2024 MIT Science Bowl High School Invitational

Round 7

TOSS UP

1) PHYSICS *Short Answer* In seconds, what is the proper time of a photon traveling along the world line between two events separated in space by 90 million kilometers in Earth's reference frame?

ANSWER: 0

BONUS

1) PHYSICS *Short Answer* Two 1 microcoulomb charges with masses of 1 kilogram each are placed at varying distances apart, and the magnitudes of their initial accelerations are measured. The square root of the acceleration measurements is then graphed against the inverse of the distance of separation. To one significant figure, what is the slope of this graph?

ANSWER: 0.1

TOSS UP

2) CHEMISTRY *Multiple Choice* In which of the following unit cells are atoms octahedrally coordinated?

W) Simple cubic
X) Body-centered cubic
Y) Face-centered cubic
Z) Hexagonal closest packing

ANSWER: W) Simple cubic

BONUS

2) CHEMISTRY *Short Answer* Rank the following three aryl halides by increasing strength of the carbon halogen bond:

1) Phenyl fluoride
2) Phenyl chloride
3) Phenyl iodide

ANSWER: 3, 2, 1

TOSS UP

3) ENERGY *Multiple Choice* Researchers in the Kulik Group at MIT are studying enzyme catalysis. Which of the following is true regarding Michaelis-Menten enzyme kinetics?

 W) The rate of product formation is proportional to the concentration of substrate
 X) Michaelis-Menten kinetics is applicable to enzymes that exhibit cooperativity
 Y) The steady-state approximation cannot be used in situations described by Michaelis-Menten kinetics
 Z) The Michaelis constant is equal to the substrate concentration at half-maximal product formation

ANSWER: Z) The Michaelis constant is equal to the substrate concentration at half-maximal product formation

BONUS

3) ENERGY *Multiple Choice* Researchers in the Kulik group at MIT are using generative artificial intelligence to predict the transition states of chemical reactions. One of these reactions, nucleophilic attack on a carbonyl, is predicted to have a bimolecular transition state with the nucleophile at which of the following angles relative to the carbonyl, in degrees?

 W) 71
 X) 90
 Y) 109
 Z) 120

ANSWER: Y) 109

TOSS UP

4) BIOLOGY *Short Answer* The glyoxylate shunt in plants bypasses the carbon liberating steps of a particular major metabolic cycle, allowing the seed to synthesize complex sugars like malate and oxaloacetate from two-carbon precursors. What is the name of this major metabolic cycle?

ANSWER: Krebs cycle (ACCEPT: Tricarboxylic acid cycle, Citric acid cycle)

BONUS

4) BIOLOGY *Multiple Choice* On the evolutionary tree, which of the following phyla is least related to Arthropoda?

  W) Mollusca
  X) Chordata (*kor-dah-tah*)
  Y) Cnidaria (*Nye-dare-ee-ah*)
  Z) Echinodermata (*Eh-kine-oh-der-mah-tah*)

ANSWER: Y) Cnidaria (*Nye-dare-ee-ah*)

---

5) EARTH AND SPACE *Short Answer* Rank the following three planets by increasing day length:

   1) Venus
   2) Mars
   3) Jupiter

ANSWER: $3, 2, 1$

BONUS

5) EARTH AND SPACE *Multiple Choice* From which of the following chemical sources do cold seep ecosystems on the ocean floor derive their energy?

   W) Geothermal activity
   X) Methane Clathrate Bond Energy
   Y) Petroleum Bond Energy
   Z) Iron Oxide Oxidation Energy

ANSWER: Y) Petroleum Bond Energy

TOSS UP

6) MATH *Multiple Choice* On the island of Timlandia, citizens pay an identical monthly tax using two forms of currency: bits and bots. If Alice pays using 7 bits and 2 bots, while Bob pays using 4 bits and 4 bots, which of the following could Charlie use to pay the same tax?

  W) 1 bit and 6 bots
  X) 5 bits and 3 bots
  Y) 9 bits and 1 bot
  Z) 11 bits

ANSWER: W) 1 bit and 6 bots

BONUS

6) MATH *Short Answer* Given r is a real number, what is the maximum number of intersections between the equations $y = x^2 - 4x + 7$ and $x^2 + y^2 - 4x - 6y = r$?

ANSWER: 2

TOSS UP

7) EARTH AND SPACE *Short Answer* Kyanite, andalusite, and sillimanite are all mineral polymorphs that share what chemical formula?

ANSWER: Al_2SiO_5

BONUS

7) EARTH AND SPACE *Short Answer* Starburst galaxies emit the majority of their light in which region of the electromagnetic spectrum?

ANSWER: Infrared

TOSS UP

8) PHYSICS *Short Answer* What circuit element is used in a rectifier to allow current to flow in only one direction?

ANSWER: Diode

BONUS

8) PHYSICS *Short Answer* A flat hollow washer with mass 4 kilograms, uniformly distributed, has an inner radius of 3 meters and outer radius 5 meters. What is its moment of inertia about its diameter?

