2023 MIT Science Bowl High School Invitational Round 9

TOSS UP

1) MATH *Multiple Choice* What is the coefficient of x^2y^2 (read: *x squared y squared*) in the expansion of $(x + 3y)^4$ (read: *the quantity x plus three y all to the fourth power*)?

W) 6
X) 18
Y) 54
Z) 162

ANSWER: Y) 54

BONUS

1) MATH *Short Answer* When the base 16 number 33333_{16} is written in base 2, how many base 2 digits does it have?

ANSWER: 18

TOSS UP

2) ENERGY *Short Answer* MIT undergrads working at the Griffith Lab have been studying fibronectin derived adhesion peptides and how they can form a synthetic extracellular matrix. Fibronectin is a protein in the ECM known to bind to which cell surface receptors that bind to micofilaments in the cytoplasm?

ANSWER: Integrins

BONUS

2) ENERGY *Multiple Choice* The Weissman Lab at MIT is using methods such as ribosome profiling to determine the levels of mRNA that are bound to ribosomes and are therefore destined for protein synthesis. Ribosome profiling is used as an alternative to what technique that measures the levels of ALL cytosolic mRNA molecules?

W) Northern blotting
X) RT-PCR
Y) RNA-seq
Z) FISH

ANSWER: Y) RNA-seq

TOSS UP

3) PHYSICS *Short Answer* In some inertial reference frame, two events happen one second apart at a distance of 1 astronomical unit apart. Identify all of the following three statements that are true about the two events:

1) There exists an inertial reference frame in which the two events occur at the same time
2) There exists an inertial reference frame in which the two events occur at the same position
3) There exists an inertial reference frame in which a beam of light emitted at the first event reaches the second event.

ANSWER: 1 only

BONUS

3) PHYSICS *Short Answer* A ladder weighing 60 newtons leans against a frictionless wall, forming an angle of 60 degrees with the horizontal. What is the magnitude of the force exerted by the ladder against the wall in newtons? Assume g equals 10 meters per second squared.

ANSWER: $\frac{10\sqrt{3}}{3}$

TOSS UP

4) CHEMISTRY *Short Answer* What type of nuclear decay is expected for light elements below the nuclear drip line?

ANSWER: Beta-plus decay (ACCEPT: Positron emission)

BONUS

4) CHEMISTRY *Multiple Choice* Ne (*Neigh*) is using Tollen's reagent in his UROP. Which of the following molecules will produce a characteristic "silver mirror" when he adds Tollens reagent?

W) Acetone
X) Acetaldehyde (*ass-it-TAL-dehide*)
Y) Ethanol
Z) Acetic Acid

ANSWER: X) Acetaldehyde

TOSS UP

5) EARTH AND SPACE *Multiple Choice* To one significant figure, by what factor would the speed of a shallow water wave on Mars be compared to Earth, given that Martian gravity is around 38% that of Earth, and the water waves are travelling in water columns of the same height?

W) 0.4
X) 0.6
Y) 0.8
Z) 1

ANSWER: X) 0.6

BONUS

5) EARTH AND SPACE *Short Answer* Identify all of the following three molecules that would be expected to be found at elevated abundances near a cold seep relative to elsewhere on the ocean floor:

1) Methane
2) Hydrogen Sulfide
3) Carbon Dioxide

ANSWER: All

TOSS UP

6) BIOLOGY *Multiple Choice* You are studying a mutant plant, that grows shorter, thicker, and more horizontally relative to its wild-type counterparts. Which of the following mutations would be consistent with these observations?

W) A loss-of-function mutation of ethylene (*ETH-ul-een*) receptors
X) A loss-of-function mutation of an inhibitor of ethylene signal transduction
Y) A mutation causing overproduction of abscisic (*ab-SIZZ-ic*) acid
Z) A loss-of-function mutation of a kinase (*KAI-nase*) involved in abscisic acid signal transduction

ANSWER: X) A loss-of-function mutation of an inhibitor of ethylene signal transduction

BONUS

6) BIOLOGY *Short Answer* Identify all of the following four conditions that would decrease transpiration rate of an angiosperm:

1) Increasing leaf surface area
2) Increasing environmental humidity
3) Secreting abscisic acid from the plant
4) Increasing the water potential of the soil relative to the inside of the root

ANSWER: 2 and 3

TOSS UP

7) ENERGY *Multiple Choice* Researchers in the Schlau-Cohen Lab at MIT are studying energy transfer in light-harvesting complexes. Which of the following types of microscopy are the scientists using to image these membrane-embedded proteins?

