2023 MIT Science Bowl High School Invitational Round 10

TOSS UP

1) EARTH AND SPACE *Multiple Choice* Which of the following would suppress hurricane formation?

W) Weak vertical wind shear
X) Warmer than average sea surface temperatures
Y) Moving onto the equator as a tropical depression
Z) Prescence of a strong tropical wave

ANSWER: Y) Moving onto the equator as a tropical depression

BONUS

1) EARTH AND SPACE *Multiple Choice* Wollastonite is an important intermediate mineral in the long term carbonate cycle that stores carbon in the form of carbonate minerals and incorporates them into the mantle. Which of the following is the chemical formula for wollastonite?

W) $CaCO_3$
X) $CaSiO_3$
Y) SiO_2
Z) $MgCO_3$

ANSWER: X) $CaSiO_3$

TOSS UP

2) PHYSICS *Multiple Choice* A car with mass 1000 kilograms is driving forward starting from rest, with its engines outputting a constant power of 20,000 watts. Neglecting energy lost to drag and friction, in meters per second, what is the velocity of the car after 10 seconds?

W) 20
X) 30
Y) 40
Z) 50

ANSWER: W) 20

BONUS

2) PHYSICS *Short Answer* A box filled with monatomic ideal gas has energy density 3000 joules per cubic meter. In pascals, what is the pressure of the gas?

ANSWER: 2000

TOSS UP

3) MATH *Multiple Choice* Let the function $f(x) = \lfloor \sqrt{x} \rfloor$ (read: *f of x equal the floor of the square root of x*). If $f(f(a))$ (read: *f of f of a*) equals 1, what is the largest possible integer value of a?

W) 9
X) 11
Y) 13
Z) 15

ANSWER: Z) 15

BONUS

3) MATH *Short Answer* Let a be an integer. Suppose that $\int_0^a (1 + 2x)\mathrm{d}x = 2$ (read: *the integral from 0 to a of the quantity one plus two x dx is equal to 2*). What is the largest possible value of a?

ANSWER: 1

TOSS UP

4) BIOLOGY *Short Answer* Apomixis is to plants as what process is to animals?

ANSWER: Parthenogenesis

BONUS

4) BIOLOGY *Short Answer* Spina bifida (*SPINE-uh BIFF-uh-duh*) is a disorder in which the neural tube in infants is not closed when they are born. This is usually caused by the lack of which vitamin in the mother?

ANSWER: Folic Acid (ACCEPT: B9, Folate)

TOSS UP

5) ENERGY *Short Answer* Scientists at the MIT Center for Gynepathology Research are studying diseases of the female reproductive tract that have historically suffered from less attention in the research community. Specifically, they seek to uncover the causes of a condition in which cells of the uterine lining grow ectopically, causing extreme pain at certain points of the menstrual cycle. What is the term for this condition?

ANSWER: Endometriosis

BONUS

5) ENERGY *Multiple Choice* Scientists at the Kellis group at MIT are studying nonshivering thermogenesis. Instead of muscle contraction, this mechanism utilizes a protein that allows protons to diffuse across the inner mitochondrial membrane. That protein component is most functionally similiar to which of the following?

W) F0 component of ATP synthase
X) F1 component of ATP synthase
Y) Photosystem I complex
Z) TIM/TOM complex

ANSWER: W) F0 component of ATP synthase

TOSS UP

6) CHEMISTRY *Multiple Choice* What industrial process involves the reaction of carbon monoxide with unrefined nickel metal to form nickel tetracarbonyl?

W) Ostwald process
X) Mond process
Y) Kroll process
Z) Bayer process

ANSWER: X) Mond process

BONUS

6) CHEMISTRY *Multiple Choice* Upon addition of one equivalent of methyl Grignard (*grin-YARD*) to acetic acid, which of the following types of reactions occurs?

W) Oxidation
X) Reduction
Y) Substitution
Z) Neutralization

ANSWER: Z) Neutralization

TOSS UP

7) ENERGY *Multiple Choice* Researchers in the Swager group at MIT are studying how biradical molecules can transfer their spin to nuclei. This so called "dynamic nuclear polarization" leads to better resolution in which of the following laboratory techniques?

W) UV-vis spectroscopy
X) Mass spectrometry (*spect-ro-met-ree*)
Y) IR (*read* : *I-R*) spectroscopy
Z) NMR (*read* : *N-M-R*) spectroscopy

ANSWER: Z) NMR spectroscopy

BONUS

7) ENERGY *Short Answer* Researchers in the Cao lab at MIT are working to investigate the quantum dynamics of photochemical systems. They are working to improve what quantity, defined as the number of reactions that occur per photon?

ANSWER: Quantum yield

TOSS UP

8) CHEMISTRY *Short Answer* What is the degeneracy of the first excited state of the rigid rotor model?

ANSWER: 3

BONUS

8) CHEMISTRY *Short Answer* Identify all of the following three reagents that are capable of adding across a carbon-carbon double bond:

1) Thionyl chloride
2) Peroxy acid
3) Iodine

ANSWER: 2 and 3

TOSS UP

9) BIOLOGY *Multiple Choice* Which of the following statements is NOT true regarding the avian (*AY-vian*) respiratory system?

