FE!M 2025

Round 13

TOSS UP

1) CHEMISTRY *Short Answer* Which stereochemical model is used to predict the diastereoselectivity of nucleophilic addition to an α-chiral carbonyl compound, based on the transition state that places the nucleophile's approach opposite the largest substituent on the α-carbon?

ANSWER: Felkin-Ahn Model [AA]

VISUAL BONUS

1) CHEMISTRY *Short Answer* Shown in the image is an intermediate step in the production of basketene, a polycyclic system that can be used as a molecular cage. Answer the following three questions about this reaction:

1) When 1 mole of compound 5 is burned, to two significant figures and at STP, how many liters of water vapor are produced?
2) Under what conditions does the reaction shown take place?
3) How many carbon-13 NMR peaks would compound 4 display?

ANSWER: 1) 90; 2) Photochemically (ACCEPT: UV light, Radiation); 3) 6 [TS]

TOSS UP

2) PHYSICS *Short Answer* Order the following four interactions between a photon and an atom by increasing energy of the incident photon:

1) Photoelectric effect

2) Compton scattering

3) Pair production

4) Photodisintegration

ANSWER: 1234 [RoA]

BONUS

2) PHYSICS *Short Answer* What theorem, in vector calculus, states that a vector field is uniquely determined if its divergence, curl, and boundary conditions are known?

ANSWER: Helmholtz's theorem [RuA]

TOSS UP

3) ESS *Multiple Choice* After the retreat of glaciers at the end of the Pleistocene, soils began forming on freshly deposited parent material in Massachussetts. Which of the following soils orders is most dominant in Massachussetts?

W) Gelisols

X) Oxisols

Y) Inceptisols

Z) Ultisols

ANSWER: Y) Inceptisols [RoA]

BONUS

3) ESS *Multiple Choice* Which of the following best describes the feedback effect of wildfires on atmospheric oxygen concentrations during the Late Carboniferous and Early Permian periods?

W) Positive feedback due to increased wildfires

X) Positive feedback due to decreased wildfires

Y) Negative feedback due to increased wildfires

Z) Negative feedback due to decreased wildfires

ANSWER: Y) Negative feedback due to increased wildfires [RoA]

TOSS UP

4) MATH *Short Answer* When expressing a jump discontinuity as a sum of sinusoids, it is common to observe a slight overshoot on either side of the discontinuity. This is known as what phenomenon?

ANSWER: Gibb's phenomenon [AdM]

BONUS

4) MATH *Short Answer* In a 10 by 10 grid, how many distinct lines pass through the bottom left point and at least one other point on the grid?

ANSWER: 56 [AdM]

TOSS UP

5) BIOLOGY *Short Answer* Similar to blastodermal patterning in arthropods, cell identity in the angiosperm embryo sac is determined by a morphogen gradient. What major class of plant hormones controls this process?

ANSWER: Auxins [TS]

BONUS

5) BIOLOGY *Short Answer* An alien species replicates its sextuple-stranded genome as follows: the six strands are split at random and each set of three are used as templates for the new copy. If a Meselson-Stahl experiment is performed on cells of this species, how many bands will be observed in the radiograph?

ANSWER: 4 [TS]

TOSS UP

6) CHEMISTRY *Multiple Choice* The Joule-Thomson effect describes the change in temperature of a real gas as it is expanded in an isenthalpic process. Which of the following best describes the sign of the Joule-Thomson coefficient around the inversion temperature?

W) Positive both above and below the inversion temperature

X) Positive above the inversion temperature, negative below the inversion temperature

Y) Negative above the inversion temperature, positive below the inversion temperature

Z) Negative both above and below the inversion temperature

ANSWER: X) Positive above the inversion temperature, negative below the inversion temperature [AA]

VISUAL BONUS

6) CHEMISTRY *Short Answer* Shown in the image are the first two steps of a possible route to the synthesis of tolmetin. In this synthesis, *N*-methylpyrrole reacts with Me_2NH, formaldehyde, and acetic anhydride in Step 1. Answer the following two questions about this synthesis:

1) What is the name of the type of reaction shown in Step 1?

2) Given that Step 2 is a Vilsmeier-Haack reaction, and that two of the reagents are $POCl_3$ and base

W) 4-methyl-N,N-dimethylbenzamide

X) 3-methyl-N,N-dimethylbenzamide

Y) 4-ethyl-N,N-dimethylbenzamide

Z) 3-ethyl-N,N-dimethylbenzamide

ANSWER: X) 3-buten-2-one [TS]

TOSS UP

7) PHYSICS *Multiple Choice* In quantum mechanics, time-evolution operators must preserve the total probability. Which of the following properties must these operators have to ensure conservation of probability?

W) Hermitian

X) Unitary

Y) Orthogonal

Z) Singular

ANSWER: X) Unitary [RoA]

BONUS

7) PHYSICS *Short Answer* Consider a hypothetical one-dimensional particle moving in four-dimensional space whose energy E depends on its momentum p according to the relation $E = p^3$. What is the adiabatic index for this particle?