W) Confocal microscopy
X) Cryogenic electron microscopy
Y) Scanning electron microscopy
Z) Transmission electron microscopy

ANSWER: X) Cryogenic electron microscopy

BONUS

7) ENERGY *Short Answer* Researchers from the Imperiali Lab at MIT are studying N-linked glycosylation across different domains of life. N-linked glycosylation couples an oligosacharide with what functional group in asparagine?

ANSWER: Amide

TOSS UP

8) CHEMISTRY *Short Answer* Rank the following three types of carbon-hydrogen bonds in terms of increasing bond dissociation energy:

1) Primary
2) Vinylic
3) Allylic

ANSWER: 3, 1, 2

BONUS

8) CHEMISTRY *Short Answer* Rank the following three conformations of butane by increasing energy:

1) Anti
2) Eclipsed
3) Gauche

ANSWER: 1, 3, 2

TOSS UP

9) EARTH AND SPACE *Short Answer* What term describes the texture of certain sedimentary rocks that includes rounded, accretionary grains, such as bauxite?

ANSWER: Pisolitic

BONUS

9) EARTH AND SPACE *Multiple Choice* Which of the following observations would be able to differentiate a hydraulic and hydrostatic pingo?

W) Prescence of ice in the center of the pingo
X) Located in a periglacial region
Y) Annual growth of the hill's size
Z) Located near a river

ANSWER: Y) Annual growth of the hill's size

TOSS UP

10) BIOLOGY *Multiple Choice* Notch signaling involves the binding of extracellular Notch receptors to ligands on adjacent cell membranes. Which of the following types of cell signaling correctly classifies Notch signaling?

W) Autocrine
X) Juxtacrine
Y) Paracrine
Z) Endocrine

ANSWER: X) Juxtacrine

BONUS

10) BIOLOGY *Short Answer* A bear consumes 400 kilojoules of food. Of this, 150 kilojoules are excreted in waste products, 120 kilojoules are used in cellular respiration, and 130 kilojoules were used to make new biomass. As a percentage, what is the production efficiency of this bear?

ANSWER: 52%

TOSS UP

11) PHYSICS *Multiple Choice* A conducting wire is placed on the z-axis, and carries a current in the positive z-direction. An electron is placed at position $(2, 0, 0)$ (read: *two comma zero comma zero*) meters and given an initial velocity of $(1, 0, 0)$ (read: *one comma zero comma zero*) meters per second. What is the initial direction of the net force on the electron?

W) Positive z direction
X) Negative z direction
Y) Positive y direction
Z) Negative y direction

ANSWER: X) Negative z direction

BONUS

11) PHYSICS *Short Answer* The Sun's radius and average distance from the Earth are each 400 times greater than that of the moon, while the moon's mass is 40 nano-solar masses. To the nearest ten percent, the tidal force exerted by the Sun on the Earth is what percent of the tidal force exerted by the Moon on the Earth?

ANSWER: 40%

TOSS UP

12) MATH *Short Answer* In graph theory, what is the name of a graph in which every pair of vertices are connected with a unique edge?

ANSWER: Complete graph

BONUS

12) MATH *Short Answer* Triangle ABC is constructed such that side AB has length 13, side BC has length 14, and side AC has length 15. What is the tangent of angle C?

ANSWER: $\frac{4}{3}$

TOSS UP

13) EARTH AND SPACE *Short Answer* Order the following four planetary bodies in order of increasing axial tilt, assuming rotation is defined to be counterclockwise looking from above the plane of the solar system:

1) Mercury
2) Venus
3) Earth
4) Uranus

ANSWER: 1, 3, 4, 2

BONUS

13) EARTH AND SPACE *Short Answer* Identify the following three statements that are true regarding globular clusters:

1) They may be torn apart to form tidal streams
2) Massive objects tend to drift inward with time
3) Hypernovae are often observed within globular clusters

ANSWER: 1, 2

TOSS UP

14) MATH *Short Answer* Arjun has one quarter, one dime, one nickel, and one penny. Using at least one coin from his collection, how many different sums of money are possible?

ANSWER: 15

BONUS

14) MATH *Short Answer* Let S be the set of the first five positive integers. Let P be the power set of S. To the nearest power of 10, how many subsets of P are there?

ANSWER: 10^9

TOSS UP

15) PHYSICS *Multiple Choice* Which of the following is a property of the vector field describing a central force?

W) The divergence of the field is zero everywhere
X) The divergence of the field is non-zero everywhere
Y) The curl of the field is zero everywhere
Z) The curl of the field is non-zero everywhere

ANSWER: Y) The curl of the field is zero everywhere

BONUS

15) PHYSICS *Short Answer* A simple pendulum consists of a 10 kilogram mass swinging from a 5 meter long massless string. During the course of the swing, the mass makes a maximum angle of 60 degrees with the vertical. In newtons, at that moment, when the mass is stationary, what is the tension in the string?

