} - 4\hat{k}$ (read: *three i hat minus four k hat*) orthogonal?

ANSWER: -12

BONUS

10) MATH *Short Answer* What is the volume formed when the area between the function $f(x) = x^2$ (read: *f of x equals x squared*) and the x -axis from $x = 0$ to $x = 4$ is revolved about the y -axis?

ANSWER: 128π

TOSS UP

11) CHEMISTRY *Multiple Choice* Which of the following ligands is most likely to lead to the formation of a high-spin complex?

- W) Cyanide
- X) Fluoride
- Y) Ammonia
- Z) Phosphine

ANSWER: X) Fluoride

BONUS

11) CHEMISTRY *Short Answer* Rank the following three gases in terms of increasing root mean square speed according to the Maxwell-Boltzmann distribution:

- 1) Hydrogen at 200 kelvin
- 2) Helium at 200 kelvin
- 3) Nitrogen at 400 kelvin

ANSWER: 3, 2, 1

TOSS UP

12) BIOLOGY *Short Answer* Right before fertilization, what stage of meiosis are oocytes (*ooh-oh-sites*) arrested in?

ANSWER: Metaphase II

BONUS

12) BIOLOGY *Short Answer* In addition to lignin, what other main constituent of the Casparian strip helps ensure that water and minerals take the symplastic route to the vascular cylinder?

ANSWER: Suberin

TOSS UP

13) ENERGY *Multiple Choice* Researchers at MIT's Lincoln Laboratory are investigating Josephson junction-based superconducting circuits. Which of the following is NOT a property of a superconductor?

- W) Zero resistance
- X) Paramagnetism
- Y) Meissner effect
- Z) Critical temperature

ANSWER: X) Paramagnetism

BONUS

13) ENERGY *Short Answer* Researchers at MIT's Coley Group are applying computational methods to predict the mass spectra of various metabolites. Mass spectra plot relative abundance against what ratio?

ANSWER: Mass to charge ratio

TOSS UP

14) CHEMISTRY *Short Answer* Rank the following three elements in terms of increasing binding energy per nucleon:

- 1) Helium-4
- 2) Lithium-6
- 3) Carbon-12

ANSWER: 2, 1, 3

BONUS

14) CHEMISTRY *Multiple Choice* Which of the following is closest to the packing efficiency of a body-centered cubic lattice?

- W) 0.52
- X) 0.61
- Y) 0.68
- Z) 0.74

ANSWER: Y) 0.68

TOSS UP

15) MATH *Multiple Choice* If the base ten logarithm of 2 is 0.301 and the base ten logarithm of 3 is 0.477, then which of the following whole numbers is closest to the base ten logarithm of 6^{1000} (read: *6 raised to the power of 1000*)?

- W) 770
- X) 780
- Y) 790
- Z) 800

ANSWER: X) 780

BONUS

15) MATH *Short Answer* Amazon has small boxes and large boxes. The small boxes have dimensions of 5 inches by 6 inches by 7 inches. The large boxes have dimensions of 11 inches by 13 inches by 15 inches. What is the maximum number of small boxes that can fit in a large box?

ANSWER: 8

TOSS UP

16) EARTH AND SPACE *Multiple Choice* Jupiter's clouds are commonly classified into three layers. Which of the following molecules is the primary constituent of the uppermost, visible layer?

- W) Ammonia
- X) Methane
- Y) Nitrogen
- Z) Water

ANSWER: W) Ammonia

BONUS

16) EARTH AND SPACE *Multiple Choice* Which of the following best explains what molecule is commonly used to map molecular clouds and why?

- W) Hydrogen gas is used because it is the most common
- X) Hydrogen gas is used because it radiates radio wavelengths well
- Y) Carbon monoxide is used because it is the second most common
- Z) Carbon monoxide is used because it radiates radio wavelengths well

ANSWER: Z) Carbon monoxide is used because it radiates radio wavelengths well

TOSS UP

17) BIOLOGY *Multiple Choice* Which of the following missense mutations would you expect to have the least impact on a protein's function?

