ROUND 11

TOSS-UP

1) Math – *Multiple Choice* If one two squared in base *b* is two one zero, what is *b*?

W) 3
X) 4
Y) 6
Z) 8

ANSWER: X) 4

BONUS

1) Math – *Short Answer* Paul has an infinite supply of 1-by-1, 1-by-2, 1-by-3, and 1-by-4 tiles. In how many ways can he completely tile his bathroom floor, which has dimensions of 1-by-8, if tiles must be entirely in the bathroom floor and tiles cannot overlap?

ANSWER: 108

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TOSS-UP

2) Earth and Space – *Short Answer* The luminosity of a main sequence star is approximately proportional to what power of its mass?

ANSWER: 3.5 (ACCEPT: 7/2)

BONUS

2) Earth and Space – *Short Answer* Identify all of the following three statements that are true regarding the solar corona: 1) It is physically impossible for energy to be transferred from the photosphere to the corona by direct heat transfer; 2) When there are minimal sunspots on the photosphere, there are usually more than five coronal mass ejections per day; 3) Coronal arches connect regions of opposite magnetic polarity.

ANSWER: 1 AND 3
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TOSS-UP

3) Biology – *Short Answer* For a population of haplodiploid bees, what is the coefficient of relatedness between a female and her brother?

ANSWER: 0.25 (ACCEPT: 1/4)

BONUS

3) Biology – *Short Answer* Systemic acquired resistance is a defense mechanism in plants that is activated by what plant hormone?

ANSWER: SALICYLIC ACID

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TOSS-UP

4) Chemistry – *Short Answer* Identify all of the following three reaction mechanisms that involve a negatively-charged intermediate: 1) Electrophilic aromatic substitution; 2) Nucleophilic aromatic substitution; 3) Elimination-addition.

ANSWER: 2 AND 3

VISUAL BONUS

4) Chemistry – *Short Answer* Shown in the image is the reaction between sodium metal and cold liquid ammonia. Answer the following two questions about the image:

1. What chemical species causes the characteristic blue color?
2. When 2-butyne is treated with this solution, what will be IUPAC systematic name of the major product?

ANSWER: 1 – SOLVATED ELECTRONS (ACCEPT: ELECTRONS); 2 – TRANS-2-BUTENE
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TOSS-UP

5) Physics – *Short Answer* Rank the following three phases in terms of increasing pressure at 30 kelvin in condensed matter physics: 1) Ordered state; 2) Disordered state; 3) Quantum critical.

ANSWER: 1, 3, 2

BONUS

5) Physics – *Short Answer* An instantaneous imbalance of electrons in an atom or a molecule can induce changes in the energy levels of that atom or molecule. What is the term for this changed state, which can be thought of as the intramolecular analogue of London dispersion forces?

ANSWER: HYPERFINE STRUCTURE

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TOSS-UP

6) Energy – *Short Answer* Scientists at Argonne National Lab are studying the properties of yttrium iron garnet, a material with chemical formula $Y_3Fe_5O_{12}$. Identify all of the following three statements that are true regarding yttrium iron garnet: 1) It is naturally occurring; 2) It is ferromagnetic; 3) All cations are in the 3+ oxidation state.

ANSWER: 2 AND 3

VISUAL BONUS

6) Energy – *Short Answer* Geophysicists at Princeton Plasma Physics Lab are modeling the magnetosphere of Mercury, which is shown in the image. The blue lines represent magnetic field lines. Answer the following two questions about the image:

1. What feature of the magnetosphere is labeled A?
2. Mercury's magnetosphere is unusually asymmetric across the northern and southern hemispheres. Currently, this is partly attributed to core stratification, which disturbs what process that generates the planetary magnetic field from convecting liquid metal?

ANSWER: 1 – BOW SHOCK; 2 – DYNAMO EFFECT
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TOSS-UP

7) Math – *Multiple Choice* Let G be a group with an order of 2020 and S be a subgroup of G. Which of the following could NOT be the order of S?