ANSWER: $\frac{7}{4}$ [RuA]

TOSS UP

8) ESS *Multiple Choice* Which of the following pairs of minerals would least likely be found coexisting in the same rock?

W) Biotite and Muscovite

X) Nepheline and Quartz

Y) Pigeonite and Olivine

Z) Sodalite and Leucite

ANSWER: X) Nepheline and Quartz [RoA]

BONUS

8) ESS *Short Answer* Identify all of the following three properties of groundwater and soil that, when increased, would increase the thickness of the capillary fringe layer:

1) Salinity of groundwater

2) Soil grain size

3) Groundwater temperature

ANSWER: 1 only [RoA]

TOSS UP

9) MATH *Short Answer* Identify all of the following three groups that are abelian:

1) Dihedral group of 2n elements
2) The symmetric group on n elements
3) General linear group of degree n over the real numbers

ANSWER: None [AdM]

BONUS

9) MATH *Short Answer* Compute the eigenvalues of the 2 by 2 matrix with first row 1, 3 and second row 3, 1.

ANSWER: -2 and 4 [AdM]

TOSS UP

10) BIOLOGY *Multiple Choice* 5' RACE PCR is a technique used to quantitatively identify low-abundance mRNAs by ligating adapters to cDNA. Which of the following best describes why adapter ligation is used in this procedure?

W) Adapter hairpins increase Taq polymerase processivity
X) Adapters denature at lower temperatures than native primers
Y) Native primers bind to cDNA with varying affinities
Z) Native primers are degraded more quickly by reverse transcriptase

ANSWER: Y) Native primers bind to cDNA with varying affinities

BONUS

10) BIOLOGY *Multiple Choice* Scientists in Roshan's basement are studying porphyrin compounds due to their fluorescent properties. Alongside 5-amino levulinic acid, which of the following amino acids is a precursor in heme biosynthesis?

W) Serine

X) Histidine

Y) Glycine

Z) Alanine

ANSWER: Y) Glycine

TOSS UP

11) CHEMISTRY *Short Answer* Identify all of the following three groups that are to be present in the product of the reaction of tert-butyl chloroacetate with ethyl acrylate:

1) Cycloalkane

2) Ester

3) Ketone

ANSWER: 1 and 2 [AA]

BONUS

11) CHEMISTRY *Short Answer* Molecule A with chemical formula $C_{13}H_{17}NO$ has the following NMR spectrum: H (ppm) 1.27 (6H, s), 1.70 (4H, m), 2.88 (2H, m), 5.4-6.1 (2H, broad s, exchanges with D2O) and 7.0-7.5 (3H, m). Identify all of the following 3 statements that are likely true of molecule A:

1) It has 3 aromatic hydrogens
2) It has 2 hydrogens bound to the nitrogen
3) It has an amine functional group, but not an amide functional group

ANSWER: 1 and 2 [AA]

TOSS UP

12) PHYSICS *Short Answer* The Hawking temperature of a black hole is proportional to its mass raised to what power?

ANSWER: -1 [RuA]

BONUS

12) PHYSICS *Short Answer* What electromagnetic force results from the interaction between a nonrelativistic accelerating particle and its own emitted radiation?

ANSWER: Abraham-Lorentz force [RuA]

TOSS UP

13) ESS *Multiple Choice* Bolometric correction is the correction required to convert the absolute visible magnitude of an object to its bolometric magnitude. Stars belonging to which spectral classes generally have the smallest bolometric correction?

W) O

X) B

Y) G

Z) M

ANSWER: Y) G [RoA]

BONUS

13) ESS *Short Answer* Sideromelane is variety of tachylite that lacks iron oxide crystals dispersed throughout its matrix. Identify all of the following three statements that are true about sideromelane compared to tachylite:

1) It forms at higher temperatures

2) It has a higher refractive index

3) It forms under a higher cooling rate

ANSWER: 1 and 3 [RoA]

TOSS UP

14) MATH *Short Answer* Evaluate $\cos(i \ln 3)$ (read: *the cosine of quantity i times ln 3*)

ANSWER: 5/3 [AdM]

BONUS

14) MATH *Multiple Choice* Which of the following is not true about the p-adic numbers and the p-adic metric?

W) The cardinality of the p-adic numbers is the same as that of the real numbers

X) The p-adic metric satisfies the triangle inequality

Y) The p-adic numbers form an orderable field

Z) p-adic integers can be represented by formal power series

ANSWER: Y) The p-adic numbers form an orderable field [AdM]

TOSS UP

15) BIOLOGY *Multiple Choice* Which of the following options best explains why the measured voltage for EEGs is significantly lower than that of an action potential?

