TOSS-UP

1. Chemistry *Multiple Choice* The Laporte **[la-PORT]** selection rule forbids centrosymmetric **[cen-tro-sim-MET-ric]** d-d transitions. However, some octahedral complexes are able to get around this by undergoing Jahn-Teller **[yong TELL-er]**distortion. Which of the following octahedral complexes would NOT be expected to distort to enable d-d transitions?

W) $CoCl_6^{3-}$
X) $NiCl_6^{4-}$
Y) $FeCl_6^{3-}$
Z) $Fe(CN)_6^{4-}$

ANSWER: Z) $Fe(CN)_6^{4-}$ **[YL]**

LONG BONUS

1. Chemistry *Short Answer* A certain pericyclic reaction involves five components. Four of them are ${}_{\sigma}2_s$ **[sigma-2-s]**, ${}_{\pi}4_a$ **[pi-4-a]**, ${}_{\sigma}4_a$ **[sigma-4-a]**, and ${}_{\pi}6_s$ **[pi-6-s]**. Select all of the following which could be the fifth component:

1) ${}_{\sigma}2_a$ **[sigma-2-a]**
2) ${}_{\sigma}4_a$ **[sigma-4-a]**
3) ${}_{\pi}4_s$ **[pi-4-s]**

ANSWER: 2 ONLY **[YL]**

TOSS-UP

2. Math *Short Answer* What is the first fibonacci number that is divisible by 10?

ANSWER: 610 **[EZ]**

LONG BONUS

2. Math *Short Answer* A random square of an empty chess board is chosen and a knight is placed on it. What is the expected number of legal moves the knight has?

ANSWER: 5 **[EZ]**

TOSS-UP

3. Earth and Space *Multiple Choice* Ace has picked a comfortable spot in front of two mountains in a desert. After sitting there for a long time, they note that the mountains have

subsided away from each other, thinning the crust between them and allowing erosion to expose deeper material. What is the term for this process?

W) Eduction
X) Exfoliation
Y) Saltation
Z) Stoping

ANSWER: W) EDUCTION **[SC]**

BONUS

3. Earth and Space *Short Answer* In a given region of the atmosphere, the dry adiabatic lapse rate is 10 degrees C/km, the wet adiabatic lapse rate is 8 C/km, and the environmental lapse rate is 6 C/km. If the cloud base is at 4 km, what altitude in kilometers does a parcel of air 20 degrees C hotter than ambient at sea level rise to?

ANSWER: 6 KM **[SC]**

TOSS-UP

4. Biology *Short Answer* Caleb is titrating some amino acids with a strong base. Identify all of the following 3 amino acids that would have 3 equivalence points in their titration curve:

1) Cysteine (*SIS-teen)*
2) Selenocysteine (*suh-LEE-no-sis-teen*)
3) Glutamic Acid

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

BONUS

4. Biology *Short Answer* Stephen is observing the effects of two genes that control whether a goldfish is *Bong* or *Quong.* He notices that crossing two true-breeding strains of *Bong* goldfish yields an F1 generation of only *Quong* goldfish. Then, crossing these F1 goldfish to each other yields an F2 generation with a ratio of 9 *Quong* goldfish to 7 *Bong* goldfish. What fraction of the F2 *Quong* fish would produce a similar ratio of 9:7 offspring when self-crossed?

ANSWER: 4/9 **[KD]**

TOSS-UP

5. Physics *Multiple Choice* Suzuko is watching Kian ride a juvenile shark across the Atlantic, and notices that the angle of the wake the shark makes in the water is invariant as it accelerates. Why is this the case?

W) The shark is approximately shaped like a shock cone
X) Subsurface turbulence influences surface wave crests
Y) The speed of sound in water is extremely slow
Z) Surface waves in water are highly dispersive

ANSWER: Z) SURFACE WAVES IN WATER ARE HIGHLY DISPERSIVE **[SC]**

BONUS

5. Physics *Short Answer* A space fly is moving at a **constant speed** near Spaceman Fred and broadcasting a continuous, unchanging radio signal. Which of the following trajectories for the fly would make Fred observe a chirped signal?