ANSWER: 34

TOSS UP

9) ENERGY *Multiple Choice* Researchers at MIT CSAIL's computational biology group have been optimizing computer architectures for sequence alignment. When aligning two protein sequences, algorithms must account for the varying probabilities of different mutations. Which of the following mutations is least likely to occur in the middle of a highly conserved housekeeping gene?

  W) Silent
  X) Missense
  Y) Nonsense
  Z) Triple Base Pair Deletion

ANSWER: Y) Nonsense

BONUS

9) ENERGY *Short Answer* Researchers at MIT CSAIL's Machine Learning group are developing cutting-edge generative AI models. Early generative AI models were based on what sequential representation of a memoryless stochastic process?

ANSWER: Markov Chain (ACCEPT: Hidden Markov Model)

TOSS UP

10) MATH *Short Answer* How many 2 digit numbers are there where the sum of the two digits is even?

ANSWER: 45

BONUS

10) MATH *Short Answer* A sequence starts with the terms 360 and 195. Each subsequent term is the absolute difference of the previous 2 terms. Which non-zero number appears infinitely many times in this sequence?

ANSWER: 15

TOSS UP

11) CHEMISTRY *Multiple Choice* Which of the following salts will produce a saturated solution with the highest pH?

  W) Potassium nitrate
  X) Iron (III) chloride
  Y) Potassium bisulfate
  Z) Ammonium nitrate

ANSWER: W) Potassium nitrate

BONUS

11) CHEMISTRY *Multiple Choice* Which of the following best describes the electrons filling the highest occupied molecular orbital of carbon dioxide?

  W) Bonding pi electrons
  X) Antibonding pi electrons
  Y) Bonding sigma electrons
  Z) Nonbonding electrons

ANSWER: Z) Nonbonding electrons

TOSS UP

12) BIOLOGY *Multiple Choice* Which of the following best contrasts the anatomy of fast pain and slow pain nerve fibers?

  W) Fast pain fibers are wider and less myelinated
  X) Fast pain fibers are wider and more myelinated
  Y) Fast pain fibers are narrower and less myelinated
  Z) Fast pain fibers are narrower and more myelinated

ANSWER: X) Fast pain fibers are wider and more myelinated

BONUS

12) BIOLOGY *Short Answer* Identify all of the following three statements that are accurate regarding cellular respiration:

  1) The efficiency of chemiosmosis is reduced in brown fat
  2) The action of hexokinase traps glucose inside the cell
  3) Fermentation in humans produces carbon dioxide.

ANSWER: 1 and 2

TOSS UP

13) ENERGY *Multiple Choice* MIT Scientists at the Koch institute are studying compounds derived from tryptophan. Which of the following compounds would they NOT be studying?

W) Serotonin
X) Auxin
Y) Melatonin
Z) Prostacyclin

ANSWER: Z) Prostacyclin

BONUS

13) ENERGY *Short Answer* Physicists in the MIT Center for Theoretical Physics are studying quantum gravity. What is the characteristic length scale for gravitational effects?

ANSWER: Planck length

TOSS UP

14) CHEMISTRY *Multiple Choice* Which of the following organic compounds is the most soluble in water?

W) n-propanol
X) n-butanol
Y) n-pentanol
Z) n-hexanol

ANSWER: W) n-propanol

BONUS

14) CHEMISTRY *Multiple Choice* Among the following four carbonate salts, which one has the lowest decomposition temperature?

W) Magnesium carbonate
X) Calcium carbonate
Y) Strontium carbonate
Z) Barium carbonate

ANSWER: W) Magnesium carbonate

TOSS UP

15) MATH *Multiple Choice* How many times does the curve $x = 3y^2 - 5y + 4$ (read: *x equals three y squared minus five y plus four*) intersect the x- and y-axes, respectively?

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

ANSWER: Y) 1, 0

BONUS

15) MATH *Short Answer* Cyan lives in Arizona. Her wall thermometer shows that both the Celsius and Fahrenheit temperatures are currently positive integers ending in zero. What is the least possible three-digit Fahrenheit temperature that Cyan could be measuring?

ANSWER: 140

TOSS UP

16) EARTH AND SPACE *Multiple Choice* Researchers at the European Southern Observatory are planning the Overwhelmingly Large Telescope, which will have a main mirror with a diameter of 100 meters. Which of the following telescope mounts is most likely to be used for the Overwhelmingly Large Telescope?

  W) Altazimuth mount
  X) Transit mount
  Y) Equatorial mount
  Z) Hexapod mount

ANSWER: Y) Equatorial mount

BONUS

16) EARTH AND SPACE *Multiple Choice* Which of the following is correct regarding magma series?

  W) Tholeiitic magmas have a consistent decrease in iron relative to magnesium and aluminum, while calc-alkaline magmas see a peak in relative iron concentration midway through evolution
  X) Calc-alkaline magmas is found in hotspots, while tholeiitic magmas are found in convergent plate boundaries
  Y) Tholeiitic magmas are less oxidized than Calc-alkaline magmas
  Z) Calc-alkaline lava formed the majority of basalt on the moon

ANSWER: Y) Tholeiitic magmas are less oxidized than Calc-alkaline magmas

TOSS UP

17) BIOLOGY *Multiple Choice* Which of the following single amino acid substitutions would be most detrimental to protein structure?

