TOSS-UP

1. Chemistry *Multiple Choice* Which of the following orbital interactions best characterizes π-back bonding?

W) Sigma bonding with pi antibonding
X) Pi bonding with sigma antibonding
Y) Metal d with pi bonding
Z) Metal d with pi antibonding

ANSWER: Z) METAL D WITH PI ANTIBONDING **[YL]**

LONG BONUS

1. Chemistry *Short Answer* Answer the following two questions about the Curtius rearrangement:

1) What is the name of the intermediate containing a hypovalent nitrogen atom?
2) What is the name of the final product of the Curtius rearrangement, containing an sp central carbon atom?

ANSWER: 1) NITRENE; 2) ISOCYANATE **[YL]**

TOSS-UP

2. Math *Short Answer* What is the limit as (x, y) approaches (0, 0) of the function f(x, y) = (x + y)/(x - y) **[READ AS: the quantity x plus y all over the quantity x minus y]**?

ANSWER: UNDEFINED **[YL]**

BONUS

2. Math *Short Answer* Calculate the line integral along a straight line from the point (0, 0) to the point (3, 4) of the function f(x, y) = x + y.

ANSWER: 12.5 **[YL]**

TOSS-UP

3. Earth and Space *Multiple Choice* Which of the following classes of currents in the magnetosphere of the Earth are aligned with the geomagnetic field?

W) Equatorial electrojet
X) Hall current

Y) Pedersen current
Z) Birkeland current

ANSWER: Z) BIRKELAND CURRENT **[SC]**

BONUS

3. Earth and Space *Multiple Choice* Which of the following exotic star types is incorrectly matched with its likely origin?

W) Thorne-Zytkow object, stellar collision
X) Carbon star, dredge-up
Y) Wolf-Rayet star, close gravitational interaction
Z) Extreme helium star, white dwarf merger

ANSWER: Y) WOLF-RAYET STAR, CLOSE GRAVITATIONAL INTERACTION **[SC]**

TOSS-UP

4. Biology *Short Answer* What modified amino acid, which provides methyl groups to DNA methyltransferase, is the primary shuttle for methyl groups during a variety of biochemical processes?

ANSWER: S-ADENOSYL-METHIONINE (ACCEPT: SAM) **[KD]**

BONUS

4. Biology *Short Answer* Identify all of the following comparisons that are TRUE between Size Exclusion Chromatography, also known as SEC, and SDS-PAGE, both of which are common laboratory techniques for purification of proteins:

1) In SEC, larger proteins travel faster while in SDS-PAGE smaller proteins travel faster
2) SEC preserves the structure of the protein while SDS-PAGE denatures the protein
3) SEC uses beads to impede protein movement while SDS-PAGE relies on an electric field that causes the proteins to migrate

ANSWER: ALL **[KD]**

TOSS-UP

5. Physics *Short Answer* When plotted on a T-S diagram, which of the following three thermodynamic cycles have at least one pair of parallel sides?

1) Carnot

2) Stirling
3) Brayton

ANSWER: ALL **[SC]**

BONUS

5. Physics *Short Answer* Jonathan falls onto a piston capping a closed canister of monatomic gas, and it compresses to one sixth of its original size. To the nearest integer, many times heavier than the piston is Jonathan?

ANSWER: 11 **[SC]**

TOSS-UP

6. Chemistry *Multiple Choice* In the absence of any protic species adding sodium metal to a ketone will result in pinacol coupling. However, in the presence of protic solvents such as ethanol, sodium will react with carbonyl compounds differently. Which of the following compounds reacts most similarly to sodium in the presence of protic solvents?

W) $NaBH_4$
X) BH_3
Y) AIBN
Z) LDA

ANSWER: W) $NaBH_4$ **[YL]**

LONG BONUS

6. Chemistry *Short Answer* Caleb is attempting an organic synthesis. He reacts acetone with NH_2OH to form compound **A**, which he then reacts with P_2O_5 to induce a rearrangement and form compound **B**. Answer the following three questions about this synthesis:

1) Compound A is an oxime, which is a hydroxylated form of what common moiety?
2) What is the name of the reaction forming compound **B** from compound **A**?
3) Give the IUPAC name of compound B.

ANSWER: 1) IMINE; 2) BECKMANN REARRANGEMENT; 3) N-METHYLACETAMIDE **[YL]**

TOSS-UP

7. Math *Multiple Choice* Yunyi is reading at night, stopping at midnight. When he started, the minute and hour hands of his clock formed a 176 degree angle. How many minutes did he read for?