- W) Methionine (*meth-THIGH-oh-neen*) to Valine (*VAY-leen*)
- X) Leucine (*LOO-seen*) to Lysine (*LAI-seen*)
- Y) Serine (*SAYR-een*) to Tyrosine (*TIE-roh-seen*)
- Z) Histidine (*HISS-tih-deen*) to Tryptophan (*TRIP-toe-fan*)

ANSWER: W) Methionine to Valine

BONUS

17) BIOLOGY *Short Answer* Identify all of the following four mechanisms that could enable a proto-oncogene to turn into an oncogene:

- 1) Histone acetylation (*ah-SEE-tul-ation*) surrounding the proto-oncogene
- 2) Translocation of the proto-oncogene under a new promoter
- 3) Duplication of the proto-oncogene
- 4) Point mutation within the proto-oncogene

ANSWER: 1, 2, 3, and 4 (ACCEPT: All)

TOSS UP

18) PHYSICS *Short Answer* The orbital angular momentum of an electron around a nucleus is always a multiple of what fundamental physical constant?

ANSWER: Reduced Planck's constant (ACCEPT: \hbar , DO NOT ACCEPT: Planck's constant, h)

BONUS

18) PHYSICS *Short Answer* A toy pig with mass 1 kilogram is attached to the ceiling via a string, and given a velocity of 12 meters per second such that it undergoes uniform circular motion with a radius of 6 meters. Taking g to be 10 meters per second squared, in newtons, what is the tension in the string?

ANSWER: 26

TOSS UP

19) EARTH AND SPACE *Multiple Choice* Which cosmological distance is equivalent to the proper distance at the present time?

- W) Relativistic Distance
- X) Luminosity Distance
- Y) Angular Distance
- Z) Comoving Distance

ANSWER: Z) Comoving distance

BONUS

19) EARTH AND SPACE *Multiple Choice* The magnetic fields of black holes can be best studied via what type of observations?

- W) Polarization of light emitted from the accretion disk
- X) Polarization of light emitted from G objects
- Y) Slight differences in detected neutrino flavors from the blackhole
- Z) Observed deflection and acceleration of broadline regions

ANSWER: W) Polarization of light emitted from the accretion disk

TOSS UP

20) CHEMISTRY *Multiple Choice* Which of the following compounds is closest to having a covalent bond?

- W) LiF
- X) LiCl
- Y) AlF_3
- Z) AlCl_3

ANSWER: Z) AlCl_3

BONUS

20) CHEMISTRY *Multiple Choice* Which of the following pairs of systems would have the same total entropy as a 2 liter box with 2 moles of gas?

- W) 2 boxes of volume 1 liter, each with 1 mole of gas
- X) 2 boxes of volume 1 liter, each with $\ln(2)$ (read: *natural log of 2*) moles of gas
- Y) 2 boxes of volume $\ln(2)$, each with 1 mole of gas
- Z) 2 boxes of volume 1 liter, each with 2 moles of gas

ANSWER: X) 2 boxes of volume 1 liter, each with $\ln(2)$ moles of gas

TOSS UP

21) MATH *Short Answer* How many natural numbers have two digits in both base 4 and base 5?

ANSWER: 11

BONUS

21) MATH *Short Answer* In a particular sequence a_i (read: *a sub i*), every term is the sum of the previous two terms. Let a_2 equal 5 and a_6 equal 1. What is the value of a_1 ?

ANSWER: -8

TOSS UP

22) PHYSICS *Multiple Choice* A skydiver is falling directly downwards, reaching a terminal velocity of 40 meters per second. In meters per second, if the density of air were quadrupled, what would be the new terminal velocity of the skydiver?

- W) 2.5
- X) 10
- Y) 20
- Z) 40

ANSWER: Y) 20

BONUS

22) PHYSICS *Short Answer* An ideal diatomic gas has an average energy of 3000 joules per mole. In joules per mole, what is the average translational energy of the gas?

ANSWER: 1800

TOSS UP

23) BIOLOGY *Short Answer* When auxin causes protons to be pumped into the cell wall, hydrogen bonds between cellulose microfibrils and other cell wall components are broken by which group of proteins?

ANSWER: Expansins

BONUS

23) BIOLOGY *Short Answer* You survey an area and find 10 oak trees, 5 pine trees, and 5 fir trees. Identify all of the following three changes that would increase the Shannon diversity index of this area:

- 1) Planting five birch trees
- 2) Cutting down five pine trees
- 3) Cutting down five oak trees

ANSWER: 1 and 3