W) Leucine to valine
X) Arginine to lysine
Y) Serine to threonine (*THREE-in-een*)
Z) Tryptophan (*TRIPPED-oh-fan*) to asparagine (*us-PAIR-uh-jean*)

ANSWER: Z) Tryptophan (*TRIPPED-oh-fan*) to asparagine (*us-PAIR-uh-jean*)

BONUS

17) BIOLOGY *Short Answer* Identify all of the following three characteristics that would lead to a positive Allee effect:

1) Reciprocal altruism
2) Living in colonies
3) Presence of transmissible disease.

ANSWER: 1 and 2

18) PHYSICS *Short Answer* Adeline has an insulating and infinitely long, solid cylinder of radius 1 meter with uniform volume charge density. What is the ratio between the magnitude of the electric field at a point located 0.5 meters from the center of the cylinder and a point located 3 meters from the center?

ANSWER: 1.5

BONUS

18) PHYSICS *Short Answer* Tavishi is riding a vehicle that exerts a constant power. Assuming that the vehicle starts from rest and that all of the exerted power goes toward its motion, to what power of time is the vehicle's displacement proportional to?

ANSWER: 1.5

TOSS UP

19) EARTH AND SPACE *Short Answer* In oceanography, what term describes the ratio of nutrients in algae tissue given that there are no limiting nutrients?

ANSWER: Redfield Ratio

BONUS

19) EARTH AND SPACE *Short Answer* To one significant figure, what is the speed of a shallow ocean wave's propagation if the wavelength of the wave is 150 meters, the wave's height is 2 meters, and the wave's depth of 5 meters?

ANSWER: 7

TOSS UP

20) CHEMISTRY *Multiple Choice* Joe is analyzing how the vapor pressure of a liquid varies with its temperature. Plotting which of the following quantities against each other would yield a linear relationship?

  W) Pressure against temperature
  X) The logarithm of pressure against temperature
  Y) Pressure against the reciprocal of temperature
  Z) The logarithm of pressure against the reciprocal of temperature

ANSWER: Z) The logarithm of pressure against the reciprocal of temperature

BONUS

20) CHEMISTRY *Short Answer* Identify all of the following three metal ions that will form paramagnetic octahedral coordination complexes with cyanide:

  1) Titanium (III)
  2) Iron (II)
  3) Nickel (II)

ANSWER: 1 and 3

TOSS UP

21) MATH *Multiple Choice* Which of the following expressions is a factor of the expression $a^{210} + b^{210}$ (read: *quantity a to the power of two hundred ten plus quantity b to the power of two hundred ten*)?

  W) $a^2 + b^2$ (read: *quantity a to the power of two plus quantity b to the power of two*)
  X) $a^3 + b^3$ (read: *quantity a to the power of three plus quantity b to the power of three*)
  Y) $a^5 + b^5$ (read: *quantity a to the power of five plus quantity b to the power of five*)
  Z) $a^7 + b^7$ (read: *quantity a to the power of seven plus quantity b to the power of seven*)

ANSWER: W) $a^2 + b^2$ (read: *quantity a to the power of two plus quantity b to the power of two*)

BONUS

21) MATH *Multiple Choice* The point at which the quadratic $ax^2 + bx + c$ is closest to the origin is the point $(\frac{1}{2}, -\frac{1}{4})$ (read: *One-half comma negative one-fourth*). What is the slope of the tangent line to the quadratic at this point?

  W) -2
  X) -0.5
  Y) 0.5
  Z) 2

ANSWER: Z) 2

TOSS UP

22) PHYSICS *Multiple Choice* Which of the following particles obeys Fermi-Dirac statistics?

  W) Kaon
  X) Neutrino
  Y) Gluon
  Z) Graviton

ANSWER: X) Neutrino

BONUS

22) PHYSICS *Multiple Choice* A particle moves in the $x - y$ plane with potential energy $U = x^2 - y^2$ (read: *U equals x squared minus y squared*). At which of the following points is the particle at mechanical equilibrium?

  W) (1, 1)
  X) (1, -1)
  Y) (-1, -1)
  Z) (0, 0)

ANSWER: Z) (0, 0)

TOSS UP

23) BIOLOGY *Multiple Choice* What class of lipid-based plant hormones containing a five-carbon ring is known to promote fertility in flowers, inhibit germination, and mediate the release of methylsalicylic acid in systemic acquired resistance?

  W) Jasmonates
  X) Gibberellins (*JIB-er-el-ins*)
  Y) Strigolactones (*strig-OH-lac-tones*)
  Z) Brassinosteroids (*brass-in-OH-ster-oids*)

ANSWER: W) Jasmonates

BONUS

23) BIOLOGY *Short Answer* Tenz is studying reaction time and notices that, following the administration of caffeine to his bloodstream, his reaction time DECREASES. Caffeine's mechanism of action involves it acting as a competitive inhibitor of the receptor for what substance in the brain that causes drowsiness?

ANSWER: Adenosine