W) 2
X) 3
Y) 4
Z) 5

ANSWER: X) 3

BONUS

7) Math – *Short Answer* Amelia chooses either a standard 6-sided die or a standard 4-sided die with equal probability. She then rolls the selected die twice and records the sum of the results. Given that the sum is prime, what is the probability that she chose the 6-sided die?

ANSWER: 20/47

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TOSS-UP

8) Earth and Space – *Short Answer* Identify all of the following three statements regarding stellar evolution on the Asymptotic Giant Branch that are true: 1) Most fusion occurs in the core; 2) Thermally pulsing AGB stars fuse hydrogen in a shell around an inert helium shell; 3) The temperature gradually increases during evolution along the AGB.

ANSWER: 2 ONLY

BONUS

8) Earth and Space – *Multiple Choice* The weathering of wollastonite produces silica, releases its primary cation, and acts as a sink for carbon dioxide. Which of the following is likely the chemical formula of wollastonite?

W) $CaSiO_3$
X) $FeSiO_3$
Y) $MgSiO_3$
Z) Na_2SiO_3

ANSWER: W) $CaSiO_3$
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TOSS-UP

9) Biology – *Short Answer* What is the anticodon for the codon that reads five prime GGC three prime?

ANSWER: THREE PRIME CCG FIVE PRIME (ACCEPT: FIVE PRIME GCC THREE PRIME)

VISUAL BONUS

9) Biology – *Short Answer* Shown in the image are the results of a three-point testcross. The number of offspring with each genotype is indicated at the right. What is the proportion of recombinants?

ANSWER: 1/18

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TOSS-UP

10) Chemistry – *Multiple Choice* A student treats methyl acetate with lithium aluminum hydride, followed by the addition of water to the reaction vessel. Which of the following functional groups is he most likely to observe as the major product?

W) Primary alcohol
X) Secondary alcohol
Y) Tertiary alcohol
Z) Aldehyde

ANSWER: W) PRIMARY ALCOHOL

BONUS

10) Chemistry – *Short Answer* What diagram used in spectroscopy plots electronic states to describe effects such as fluorescence and phosphorescence?

ANSWER: JABLONSKI DIAGRAM
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TOSS-UP

11) Physics – *Multiple Choice* Which of the following statements best describes the movement of an electron placed off-center inside a hollow conducting sphere?

W) It would move to the center of the sphere
X) It would move to the edge of the sphere
Y) It would oscillate about the center of the sphere
Z) It would not move

ANSWER: X) IT WOULD MOVE TO THE EDGE OF THE SPHERE

BONUS

11) Physics – *Short Answer* Water at 20 degrees Celsius is flowing through a pipe. Identify all of the following three changes that would make the flow more laminar: 1) Increasing flow velocity; 2) Increasing pipe diameter with constant volumetric flow rate; 3) Increasing temperature to 40 degrees Celsius.

ANSWER: 2 AND 3

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TOSS-UP

12) Energy – *Multiple Choice* Scientists at Oak Ridge National Lab are developing circuits for quantum computing. In these circuits, the quantum states of qubits are operated on through quantum gates, which output normalized qubit states. Which of the following best describes these operators?

W) Unitary
X) Hermitian
Y) Singular
Z) Real

ANSWER: W) UNITARY

BONUS

12) Energy – *Short Answer* Scientists at Lawrence Berkeley National Lab are studying the atmospheric chemistry of Titan. Rank the following four gases in terms of increasing concentration in Titan's atmosphere: 1) Nitrogen; 2) Hydrogen; 3) Methane; 4) Acetylene.

ANSWER: 4, 2, 3, 1
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TOSS-UP

13) Math – *Short Answer* What is the limit as *n* approaches infinity of the integral from –*n* to 0 of 2 to the *x* power d*x*?

ANSWER: 1 OVER THE NATURAL LOG OF 2

BONUS

13) Math – *Short Answer* What is the magnitude of the gradient of the scalar field $x - y \sin z$ at the point $(6, 3, \pi)$?