1) Drawing a figure-8 on a sphere centered on Fred
2) Moving towards Fred on an archimedean spiral centered on him
3) Moving in a line that does not intersect Fred

ANSWER: 3 ONLY **[SC]**

TOSS-UP

6. Chemistry *Short Answer* What is the ratio of the energies of the third to second excited energy states for the rigid rotor model?

ANSWER: 2 **[YL]**

BONUS

6. Chemistry *Short Answer* What is the point group of NH_3?

ANSWER: C_{3v} **[YL]**

TOSS-UP

7. Math *Short Answer* What type of numerical integration method is particular to systems satisfying Hamiltonian's equations and exploits the conservation of a certain differential 2-form?

ANSWER: SYMPLECTIC INTEGRATION **[SC]**

BONUS

7. Math *Multiple Choice* Jeremy is playing with three three-dimensional vectors, a, b, c. Which of the following is not equivalent to the others?

W) Triple product of a, b, c
X) Triple product of b, c, a
Y) Geometric product of a, b, c
Z) Magnitude of the exterior product of a, b,c

ANSWER: Y) GEOMETRIC PRODUCT OF A, B, C **[SC]**

TOSS-UP

8. Earth and Space *Short Answer* In remote sensing, gravitational disturbances become exponentially harder to resolve at higher altitudes. This is because the total gravity field of the Earth approaches a smooth ellipsoid at infinity. What is the term for this effect?

ANSWER: UPWARDS CONTINUATION **[SC]**

BONUS

8. Earth and Space *Short Answer* Interstellar comet 3I/Oh Mwah Mwah is approaching the solar system at a known angle and speed. Its impact parameter is relevant only to its current inbound trajectory, but is numerically equivalent to what property of its final trajectory?

W) Semi-major axis
X) Semi-minor axis
Y) Periapsis
Z) Latus rectum

ANSWER: X) SEMI-MINOR AXIS **[SC]**

TOSS-UP

9. Biology *Multiple Choice* Fez is observing a special molecule as it transports from the Endoplasmic Reticulum to the Golgi Apparatus and finally to the plasma membrane. Which of the following types of vesicle and which motor protein, respectively, would likely be utilized in the transport of this molecule?

W) COPI *(cope-1)* and Dynein
X) COPI and Kinesin
Y) COPII (*cope-2)* and Dynein
Z) COPII and Kinesin

ANSWER: Z) COPII AND KINESIN **[KD]**

BONUS

9. Biology *Multiple Choice* Steph recently found two triploid plants in the wild and calls them plant A and plant B. He finds out that plant A uses sporophytic self-incompatibility and has genotype S1/S2/S3 at the incompatibility locus while plant B uses gametophytic self-incompatibility and has genotype S2/S3/S4. What fraction of pollen from plant A will successfully fertilize eggs from plant B and what fraction of pollen from plant B will successfully fertilize eggs from plant A, respectively?

W) ⅓ and 0
X) 0 and ⅓
Y) ⅔ and 0
Z) 0 and ⅔

ANSWER: W) ⅓ and 0 **[KD]**

TOSS-UP

10. Physics *Short Answer* Application of the Liouville equation to many-particle systems produces a set of recursive equations in which the probability distribution of the nth particle is derived from the n-1th. What is the name given to this set of equations?

ANSWER: BBGKY HIERARCHY **[SC]**

LONG BONUS

10. Physics *Short Answer* Consider the following three particle astrophysics experiments:

1) Super-Kamiokande
2) MAGIC
3) BICEP-2

Answer the following two questions about these experiments.

1) Identify all of the experiments that use photomultiplier tubes.
2) Identify all of the experiments that are on orientable mounts

ANSWER: 1: ALL; 2: 2 AND 3 **[SC]**

TOSS-UP

11. Chemistry *Short Answer* According to Wade's rules, which of the following best classifies the shape of the boron cluster B_5H_9?