ANSWER: 49

TOSS UP

16) ENERGY *Short Answer* Scientists in the Lee group at MIT are part of the CMS collaboration at the large hadron collider, where they are colliding energetic jets of particles in search of new physics. The scattering rates of these particle collisions are computed theoretically using what diagrammatic technique from quantum field theory, where the propogation and interaction of particles are represented by lines and vertices?

ANSWER: Feynman diagrams

BONUS

16) ENERGY *Short Answer* Researchers in the Jarillo-Herrero group are studying the electronic properties of magic-angle graphene. A single layer of graphene is part of what class of materials, where the top of the valence band just barely touches the bottom of the conduction band?

ANSWER: Semimetal

TOSS UP

17) CHEMISTRY *Short Answer* To the nearest power of 10 in Kelvin, a blackbody with peak radiation around 3 nanometers is at what temperature?

ANSWER: 10^3 (ACCEPT: 1000)

BONUS

17) CHEMISTRY *Multiple Choice* Which of the following crown ethers will best solvate a sodium cation?

W) 12-crown-4
X) 15-crown-5
Y) 18-crown-6
Z) 21-crown-7

ANSWER: X) 15-crown-5

TOSS UP

18) BIOLOGY *Multiple Choice* Which of the following animal phyla (*FIE-luh*) is NOT a protostome?

W) Hemichordata
X) Mollusca
Y) Annelida
Z) Rotifera

ANSWER: W) Hemichordata

BONUS

18) BIOLOGY *Short Answer* Suppose a certain diploid cell contains 8 chromosomes. If two nondisjunction events occur in the same cell during meiosis II but no nondisjunction events occur during meiosis I, how many chromosomes will the resulting gametes with fewer chromosomes contain?

ANSWER: 2

TOSS UP

19) CHEMISTRY *Multiple Choice* Which of the following molecular orbitals, constructed from the 2p orbitals of Boron, is the lowest energy?

W) Sigma bonding
X) Pi bonding
Y) Sigma antibonding
Z) Pi antibonding

ANSWER: X) Pi bonding

BONUS

19) CHEMISTRY *Short Answer* Identify all of the following three reagents that will reduce an ester to an alcohol:

1) $LiBH_4$
2) $NaBH_4$
3) $LiAlH_4$

ANSWER: 1 and 3

TOSS UP

20) EARTH AND SPACE *Multiple Choice* Currently, our galactic neighborhood is rather quiet. How far out would we begin to start expecting observations of quasars?

W) 50,000 light years
X) 1 million light years
Y) 50 million light years
Z) 1 billion light years

ANSWER: Z) 1 billion light years

BONUS

20) EARTH AND SPACE *Short Answer* Order the following three satellites from earliest to latest in the observation of the cosmic microwave background radiation.

1) Cosmic Background Explorer
2) Wilkinson Microwave Anisotropy Probe
3) Planck Satellite

ANSWER: 1, 2, 3

TOSS UP

21) BIOLOGY *Multiple Choice* Which of the following proteins would one expect to have the highest rates of ubiquitination (*you-BICK-kwi-tination*) and subsequent degradation?

W) Phosphofructokinase (*FOSS-foe-FROOCK-toe-KAI-nase*)
X) Collagen
Y) Cyclin
Z) Protein kinase A

ANSWER: Y) Cyclin

BONUS

21) BIOLOGY *Multiple Choice* Joints between which of the following bone pairs does NOT include a synovial (*sin-NO-vee-ul*) joint?

W) Femur and tibia
X) Metacarpals and phalanges (*fa-LAN-jeez*)
Y) Radius and ulna
Z) Scapula and humerus

ANSWER: Y) Radius and ulna

TOSS UP

22) PHYSICS *Short Answer* A person drops a ball from the top of a tower. Identify all of the following three forces which act on the ball, in the reference frame of an observer standing on top of the building:

1) Gravity
2) Coriolis
3) Centrifugal

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

BONUS

22) PHYSICS *Short Answer* A ramp is placed at the bottom of a hill such that objects that roll onto the ramp exit with a perfectly vertical velocity. If a frictionless block that starts at the top of the hill reaches a peak height of 3 meters after leaving the slope, what is the peak height in meters of a solid cylinder that is rolled down the hill?

ANSWER: 2

TOSS UP

23) MATH *Multiple Choice* Rhombus $ABCD$ has sidelength 13. Which of the following cannot be the area of $ABCD$?

W) 13
X) 65
Y) 144
Z) 170

ANSWER: Z) 170

BONUS

23) MATH *Short Answer* What are the coordinates of the point on the line $y = 2x - 3$ (read: *y equals two x minus three*) that is closest to the origin?

ANSWER: $(\frac{6}{5}, -\frac{3}{5})$ (read: *six over five comma negative three over five*)