W) 25
X) 27
Y) 30
Z) 32

ANSWER: Z) 32 **[EZ]**

BONUS

7. Math *Short Answer* Find the area of a regular polygon with 24 sides inscribed in a circle of radius 2.

ANSWER: 12sqrt(6) - 12sqrt(2) **[EZ]**

TOSS-UP

8. Earth and Space *Multiple Choice* The J2 spherical harmonic coefficient of a planet most directly impacts the precession of which parameter of a satellite's orbit?

W) Inclination
X) Argument of periapsis
Y) Semi-major axis
Z) Eccentricity

ANSWER: X) ARGUMENT OF PERIAPSIS **[SC]**

LONG BONUS

8. Earth and Space *Short Answer* Consider the following three geophysical isostasy models:

1) Airy-Heiskanen
2) Pratt-Hayford
3) Vening-Meinesz

Answer the following two questions about these three models:

1) Which of the models are discrete?
2) Which of the models assumes a constant Moho depth?

ANSWER: 1: 1 AND 2; 2: 2 ONLY **[SC]**

TOSS-UP

9. Biology *Short Answer* Identify all of the following 3 ions that increase in concentration in a guard cell during stomatal opening:

1) H^+
2) K^+
3) Cl^-

ANSWER: 2 AND 3 **[KD]**

BONUS

9. Biology *Short Answer* The Ames test is a common method that uses Salmonella strains to determine whether a given chemical is carcinogenic. Identify all of the following 3 statements that are true of the Ames test: what did u say

1) Rat Liver extract is used to simulate a eukaryotic metabolic environment
2) The mutation rate is measured by the number of strains able to synthesize histidine
3) The chemical is less likely to be carcinogenic if more colonies of bacteria are observed

ANSWER: 1 AND 2 **[KD]**

TOSS-UP

10. Physics *Short Answer* A tesla valve is a simple mechanical arrangement that allows fluid flow in both directions, but makes flow significantly slower in one direction. This is similar to what kind of electrical component, which does not fully block current flow but preferentially slows one direction?

ANSWER: ZENER DIODE **[SC]**

BONUS

10. Physics *Short Answer* An undamped spring-mass system consisting of a Hookean spring attached to a 50 kg mass oscillates at a fundamental angular frequency of $\omega_0 = \pi$ radians per second. A damping force with damping constant b = 0.01 kg/s. To one significant figure, what fraction of the energy of the damped system is dissipated after 80 complete oscillations?

ANSWER: 0.03 **[YL]**

TOSS-UP

11. Chemistry *Multiple Choice* Which of the following correctly describes the kinetic and thermodynamic reactivities of nitrous and nitric acid?

W) Nitrous acid has higher kinetic reactivity and higher thermodynamic reactivity
X) Nitrous acid has higher kinetic reactivity and lower thermodynamic reactivity
Y) Nitrous acid has lower kinetic reactivity and higher thermodynamic reactivity
Z) Nitrous acid has lower kinetic reactivity and lower thermodynamic reactivity

ANSWER: X) Nitrous acid has higher kinetic reactivity and lower thermodynamic reactivity **[YL]**

BONUS

11. Chemistry *Short Answer* $SOCl_2$ is a commonly used chlorinating agent. How many moles of $SOCl_2$ can one mole of citric acid react with?

ANSWER: 4 **[YL]**

TOSS-UP

12. Math *Short Answer* John is trying to estimate the density of fertilizer inside his neighbor's farm. He can observe the gradient of fertilizer density at the fence surrounding the farm and also the density under the fence. If fertilizer density is a scalar function and is harmonic, what is the name for this type of boundary condition?

ANSWER: DIRICHLET BOUNDARY CONDITION **[SC]**

BONUS

12. Math *Short Answer* Inversion about which of the following 3 circles would always transform the circumcircle to a line?

1) Mixtilinear incircle
2) Orthic excircle
3) Nine-point circle

ANSWER: 2 ONLY **[SC]**

TOSS-UP

13. Earth and Space *Multiple Choice* Which of the following bodies is not known to possess large areas of chaos terrain?

W) Mercury
X) Mars
Y) Europa
Z) Titan

ANSWER: Z) TITAN **[SC]**

BONUS

13. Earth and Space *Short Answer* Asteroid 50-WHAT is shaped like a cylinder spinning very rapidly about its long axis. Notably, this asteroid's obliquity was initially observed to be very high, but over a long period of time, the inclination of its orbit has changed such that its obliquity has decreased. If perturbations from bodies other than the Sun can be ignored, what effect is likely driving this phenomenon?

ANSWER: YORP EFFECT (DO NOT ACCEPT YARKOVSKY EFFECT, ACCEPT YARKOVSKY-O'KEEFE-RADZIEVSKII-PADDACK EFFECT WITH AWE) **[SC]**

TOSS-UP

14. Biology *Short Answer* A certain peptide containing 5 amino acids has sequence Arginine - Alanine - Glutamic acid - Cysteine - Leucine. How many ionizable groups are in this peptide?