W) Closo
X) Nido
Y) Arachno
Z) Hypho

ANSWER: X) NIDO **[YL]**

LONG BONUS

11. Chemistry *Short Answer* Identify all of the following four reactions that would result in the formation of an amide:

1) Baeyer-Villiger **[BAY-er VIL-li-ger]** Oxidation of a ketone
2) Beckmann Rearrangement of an oxime **[OX-eem]**
3) Wolff Rearrangement of an alpha diazoketone **[die-ey-zo-KE-tone]** followed by addition of methylamine **[meth-il-AME-ine]**
4) Curtius Rearrangement of an acyl azide **[EY-sil EY-zide]** followed by hydrolysis **[high-DROL-i-sis]**

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

TOSS-UP

12. Math *Short Answer* A certain spherical triangle has three angles of 60, 75, and 90. In steradians, what is its area?

ANSWER: π/8 **[SC]**

LONG BONUS

12. Math *Short Answer* Answer the following two questions about covariance matrices.

1) Identify all of the following four properties that valid covariance matrices must have:

1) Symmetric
2) Unitary
3) Positive definite
4) Periodic

2) Empirical covariance matrices can be naively modified to be valid by adding a constant matrix. What is the term for this technique?

ANSWER: 1: 1 AND 3; 2: DIAGONAL LOADING **[SC]**

TOSS-UP

13. Earth and Space *Short Answer* Solar flares sometimes generate substantial disturbances in the photosphere itself, which can propagate as visible surface waves on the sun. What is the term for these shockwaves?

ANSWER: MORETON WAVES **[SC]**

BONUS

13. Earth and Space *Short Answer* Identify all of the following that are true of the alpha process?

1) It cannot generate carbon
2) It often produces the same products as the p-process
3) It can facilitate magnesium burning
4) It is found in stars of around 6 solar masses

ANSWER: 3 ONLY **[SC]**

TOSS-UP

14. Biology *Multiple Choice* Suzuko is examining his two cucurbit plants and decides he wants to make the first one produce male flowers but he wants to make the second one produce female flowers. Which plant hormones should he apply to the first and second plants, respectively, for the desired result?

W) Brassinosteroid, Cytokinin
X) Cytokinin, Brassinosteroid
Y) Gibberellin, Ethylene
Z) Ethylene, Gibberellin

ANSWER: Y) GIBBERELLIN, ETHYLENE **[KD]**

BONUS

14. Biology *Short Answer* John's mother, Jane, has recently donated some blood and it was found to agglutinate with anti-A antibodies but not with anti-Rh antibodies. Identify all of the following 3 statements that are true about this situation:

1) Jane's blood type must be A negative
2) Jane's mother could have had blood type O positive
3) If she has a child with a man whose blood type is O negative, the child could be at risk of developing hemolytic disease of the newborn

ANSWER: 2 ONLY **[KD]**

TOSS-UP

15. Physics *Short Answer* Frequent observation and measurement of a particle may slow down its time evolution. What is the name of this effect?

ANSWER: QUANTUM ZENO EFFECT **[YL]**

LONG BONUS

15. Physics *Short Answer* Answer the following three questions about magnetic fields within superconductors:

1) Via what effect do superconductors expel internal magnetic fields?
2) λ_L is a characteristic length that determines the distance magnetic fields penetrate within superconductors. What is the name of λ_L, and to one significant figure in terms of λ_L at what distance within a superconductor does the magnetic field fall off to half its initial strength?
3) Traditional superconductors cannot contain magnetic fields as surface currents cancel out any external fields. However, what class of superconductors may contain magnetic fields above a critical field value?