W) Air requires two cycles of inhalation and exhalation to pass through the entire respiratory system.
X) The partial pressure difference of oxygen between the lungs and blood vessels is higher than in humans.
Y) Birds rely on positive pressure breathing to ventilate their lungs.
Z) Avian gas exchange is unidirectional.

ANSWER: Y) Birds rely on positive pressure breathing to ventilate their lungs.

BONUS

9) BIOLOGY *Short Answer* Some proteins have their N-terminus cleaved during their maturation process. Identify all of the following four proteins that this could apply to:

1) Angiotensin II
2) Insulin
3) Hexokinase
4) Calmodulin

ANSWER: 1 and 2

TOSS UP

10) EARTH AND SPACE *Multiple Choice* What relationship between confining pressure and a rock's shear strength is characteristic of the uppermost layer of the crust?

W) Linear, positive correlation
X) Linear, negative correlation
Y) Logarithmic, positive correlation
Z) Logarithmic, negative correlation

ANSWER: W) Linear, Positive correlation

BONUS

10) EARTH AND SPACE *Short Answer* What term best describes the transition of an ocean surface deep water wave to an intermediate wave which slows down but grows in height?

ANSWER: Shoaling

TOSS UP

11) MATH *Multiple Choice* For a given function of x, Alexis takes the tangent line at $x = 0$ to approximate its value at $x = 10$. For which of the following functions would the approximation be greater than the true value?

W) $y = x$ (read: *y equals x*)
X) $y = x^2$ (read: *y equals x squared*)
Y) $y = \frac{1}{x}$ (read: *y equals one over x*)
Z) $y = \ln x$ (read: *y equals the natural log of x*)

ANSWER: Z) $y = \ln x$

BONUS

11) MATH *Short Answer* A die is rolled 12 times so that three 1's, two 2's, four 3's, zero 4's, two 5's, and one 6 are rolled. Assuming that the die is fair, if a goodness of fit test were to be conducted, what would be the chi-squared value?

ANSWER: 5

TOSS UP

12) PHYSICS *Multiple Choice* A beam of light travelling through air meets a glass surface. Which of the following statements most accurately describes the phases of the transmitted and reflected light, compared to the phase of the incident light?

W) The transmitted and reflected light both experience no phase shift
X) The transmitted light experiences no phase shift, while the reflected light experiences a phase shift of 180 degrees
Y) The transmitted light experiences a phase shift of 180 degrees, while the reflected light experiences no phase shift
Z) The transmitted and reflected light both experience a phase shift of 180 degrees

ANSWER: X) The transmitted light experiences no phase shift, while the reflected light experiences a phase shift of 180 degrees

BONUS

12) PHYSICS *Multiple Choice* Consider three systems A, B, and C. System A has a positive point charge Q placed a small distance D above a large neutral insulating plane. System B has a positive point charge Q placed the same distance D above a large neutral conducting plane. System C has a positive point charge Q and a negative point charge $-Q$ placed a distance of $2D$ from each other. Which of the following correctly ranks the magnitude of the forces felt by the positive charge in each system?

W) A $<$ B $=$ C (read: *A is less than B is equal to C*)
X) A $=$ C $<$ B
Y) B $<$ A $<$ C
Z) A $=$ B $<$ C

ANSWER: W) A $<$ B $=$ C

TOSS UP

13) ENERGY *Short Answer* In 2022, an international team of scientists including scientists from MIT determined that neutrinoes are lighter than 0.8 electron-volts per c^2. If a neutrino has exactly this maximum mass, and has a momentum of 1.5 electron volts per c, what is the energy of this neutrino in electron-volts?

ANSWER: 1.7

BONUS

13) ENERGY *Short Answer* The model of cosmic inflation was first proposed by Alan Guth, a researcher at MIT's Center for Theoretical Physics. This model is believed to explain what property of the universe, which states that the universe appears to be the same in all directions?

ANSWER: Isotropic

TOSS UP

14) PHYSICS *Multiple Choice* One way to construct a capacitor is by nesting a solid cylinder inside a cylindrical shell. Which of the following best describes how the capacitance per unit length of this configuration depends on the radius of the inner cylinder?

W) Exponential
X) Logarithmic
Y) Linear
Z) Inverse

ANSWER: X) Logarithmic

BONUS

14) PHYSICS *Short Answer* A fish in the middle of the ocean looks up and sees the setting sun right above the horizon. If the index of refraction of water is 1.33, then to the nearest 10 degrees, at what angle from the vertical does the fish see the setting sun?

ANSWER: 50

TOSS UP

15) EARTH AND SPACE *Multiple Choice* Which of the following variable stars types have a flat relation between pulsation time and average luminosity?

W) Type I Cephied Variables
X) RR Lyrae Variables
Y) Type II Cepheid Variables
Z) Semiregular Variables

ANSWER: X) RR Lyrae Variables

BONUS

15) EARTH AND SPACE *Multiple Choice* Which of the following statements is NOT a part of current planetary theory for the Solar System?