ANSWER: 4 **[KD]**

BONUS

14. Biology *Short Answer* Identify all of the following 3 types of plastids that are specialized for food storage in plants:

1) Gerontoplast
2) Elaioplast
3) Amyloplast

ANSWER: 2 AND 3 **[KD]**

TOSS-UP

15. Physics *Short Answer* In regions where the magnetic field is approximately linear, the mean motion of plasmas tends to follow the field lines. This can be seen as the conservation of what quantity, equivalent to the flux through a helical path?

ANSWER: THIRD ADIABATIC INVARIANT **[SC]**

BONUS

15. Physics *Multiple Choice* The internal B field of a ferromagnet is zero. Which of the following must be true about the external H field it is immersed in?

W) The magnitude of the external H field is the magnet's retentivity
X) The magnitude of the external H field is the magnet's coercivity
Y) Varying the external H field causes a relatively small change in the internal B field
W) There is insufficient information to determine an answer

ANSWER: X) THE MAGNITUDE OF THE EXTERNAL H FIELD IS THE MAGNET'S COERCIVITY **[SC]**

TOSS-UP

16. Chemistry *Short Answer* Identify all of the following four ring sizes that can be formed by a conrotatory electrocyclic ring closure under thermal conditions:

1) 4
2) 6
3) 8
4) 10

ANSWER: 1 AND 3 **[YL]**

BONUS

16. Chemistry *Short Answer* Kwanga heard that pure sodium metal explodes upon contact with water and now wants some sodium for herself. She sets up an electrolytic cell with a current of 20 amperes. Approximating Faraday's constant as 100,000 coulombs per mole, to two significant figures how long, in minutes, must she run her electrolytic cell if she wishes to obtain 69 grams of sodium?

ANSWER: 250 **[YL]**

TOSS-UP

17. Math *Short Answer* For a function f(x) that is positive and continuous for all real numbers x, it is known that the sum from n=1 to infinity of f(n) converges to a finite value. Identify all of the following 3 statements that must be true:

1) The definite integral from 1 to infinity of f(x) dx converges to a finite value
2) If g(x) is less than f(x) for all real numbers x, then the sum from n=1 to infinity of g(n) converges to a finite value
3) The limit as x approaches infinity of f(x) equals 0

ANSWER: 1 AND 3 **[KD]**

BONUS

17. Math *Short Answer* What is the approximation of e^(sqrt2) using the 3rd degree Maclaurin Polynomial for e^(sqrtx) **[READ AS: e to the power of the square root of x]**, in simplest radical form?

ANSWER: 2 + 4sqrt(2)/3 **[KD]**

TOSS-UP

18. Earth and Space *Short Answer* In deserts, rainwater infiltrating the soil often evaporates before it reaches the water table. This leaves deposits of calcite in the B horizon, which cements the surrounding gravel together to form what rock?

ANSWER: CALICHE (ACCEPT: CALCRETE) **[KW]**

BONUS

18. Earth and Space *Multiple Choice* A missile hits the ISS, shattering it into a linear stream of small particles of debris, all initially moving in the same direction in the ISS's frame. Assuming the projectile's velocity was pointed away from the Earth and is equal in magnitude to the orbital velocity of the ISS, which of the following four statements is always true about the initial osculating orbits of the debris particles?

W) No debris particle has a period higher than that of the ISS
X) No debris particle has a semi*minor* axis higher than that of the ISS
Y) No debris particle has a periapsis higher than that of the ISS
Z) No debris particle has an apoapsis higher than that of the ISS

ANSWER: Y) NO DEBRIS PARTICLE HAS A PERIAPSIS HIGHER THAN THAT OF THE ISS **[SC]**

TOSS-UP

19. Biology *Short Answer* Identify all of the following 3 cellular processes that take place in the cytosol of eukaryotic cells:

1) Glycolysis
2) Glyoxylate Cycle
3) Pentose Phosphate Cycle

ANSWER: 1 AND 3 **[KD]**

BONUS

19. Biology *Short Answer* Order the following 3 ion channels in terms of when they reach their peak permeability in the Sinoatrial Node pacemaker cycle, starting from the beginning of pacemaker potential:

1) T-Type Calcium Channel
2) L-type Calcium Channel
3) Voltage-Gated Potassium Channel

ANSWER: 1, 2, 3 **[KD]**

TOSS-UP

20. Physics *Short Answer* Two spacecraft are maneuvering to Jupiter from Earth, both of which can be assumed to have circular orbits. Spacecraft A uses a rocket engine to enter an elliptical orbit whose apoapsis barely reaches Jupiter. Spacecraft B uses a large solar sail that it keeps oriented directly at the sun, choosing a trajectory that also barely touches Jupiter's orbit. If both spacecraft depart at the same time, which of the following is true about their arrival times at Jupiter?

