AVES

DE 7

TOSS-UP

1) MATH *Multiple Choice* Rohan is trying to compute the transpose of the matrix A*B, assuming A*B is defined. He computes this as the transpose of A times the transpose of B, incorrectly. Somehow, he arrives at the correct answer. Which of the following could be the dimensions of A and B, respectively?

W) 3 by 2 and 2 by 2

X) 3 by 4 and 4 by 2

Y) 4 by 5 and 5 by 4

Z) 1 by 2 and 2 by 4

ANSWER: Y) 4 by 5 and 5 by 4 [RG]

BONUS

1) MATH *Short Answer* Rohan starts at the point $(0, 0)$ and wants to move to $(2, 2)$. In one move, he can either move one unit to the right, one unit up, or 1 unit up and 1 unit right. How many ways can he reach his destination?

ANSWER: 13 [RG]

TOSS-UP

2) BIOLOGY *Short Answer* Once T DNA is transferred through the mating bridge, T DNA must be converted from a linear strand to a circular molecule before it can be replicated**.** What enzyme bound to T DNA catalyzes the joining of the ends of this linear DNA?

ANSWER: Relaxase (Do not accept: relaxosome) [EH]

BONUS

2) BIOLOGY *Short Answer* Identify all of the following four statements regarding ion transport in the thick part of the ascending loop of Henle that are true:

1) K+ is cotransported with Cl- into the tubular lumen;

2) Na+ is cotransported with Cl- out of the tubular lumen;

3) Cl- diffuses into the interstitial fluid;

4) K+ is pumped out of the interstitial fluid**.**

ANSWER: 2, 3, and 4 [EH]

TOSS-UP

3) PHYSICS *Short Answer* Majorana fermions and Dirac fermions differ because Majorana fermions are their own antiparticle while Dirac fermions are distinct from their antiparticle. What other class of fermions also differ from their antiparticles like Dirac fermions, but only contain massless particles?

ANSWER: Weyl fermions [RG]

BONUS

3) PHYSICS *Short Answer* Two ropes are tied around the same pole and the coefficient of static friction between the ropes and the pole is 0.31. The other end of each rope is attached to Edwin's car. The first rope makes a single revolution around the pole while the second makes 2 revolutions around the pole. Edwin pulls on both ropes with the same force. To the nearest integer, what is the ratio of the maximum possible force that the second rope can exert on the car to the maximum possible force that the first rope can exert on the car?

ANSWER: 7 [RG]

TOSS-UP

4) EARTH AND SPACE *Short Answer* According to Jean's criterion, the minimum radius for star formation to occur is proportional to what power of temperature?

W) -1

X) -1/2

Y) 1/2

Z) 1

ANSWER: Y) 1/2 [RG]

BONUS

4) EARTH AND SPACE *Short Answer* Internal waves in the ocean necessarily propagate along boundaries between layers with a significant difference in what quantity?

ANSWER: Density [PB]

TOSS-UP

5) CHEMISTRY *Short Answer* Identify all of the following 3 reactions for which enantiomeric excess is preserved:

1) Oxymercuration demercuration;

2) Acid catalyzed hydration;

3) Hydroboration oxidation.

ANSWER: 3 only [RG]

BONUS

5) CHEMISTRY *Short Answer* Rohan is studying two first order reactions and both are performed at a temperature of 120 Kelvin. The first reaction has an activation energy of 1 kilojoule per mole and the second reaction has an activation energy of 2 kilojoules per mole. In the first reaction, it takes 10 seconds for a reactant to reach 50% of its initial concentration. Assuming the reactions have the same frequency factor, how long, to one significant figure, would it take a reactant to reach 25% of its initial concentration in the second reaction?

ANSWER: 50 [RG]

TOSS-UP

6) MATH *Short Answer* Four people sit in 4 seats and leave. When they come back, the seats have been shuffled randomly, and each person picks a random seat to sit on. What is the probability that exactly 1 person sat in the same seat as last time?

ANSWER: 1/3 [RG]

BONUS

6) MATH *Short Answer* Rohan really loves the number e. He starts with the number one and for each second for 60 seconds, he multiplies his current number by e. His final number is not an integer, but he takes the floor of it to get a new integer, call it n. Then he computes the sum from i=1 to n of 1 over i. To the nearest tenth, what is the value of the summation?

ANSWER: 60.6 [RG]

TOSS-UP

7) BIOLOGY *Multiple Choice* A bug that displays Wasmannian mimicry would most likely mimic an organism in which of the following orders of insect?