ANSWER: 1) MEISSNER EFFECT; 2) LONDON PENETRATION DEPTH, $0.7\lambda_L$; 3) TYPE II SUPERCONDUCTORS **[YL]**

TOSS-UP

16. Chemistry *Short Answer* The pH scale is a useful function for measuring the acidity of mild acids. For concentrated solutions of superacids, however, the pH scale breaks down as concentration is no longer a valid approximation for activity. What function that resembles the Henderson-Hasselbalch **[HEN-der-son HA-sol-bach]** equation is instead used?

ANSWER: HAMMETT ACIDITY FUNCTION **[YL]**

LONG BONUS

16. Chemistry *Short Answer* A certain thermodynamic system has energy levels with energies of U, 2U, 3U, 4U, and so on. This system follows a Maxwell Boltzmann energy distribution. If the temperature is chosen such that $U = k_bT$, in simplified form in terms of e denoting Euler's

number, what is the probability that a randomly chosen particle is in the ground state energy level?

ANSWER: 1 - 1/e **[YL]**

TOSS-UP

17. Math *Short Answer* How many integers n between 1 and 100 inclusive have the property that $n!/n^2$ **[n factorial over n squared]** is an integer?

ANSWER: 74 **[EZ]**

LONG BONUS

17. Math *Short Answer* A dodecahedron has 12 faces in the shape of regular pentagons. How many space diagonals does it have?

ANSWER: 100 **[EZ]**

TOSS-UP

18. Earth and Space *Short Answer* Ktang is flying a paper airplane over the Sargasso Sea and observes parallel bands of seaweed alternating with bands of open water. The seaweed was deposited by pairs of counter-rotating vortices converging beneath the surface. What are these vortices collectively called?

ANSWER: LANGMUIR CIRCULATION **[KW]**

BONUS

18. Earth and Space *Short Answer* A small dwarf galaxy approaches an elliptical galaxy and is promptly destroyed by gravitational effects. Identify all of the following four objects that this interaction could form:

1) Globular cluster
2) Tidal tail
3) Stellar stream
4) Bar

ANSWER: 1, 3, AND 4 **[SC]**

TOSS-UP

19. Biology *Short Answer* Identify all of the following 3 types of blood vessels in which extravasation, or diapedesis, can occur:

1) Arterioles
2) Capillaries
3) Venules

ANSWER: 3 ONLY **[KD]**

BONUS

19. Biology *Multiple Choice* Which of the following statements regarding vision loss in humans is NOT true?

W) A lesion in the left optic nerve before the optic chiasm would result in complete vision loss in the left eye
X) A lesion in the optic chiasm would result in loss of the right visual field from the right eye
Y) A lesion in the left optic tract would result in the loss of the right visual field from both eyes
Z) A lesion in the right optic tract would result in loss of the right visual field from the left eye

ANSWER: Z) A LESION IN THE RIGHT OPTIC TRACT WOULD RESULT IN LOSS OF THE RIGHT VISUAL FIELD OF THE LEFT EYE **[KD]**

TOSS-UP

20. Physics *Multiple Choice* Evan is playing with a slinky. Shaking the slinky left and right makes a transverse wave and stretching and compressing the slinky makes a longitudinal wave. If Evan cuts the slinky in half and then pulls on it with the same tension as before, assuming mass density remains approximately constant, which of the following correctly describes the changes in the speeds of the transverse and longitudinal waves respectively?

W) Increases, decreases
X) Decreases, increases
Y) Increases, stays the same
Z) Stays the same, stays the same

ANSWER: Z) STAYS THE SAME, STAYS THE SAME **[YL]**

BONUS

20. Physics *Short Answer* The velocity of a 1 kilogram particle satisfies $v(t) = 4t$, and $x = 0$ at $t = 0$. If the potential energy is given as $U(x) = 3x$, what is the action, in Joule-seconds, between $t = 0$ and $t = 5$ s?

ANSWER: 250/3 **[YL]**

TOSS-UP

21. Chemistry *Multiple Choice* Which of the following physical phenomena best explains why the 6s electrons are especially stable and not prone to reaction?