W) A arrives first
X) B arrives first
Y) Both arrive at the same time
Z) There is not enough information to determine

ANSWER: W) A ARRIVES FIRST **[SC]**

BONUS

20. Physics *Multiple Choice* Rocket engines often produce a distinct discontinuous, crackling noise when ascending through the lower atmosphere. Which of the following effects likely does not contribute to this phenomenon?

W) Standing waves form in stable columns of exhaust, creating an acoustic antenna
X) Rockets are loud enough to surpass the rarefaction limit of air, disrupting the sound
Y) Supersonic exhaust produces a wake of interfering sonic booms when leaving the engines
Z) Atmospheric deceleration of downstream exhaust causes turbulent vortex shedding

ANSWER: W) STANDING WAVES FORM IN STABLE COLUMNS OF EXHAUST, CREATING AN ACOUSTIC ANTENNA **[SC]**

TOSS-UP

21. Chemistry *Short Answer* The specific rotation of α-D-glucose **[READ AS: ALPHA D GLUCOSE]** is 112 degrees milliliters per gram decimeter. What is the measured optical rotation of a 0.1 grams per milliliter racemic solution of α-glucose as measured in a 1 cm cuvette?

ANSWER: 0 **[YL]**

BONUS

21. Chemistry *Short Answer* Identify all of the following four vibrational modes of carbon dioxide that are both infrared active and Raman active:

1) Symmetric stretch
2) Asymmetric stretch
3) In-plane bending
4) Out-of-plane bending

ANSWER: NONE **[YL]**

TOSS-UP

22. Math *Multiple Choice* The Weierstrass Substitution utilizes a u-substitution of $u = \tan(x/2)$ in order to integrate which of the following types of functions?

W) Rational
X) Trigonometric
Y) Exponential
Z) Logarithmic

ANSWER: W) RATIONAL **[KD]**

BONUS

22. Math *Multiple Choice* Consider the group consisting of the integers modulo n equipped with integer multiplication and integer addition. For which of the following values of n would this group not be a ring?

W) 5
X) 7
Y) 9
Z) 11

ANSWER: Y) 9 **[SC]**

TOSS-UP

23. Earth and Space *Multiple Choice* Which of the following is not the anti-solar point?

W) Convergence point of anti-crepuscular rays
X) Center of the zodiacal light
Y) Center of rainbows
Z) Center of glories

ANSWER: X) CENTER OF THE ZODIACAL LIGHT **[SC]**

BONUS

23. Earth and Space *Multiple Choice* A basaltic pluton cools after intruding on less mafic country rock. Compared to the rest of the pluton, you would expect the chilled margins to be:

W) Darker and finer-grained
X) Darker and coarser-grained
Y) Lighter and finer-grained
Z) Lighter and coarser-grained

ANSWER: W) DARKER AND FINER-GRAINED **[KW]**

TOSS-UP

24. Biology *Multiple Choice* Which of the following polysaccharides, composed of glucose subunits, is deposited in the phloem in response to tissue damage in order to seal wounds?

W) Trehalose
X) Tylose
Y) Xylose
Z) Callose

ANSWER: Z) CALLOSE **[KD]**

BONUS

24. Biology *Short Answer* Order the following 3 steps in the skeletal muscle contraction cycle from first to last, starting with the release of calcium from the Sarcoplasmic Reticulum:

1) Inorganic Phosphate is released from myosin heads
2) ATP binds to myosin heads
3) Myosin heads bind to actin filaments

ANSWER: 3, 1, 2 **[KD]**

TOSS-UP

25. Physics *Short Answer* A free-electron laser creates intense, pulsed radiation by periodically accelerating a line of charges. What term generally describes this kind of discretized emission?

ANSWER: BREMSSTRAHLUNG **[SC]**

BONUS

25. Physics *Multiple Choice* In a certain region, the magnetic field is constant in magnitude and isotropic, but its direction rotates with a constant angular velocity vector pointing in the positive z direction. A small magnetic dipole and a small electric dipole are placed in this field, oriented with their moments in the positive x direction, gaining angular velocities of **m** and **e** as a result. Which of the following is true of **m** and **e** after a long time?

W) **m** points along the positive z direction, **e** is zero
X) **m** points along the negative z direction, **e** is zero
Y) **m** is zero, **e** points along the positive z direction
Z) **m** is zero, **e** points along the negative z direction

ANSWER: W) **m** POINTS ALONG THE POSITIVE Z DIRECTION, **e** IS ZERO **[SC]**