W) Lepidoptera

X) Diptera

Y) Hymenoptera

Z) Orthoptera

ANSWER: Y) Hymenoptera [EH]

BONUS

7) BIOLOGY *Short Answer* An organism contains a gene controlling one phenotype, with 4 alleles for that gene**.** The phenotype is dominant if at least one of the alleles on the gene are dominant, and recessive otherwise**.** The genotypes of gametes are determined by randomly selecting half of the organism's alleles**.** If two individuals with genotype Aaaa [**read as: big A, little a, little a, little a**] are crossed with each other, what is the probability that the resulting offspring will have a dominant phenotype?

ANSWER: 3/4 [DL]

TOSS-UP

8) PHYSICS *Multiple Choice* As the distance between two quarks decreases, which of the following best describes how the strong coupling constant changes at high energies and low energies, respectively?

W) Increases, decreases

X) Decreases, increases

Y) Stays the same, decreases

Z) Stays the same, increases

ANSWER: X) Decreases, increases [EH]

BONUS

8) PHYSICS *Short Answer* A capacitor consists of two parallel plates which are identical and are polygons, with each having a perimeter of 10pi meters. Given that the distance between the two plates is one meter, to one significant figure and in scientific notation, what is the maximum possible capacitance that can be between the two plates?

ANSWER: 7 times 10^{-10} [AK/RG]

TOSS-UP

9) EARTH AND SPACE *Multiple Choice* Sillimanite is most likely to be found in which of the following mineral facies?

W) Eclogite

X) Granulite

Y) Hornfels

Z) Zeolite

ANSWER: X) Granulite [PB]

BONUS

9) EARTH AND SPACE *Short Answer* Ritwik is in the heart of a core collapse supernova observing the creation of heavy elements. Here he finds an extraordinarily high density of iron 56 nuclides, free neutrons, and a compression of electrons blocking beta decay. He is most likely observing what set of nuclear reactions?

ANSWER: R-process (Accept: rapid neutron capture process) [RA]

TOSS-UP

10) CHEMISTRY *Short Answer* Identify all of the following three thermodynamic processes in which the change in Helmholtz free energy must be equal to the change Gibbs free energy:

1) Isochoric;

2) Isobaric;

3) Isothermal.

ANSWER: None of them [RG]

BONUS

10) CHEMISTRY Multiple Choice Consider the reaction $3NO_2(g) + H_2O(l) \rightarrow 2HNO_3(l) + NO(g)$. Which of the following is true about the delta H of the reaction and the structure of the transition state respectively?

W) Negative; the transition state resembles the reactants more than the products

X) Positive; the transition state resembles the reactants more than the products

Y) Negative; the transition state resembles the products more than the reactants

Z) Positive; the transition state resembles the products more than the reactants

ANSWER: W) Negative; the transition state resembles the reactants [RG]

TOSS-UP

11) MATH *Multiple Choice* How many ways are there to tile a 2 by 6 grid with 6 dominoes of dimensions 2x1, assuming they can be rotated?

W) 8

X) 12

Y) 13

Z) 21

ANSWER: Y) 13 [RG]

BONUS

11) MATH *Short Answer* Rohan has a graph on 4 nodes and between each pair of nodes, he draws an undirected edge with 1/2 probability. What is the expected number of cycles in the graph?

ANSWER: 11/8 [RG]

TOSS-UP

12) BIOLOGY *Short Answer* Pyruvate carboxylase catalyzes the conversion of pyruvate into oxaloacetate in the mitochondria, but further steps of gluconeogenesis take place in the cytosol. Due to a lack of transporters, oxaloacetate is converted into what compound to be transported across the mitochondrial membrane?

ANSWER: Malate [EH]

BONUS

12) BIOLOGY *Multiple Choice* Edwin is doing two-dimensional gel electrophoresis. However, Edwin is an amateur, so he adds sodium dodecyl sulfate to the proteins before the first step of two-dimensional gel electrophoresis. Then he lets the first step of the technique run to completion. Which of the following best describes what Edwin sees at the end of the first step?

W) The proteins are correctly sorted by size, but not by their isoelectric point

X) The proteins are correctly sorted by their isoelectric point, but not by size

Y) The proteins are all lined up in a row closer to the positive electrode

Z) The proteins are all lined up in a row closer to the negative electrode

ANSWER: Y) The proteins are all lined up in a row closer to the positive electrode [EH]

TOSS-UP

13) PHYSICS *Short Answer* Protons were confirmed to have the same intrinsic spin as an electron. This was done using what phenomenon, in which the value of the nuclear magnetic moment causes very small changes in transitions and the observed spectral lines?

ANSWER: Hyperfine splitting [RG]

BONUS

13) PHYSICS *Short Answer* Rohan has three boxes of identical molecules with the first box having 3 molecules, the second box having 1 molecule, and the third box having 2 molecules. He moves one particle from the first box to the second box so that all the boxes have the same number of molecules. In terms of the Boltzmann constant k, what is the change in entropy of the system?