W) Photoelectric effect
X) Heisenberg Uncertainty Principle
Y) Length contraction
Z) Nuclear Overhauser Effect

ANSWER: Y) LENGTH CONTRACTION **[YL]**

BONUS

21. Chemistry *Short Answer* Identify all of the following four crystal packing patterns that contain six octahedral sites per unit cell:

1) Simple Cubic
2) Body-Centered Cubic
3) Cubic Close Packed
4) Hexagonal Close Packed

ANSWER: 2 AND 4 **[YL]**

TOSS-UP

22. Math *Short Answer* What is the maximum volume of a tetrahedron inscribed within a cube of side length 1?

ANSWER: ½ **[EZ]**

LONG BONUS

22. Math *Short Answer* Consider the following four statements:

W) The determinant of the Hessian is greater than 0, f_{xx} is greater than 0
X) The determinant of the Hessian is greater than 0, f_{xx} is less than 0
Y) The determinant of the Hessian is less than 0, f_{xx} is greater than 0
Z) The determinant of the Hessian is less than 0, f_{xx} is less than 0

Answering the following three questions about these four statements:

1) Which statement or statements is true for a relative minimum?
2) Which statement or statements is true for a relative maximum?
3) Which statement or statements is true for a saddle point?

ANSWER: 1: W); 2: X); 3: Y) and Z) **[YL]**

TOSS-UP

23. Earth and Space *Short Answer* Cyan is observing the X-ray spectrum of a galaxy cluster 30 million ly from the Milky Way. Which of the following features would likely not be visible in their observations?

1) Galactic cirrus
2) Interstellar dust
3) Intracluster medium

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

BONUS

23. Earth and Space *Multiple Choice* Which of the following statements about Wadati-Benioff zones is true?

W) They are one of only two places where deep-focus earthquakes happen, the other being hotspots
X) Mineral phase changes that increase the subducting slab's volume contribute to earthquakes
Y) The subducting slab remains brittle enough at depth to fracture because the rock is its own insulator
Z) Friction between the subducting slab and mantle plays a negligible role in earthquakes

ANSWER: Y) The subducting slab remains brittle enough at depth to fracture because the rock is its own insulator **[KW]**

TOSS-UP

24. Biology *Multiple Choice* Which of the following statements most accurately describes what occurs in the trp (*trip)* operon when tryptophan is present in high concentrations and it binds to a repressor?

W) Allosteric inhibition of the small ribosomal subunit during translation of the trp operon
X) Association of Rho protein to the trp operon, decreasing stability of the mRNA transcript
Y) Binding of negative transcription factors to repressor sequences
Z) Formation of a stem loop and attenuation during transcription of the trp operon

ANSWER: Z) FORMATION OF A STEM LOOP AND ATTENUATION DURING THE TRANSCRIPTION OF THE TRP OPERON **[KD]**

LONG BONUS

24. Biology *Short Answer* Angela the bumblebee is watching her baby sister, Daniella the bumblebee, play with dangerous folding beds, an activity with a 50% chance of causing death. Angela is debating whether to risk saving her sister or not. Given that Daniella will have 8 more offspring in her lifetime and Angela will have 4 more offspring in her lifetime, what is the largest chance Angela can have of dying when saving her sister for it to be evolutionarily favorable?

ANSWER: 75% (ACCEPT 0.75) [**KD]**

TOSS-UP

25. Physics *Short Answer* The Ehrenfest paradox concerns the internal structure of an object rotating at relativistic speeds, and notes that that circumference of such an object must be length contracted more than other parts. This suggests the unphysicality of what model for solid relativistic objects?

ANSWER: BORN RIGIDITY **[SC]**

BONUS

25. Physics *Short Answer* Two identical superconducting rings are initially coaxial. They then have the same parallel currents induced in them, and then are launched towards each other along their shared axis. Which of the following occurs?

1) The magnitude of the currents decreases monotonically
2) The rings accelerate away from each other
3) An electric field is induced in the region between the rings

ANSWER: 2 ONLY **[SC]**