ANSWER: SQUARE ROOT 10

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TOSS-UP

14) Earth and Space – *Multiple Choice* The rarity of E8 or E9 elliptical galaxies as well as the limited elongation of dark matter haloes is due to the presence of what instability?

W) Kelvin-Helmholtz Instability
X) Firehose Instability
Y) Jeans Instability
Z) Rayleigh-Taylor Instability

ANSWER: X) FIREHOSE INSTABILITY

VISUAL BONUS

14) Earth and Space – *Short Answer* Answer the following two questions about the image:

1. Letter A points to what layer of the solar atmosphere?
2. What phenomenon can be seen at letter B, caused by rugged topography of the lunar surface?

ANSWER: 1 - CORONA; 2 - BAILY'S BEADS (ACCEPT: DIAMOND RING EFFECT)
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TOSS-UP

15) Biology – *Short Answer* What specialized cyanobacterial cells have evolved to survive for years through unfavorable conditions?

ANSWER: AKINETES

BONUS

15) Biology – *Multiple Choice* The ST staple is a common four- or five-amino acid residue motif in proteins and polypeptides with serine or threonine as the C-terminal residue. It is characterized by a single hydrogen bond between the hydroxyl group of the C-terminal residue and the main chain carbonyl group that is 3 or 4 residues away. What protein structures are ST staples likely to be found in?

W) Beta sheets
X) Psi loops
Y) Alpha helices
Z) Pi helices

ANSWER: Y) ALPHA HELICES

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TOSS-UP

16) Chemistry – *Short Answer* Toluene is reacted with a mixture of nitric acid and sulfuric acid at a temperature of 30 degrees Celsius. The product is then added to metallic tin in dilute hydrochloric acid. Identify all of the following three statements that are true regarding this series of reactions: 1) An amine is formed; 2) The product is less activated towards electrophilic aromatic substitution than toluene; 3) The substituent is meta- to the methyl group.

ANSWER: 1 ONLY

VISUAL BONUS

16) Chemistry – *Short Answer* Shown in the image is ferrocene, an organometallic so-called "sandwich compound" consisting of a central iron atom "sandwiched" between two cyclopentadienyl ligands. Answer the following two questions about the image:

1. What is the oxidation state of the central iron atom?
2. According to the ionic counting method, how many electrons are donated by each cyclopentadienyl ligand?

ANSWER: 1 – 2+; 2 – 6
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TOSS-UP

17) Physics – *Short Answer* Identify all of the following three statements that are true regarding MOSFETs: 1) A positive applied voltage at the gate repels electron holes and creates a depletion layer; 2) MOSFETs can only be made with p-type semiconductors; 3) MOSFETs use more power than bipolar junction transistors.

ANSWER: 1 ONLY

BONUS

17) Physics – *Multiple Choice* Which of the following pairs of polarizers would block all incoming light?

W) Two polarizers with transmission axes tilted at 75 and 120 degrees from the vertical
X) Two polarizers with transmission axes tilted at 60 and 120 degrees from the vertical
Y) Two polarizers with transmission axes tilted at 45 and 120 degrees from the vertical
Z) Two polarizers with transmission axes tilted at 30 and 120 degrees from the vertical

ANSWER: Z) TWO POLARIZERS WITH TRANSMISSION AXES TILTED AT 30 AND 120 DEGREES FROM THE VERTICAL

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TOSS-UP

18) Energy – *Multiple Choice* DOE researchers at the Joint Genome Institute have been using shrub willows to produce biofuels. Genomic studies into shrub willows have shown that females are heterogametic. Which of the following accurately designates the sex chromosomes of shrub willows females?

W) XX
X) XY
Y) ZZ
Z) ZW

ANSWER: Z) ZW

BONUS

18) Energy – *Short Answer* Scientists on the Dark Energy Survey at Fermilab are discovering distant, high inclination Trans-Neptunian Objects with semimajor axes that are more than twice that of Pluto. Most of these high inclination TNOs belong to what group of objects?