ANSWER: k ln(3/2) [RG]

TOSS-UP

14) EARTH AND SPACE *Multiple Choice* Which of the following best explains why the Wilson-Bappu effect is mainly observed in stars of spectral classes G, K, and M?

W) G, K, and M stars exhibit more photospheric activity compared to hotter stars

X) G, K, and M stars have their rotational velocities empirically determined through Doppler broadening

Y) G, K, and M stars display prominent Ca II-K lines in their spectra

Z) G, K, and M stars spend less time on the main sequence, allowing for shorter observational periods

ANSWER: Y) G, K, and M stars display prominent Ca II-K lines in their spectra [RA]

BONUS

14) EARTH AND SPACE *Short Answer* Ritwik is studying a main sequence star and notices that the mass of the star is 16 times that of the sun and it has a radius two times that of the Sun. If the blackbody curve of the Sun peaks at a wavelength of 500 nanometers, what wavelength does the blackbody curve of the star peak at?

ANSWER: 62.5 [RG]

TOSS-UP

15) CHEMISTRY *Short Answer* Identify all of the following 3 molecules that exhibit 3 center 4 electron bonding:

1) Diborane;

2) Xenon difluoride;

3) Triiodide.

ANSWER: 2 and 3 [RG]

BONUS

15) CHEMISTRY *Short Answer* Rohan has 3 hydrocarbons with each of them having the same number of carbon atoms. The first is an alkane, the second is an alkene, and the third is an alkyne. Identify all of the following three statements that must be true:

1) The alkane has a lower percentage by mass of carbon than the alkene;

2) The alkane has a lower percentage by mass of carbon than the alkyne;

3) The alkene has a lower percentage by mass of carbon than the alkyne.

ANSWER: None of them [RG]

TOSS-UP

16) MATH *Short Answer* What is the name given to the only non cyclic group of order 4, up to isomorphism?

ANSWER: Klein four group [RG]

BONUS

16) MATH *Short Answer* Answer the following 2 questions about Galois conjugates.

1) How many Galois conjugates does the square root of 2 plus the square root of 3 have?

2) What adjective describes a number with a finite number of Galois conjugates?

ANSWER: 1) 4 2) Algebraic [RG]

TOSS-UP

17) BIOLOGY *Multiple Choice* In receptor mediated endocytosis, adaptor proteins must bind to specific locations on the plasma membrane to form a vesicle with the required cargo receptors. Which of the following types of phospholipids when phosphorylated would mark the correct location for adaptor proteins to bind?

W) Phosphatidylcholine

X) Phosphatidylserine

Y) Phosphatidylethanolamine

Z) Phosphatidylinositol

ANSWER: Z) Phosphatidylinositol [EH]

BONUS

17) BIOLOGY *Short Answer* In certain plants, a single large P-protein body called a forisome is formed that does not disperse. Identify all of the following four characteristics that the plant possessing a forisome could have:

1) Coleoptile in the seed;
2) Flagellated spores;
3) Vessel elements in the xylem;
4) Leghemoglobin in the root nodules.

ANSWER: 3 and 4 [EH]

TOSS-UP

18) PHYSICS *Short Answer* The reduced planck constant times the elementary charge divided by two times the mass of an electron is equal to what physical constant, which can be used to express the magnetic moment of an electron due to its spin angular momentum?

ANSWER: Bohr magneton [RG]

BONUS

18) PHYSICS *Short Answer* At certain points in the structure of two dimensional materials, the conduction band and valence band touch. Answer the following two questions about these points.

1) At these points, the energy of the conduction and valence bands is closest to what value for the material?

2) What are these points called?

ANSWER: 1) Fermi energy 2) Dirac points [RG]

TOSS-UP

19) EARTH AND SPACE *Short Answer* What name is given to the process by which a dense lithospheric root detaches from the crust and sinks into the mantle, allowing the remaining crust to rise isostatically and form mountains?

ANSWER: Delamination [PB]

BONUS

19) EARTH AND SPACE *Multiple Choice* Which of the following is not typically considered an incompatible element?

W) Cobalt

X) Niobium

Y) Lanthanum

Z) Rubidium

ANSWER: W) Cobalt [PB]

TOSS-UP

20) CHEMISTRY *Multiple Choice* If an electron moves from the HOMO to the LUMO in benzene, which of the following describes how the bond order changes?

W) Increases by 1

X) Decreases by 1

Y) Stays the same

Z) Decreases by 2

ANSWER: X) Decreases by 1 [RG]

BONUS

20) CHEMISTRY *Short Answer* Identify all of the following three compounds reacted with the matched base would majorly form the Hoffman product in an E2 reaction:

1) 2-bromo-2-methylbutane and tert-butoxide;

2) trans-1-chloro-2-methylcyclohexane and ethoxide;

3) 2-iodo-2-methylpentane and hydroxide.

ANSWER: 1 and 2 [RG]