W) Uranus and Neptune formed closer to the Sun and later migrated
X) The inner planets' formation temperature caused them to be metal-rich
Y) The Sun never evolved into a T-Tauri star
Z) The late heavy bombardment significantly depleted the mass of the asteroid belt

ANSWER: Y) The Sun never evolved into a T-Tauri star

TOSS UP

16) BIOLOGY *Multiple Choice* Which of the following neurotransmitters would be broken down by monoamine (*MON-oh-AY-meen*) oxidase?

W) Serotonin
X) Acetylcholine (*uh-SEE-tul-COLE-een*)
Y) Dopamine
Z) Glycine

ANSWER: Y) Dopamine

BONUS

16) BIOLOGY *Short Answer* In chickens, crossing a true-breeding black-feathered mother with a true-breeding white-feathered father yields offspring with blue feathers. In a population of chickens in Hardy-Weinberg equilibrium, 16% of chickens have black feathers. What percentage of chickens have blue feathers?

ANSWER: 48%

TOSS UP

17) CHEMISTRY *Multiple Choice* Which of the following alkanes has the lowest boiling point?

W) Hexane
X) 2-methylpentane
Y) 3-methylpentane
Z) 2,2-dimethylbutane

ANSWER: Z) 2,2-dimethylbutane

BONUS

17) CHEMISTRY *Short Answer* Order the following three electronic transitions by increasing wavelength of the photon emitted:

1) $n = 2$ to $n = 1$ in a hydrogen atom
2) pi to pi star excitation in benzene
3) *d*-*d* transition in a violet metal complex

ANSWER: 3, 2, 1

TOSS UP

18) MATH *Short Answer* G is a simple graph with 13 vertices. What is the maximum number of edges G can have so that it is not connected?

ANSWER: 66

BONUS

18) MATH *Multiple Choice* The polar coordinates of a point is $(2, \frac{\pi}{12})$ (read: *two comma pi over twelve*). If the rectangular coordinates of the same point is (x, y), what is the value of $x^2 - y^2$ (read: *x squared minus y squared*)?

W) 1
X) $\sqrt{3}$
Y) 2
Z) $2\sqrt{3}$

ANSWER: Z) $2\sqrt{3}$

TOSS UP

19) CHEMISTRY *Short Answer* An organic chemist takes a mass spectrum where he observes his M peak with a relative intensity of 100. The chemist notes that since the $M + 1$ peak has a relative intensity of 12, they can deduce that their compound has how many carbons?

ANSWER: 11

BONUS

19) CHEMISTRY *Multiple Choice* The 1H NMR spectrum of an unknown organic compound contains a peak around 10 ppm. Which of the following functional groups is most likely present in the molecule?

W) Alcohol
X) Aldehyde
Y) Ketone
Z) Carboxylic acid

ANSWER: X) Aldehyde

TOSS UP

20) EARTH AND SPACE *Short Answer* Identify all of the following four objects that have intrinsic magnetic fields:

1) Mercury
2) Venus
3) Ganymede
4) Jupiter

ANSWER: 1, 3, and 4

BONUS

20) EARTH AND SPACE *Short Answer* Identify all of the following three statements that are TRUE concerning a solar eclipse:

1) The umbra can only move from west to east
2) The penumbra is the region where a partial solar eclipse occurs
3) The moon the night before a solar eclipse is full

ANSWER: 2 only

TOSS UP

21) PHYSICS *Multiple Choice* A mass is oscillating with some angular frequency inside a potential energy well given by the function $U(x)$. If $U(x)$ is multiplied by a constant factor of 1/3, by what factor does the angular frequency of oscillation change?

W) 1/3
X) $\sqrt{3}/3$
Y) 1
Z) 3

ANSWER: X) $\sqrt{3}/3$

BONUS

21) PHYSICS *Short Answer* The potential energy between two molecules is often modeled as being proportional to $(a/r)^{12} - (a/r)^6$ (read: *a over r quantity to the twelfth minus a over r quantity to the sixth*), where r is the distance between the molecules and a is a characteristic distance of the system. What is the name of this potential?

ANSWER: Lennard-Jones

TOSS UP

22) BIOLOGY *Multiple Choice* Which of the following methods of DNA sequencing does NOT employ sequencing by synthesis?

W) Sanger (*SAIN-gur*) sequencing
X) Pyrosequencing
Y) Illumina sequencing
Z) Oxford Nanopore sequencing

ANSWER: Z) Oxford Nanopore sequencing

BONUS

22) BIOLOGY *Short Answer* Identify all of the following 3 statements that are TRUE regarding ferns:

1) A majority of ferns are heterosporous
2) The gametophyte is larger than the sporophyte
3) They have both microphylls and megaphylls

ANSWER: None of them

TOSS UP

23) MATH *Short Answer* An integer x has a remainder of three when divided by 5, two when divided by 4, and one when divided by 3. What is the minimum value of x?

ANSWER: 58

BONUS

23) MATH *Short Answer* A rectangle $ABCD$ has sidelengths of 3 and 4. A point P inside the rectangle is chosen randomly such that PA is 3, PB is 4, and PC is 3. What is the length of PD?

ANSWER: $\sqrt{2}$