ANSWER: SCATTERED DISK OBJECTS
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TOSS-UP

19) Earth and Space – *Multiple Choice* Salt fingers are an example of double-diffusive convection in the oceans. Which of the following mechanisms best describes the role of double-diffusive convection in driving salt finger formation?

W) Diffusion of heat occurs slower than diffusion of salinity
X) Diffusion of heat occurs faster than diffusion of salinity
Y) Heat can be transferred via convection, while salinity cannot
Z) Diffusion of heat occurs at almost the same rate as salinity, leading to amplified convective motions in surface water

ANSWER: X) DIFFUSION OF HEAT OCCURS FASTER THAN DIFFUSION OF SALINITY

VISUAL BONUS

19) Earth and Space – *Short Answer* Shown in the image is a composite of the Bullet Cluster, which is a collision between two galaxy clusters. Letter A shows the X-ray emissions from baryonic gas, while letter B points to the calculated mass distribution of dark matter. Answer the following two questions about the image:

1. What effect was used to calculate the mass distribution of the dark matter?
2. This was used as evidence against what anti-dark-matter theory, which proposes that the gravitational force can vary inversely with the first power of radius at small accelerations?

ANSWER: 1 – GRAVITATIONAL LENSING; 2 – MOND (ACCEPT: MODIFIED NEWTONIAN DYNAMICS)

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TOSS-UP

20) Biology – *Short Answer* Postganglionic autonomic neurons that innervate smooth muscle store their neurotransmitters in what swollen regions?

ANSWER: VARICOSITIES

VISUAL BONUS

20) Biology – *Short Answer* Pictured is the series of steps in an Edman degradation experiment. Answer the following two questions regarding the image:

1. What reagent is used in step 1?
2. Which terminus of the peptide is cleaved and sequenced during Edman degradation?

ANSWER: 1 – PHENYL ISOTHIOCYANATE; 2 – N-TERMINUS
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TOSS-UP

21) Chemistry – *Short Answer* Identify all of the following three functional groups that may be reduced by lithium aluminum hydride: 1) Ketone; 2) Aldehyde; 3) Carboxylic acid.

ANSWER: ALL

BONUS

21) Chemistry – *Short Answer* Shown in the image is an organic molecule with three of its carbon-hydrogen bonds labeled A through C. Answer the following three questions regarding this image:

1. Which two bonds have the lowest and highest bond dissociation energies, respectively?
2. What is the IUPAC systematic name of the molecule depicted in the image?
3. Would the highest-wavenumber signal of the IR spectrum of this molecule be greater than or less than 3000 inverse centimeters?

ANSWER: 1 – C AND A; 2 – 1-PENTENE; 3 – GREATER

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TOSS-UP

22) Physics – *Short Answer* A massive object starts rotating in space, which distorts its gravitational field and induces precession on nearby particles. What is the term for this effect in general relativity?

ANSWER: FRAME-DRAGGING (ACCEPT: LENSE-THIRRING EFFECT)

BONUS

22) Physics – *Short Answer* A giant insulating sphere has a uniform charge density of 0.02 coulombs per cubic meter and a radius of 200 meters. Point A is 100 meters from the center of the sphere, while point B is 300 meters from the center of the sphere. How many times as great is the electric field at point B when compared to the electric field at point A?

ANSWER: 8/9
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TOSS-UP

23) Math – *Short Answer* Let S be the set of the first 30 positive integers. How many elements of S are relatively prime to every other element of S?

ANSWER: 5

VISUAL BONUS

23) Math – *Short Answer* Shown in the image is a graph depicting three discrete distributions showing the probabilities of each of three different people receiving *k* phone calls in a given day. Answer the following two questions regarding the graph:

1. What is the specific name for these kinds of distributions?
2. Which of the following quantities is most likely to also follow this type of distribution?

W) Number of lightning strikes in Washington DC on a single day
X) Number of cancer cells in a random patient
Y) Displacement of a particle under Brownian motion
Z) Radioactive decays in a rock per second

ANSWER: 1 – POISSON DISTRIBUTION; 2 – Z) RADIOACTIVE DECAYS IN A ROCK PER SECOND