W) The voltage is muted due to recording through the scalp

X) Asynchronous firing of neurons reduces the maximal frequency

Y) The frequency is reduced due to recording through the scalp

Z) Asynchronous firing of neurons reduces the maximal voltage

ANSWER: Z) Asynchronous firing of neurons reduces the maximal voltage [TS]

BONUS

15) BIOLOGY *Short Answer* Christopher Robin performs a mark-recapture experiment to estimate the number of bears in the 100-Acre Forest. Select ALL of the following errors in his study that may result in a positive deviation from the true population size:

1) Insufficient time allotted for marked individuals to homogenize
2) Incomplete marking of the initial sample
3) Negative selection for marked individuals

ANSWER: 2 and 3 [TS]

TOSS UP

16) CHEMISTRY *Short Answer* Identify all of the following four statements that are true about the regioselectivity of the Diels-Alder reaction of 2-methyl-1,3-butadiene and 3-one-but-1-ene:

1) Doing this reaction in a closed tube with toluene at $120^{\circ}C$ means the para product is about 3 times more favored
2) Doing this reaction in a closed tube with toluene at $120^{\circ}C$ means the ortho product is about 3 times more favored
3) Doing this reaction at $0^{\circ}C$ with $SnCl_4 \cdot 5H_2O$ means the para product is about 13 times more favored
4) Doing this reaction at $0^{\circ}C$ with $SnCl_4 \cdot 5H_2O$ means the ortho product is about 13 times more favored

ANSWER: 1 and 3

VISUAL BONUS

16) CHEMISTRY *Short Answer* Shown on the left is the ^{1}H NMR spectrum of 5-chloro-1,3-dimethoxybenzene. Shown on the right is the structure of 5-chloro-1,3-dimethoxybenzene. Answer the following 2 questions about the images:

1) What type of coupling exists between hydrogen atoms (A) and (B)?
2) Match each of the hydrogen environments on the right image (A, B, or C) to the corresponding signal of the ^{1}H NMR spectrum (1, 2, or 3).

ANSWER: 1) $^{4}J_{HH}$ coupling (Accept: Allylic coupling, W-coupling); 2) A-1, B-2, C-3 [AA]

TOSS UP

17) PHYSICS *Short Answer* Hawking radiation can be viewed as a special case of what phenomenon in which an observer with constant acceleration perceives the vacuum as a thermal bath, even though an inertial observer detects no particles?

ANSWER: Unruh effect [AdM]

BONUS

17) PHYSICS *Short Answer* A triangular plate has each of its vertices connected to one point on the ceiling through three strings. The tension in the first string is 10 N and the string has length 2 m. Given that the triangular plate is uniform with a total mass of 10 kg, find the tension in a string of length 7 m.

ANSWER: 35 N [AdM]

TOSS UP

18) ESS *Multiple Choice* Which of the following best explains how galaxy collisions can trigger massive starburst events within molecular clouds?

W) Collisions heat the gas, preventing fragmentation and leading to massive star formation

X) Gravitational torques from the collision remove angular momentum from clouds, allowing them to collapse

Y) Shocks from colliding gas streams compress clouds enough to overcome internal pressure

Z) Tidal forces from the collision increase cloud densities uniformly, promoting collapse

ANSWER: X) Gravitational torques from the collision remove angular momentum from clouds, allowing them to collapse [AS]

VISUAL BONUS

18) ESS *Short Answer* Answer the following three questions using the spectrum shown:

1) Using the spectrum shown, identify the feature labeled A, which consists of numerous narrow absorption lines between the quasar's Lyman-α emission and shorter wavelengths.

2) Each line in the erratic line in the spectrum corresponds to what type of structure along the line of sight?

3) The Lyman-α lines appear at different wavelengths because of what cosmological effect?

ANSWER: 1) Lyman-α forest; 2) HI cloud; 3) Doppler effect (ACCEPT: Redshift) [AS]

TOSS UP

19) MATH *Short Answer* Order the following classifications of rings from most to least general:

1) UFD
2) PID
3) Euclidean Domain

ANSWER: 123 [AdM]

BONUS

19) MATH *Short Answer* What is the arc length from $x = 1$ to $x = \frac{4}{3}$ of the function $y = x^{1.5}$?

ANSWER: $\frac{56}{27}$ [AdM]

TOSS UP

20) BIOLOGY *Short Answer* Scientists at Memorial Sloan Kettering Cancer Center are studying glutaminolysis, a process in which tumor cells are known to utilize glutamine as a carbon source to support phospholipid synthesis for cell division. This can be attributed to what effect in which aerobic fermentation is observed in tumor cells?

ANSWER: Warburg effect [TS]

VISUAL BONUS

20) BIOLOGY *Short Answer* Answer the following two questions about the plant shown in the image:

1) What plant family contains this species?
2) Identify all of the following three fruits that are derived from plants also contained in this family:
    1) Cherry
    2) Pear
    3) Eggplant

ANSWER: 1) Rosaceae; 2) 1 and 2 [TS]

TOSS UP

21) CHEMISTRY *Multiple Choice* Rutvik decides to try to synthesize a specific compound that is important for the poisoning of catalysts. To do this, he adds aniline and glycerol to a flask along with nitrobenzene and sulfuric acid, and then heats it to 120 celcius. The result is very messy. What is the name of the reaction and the compound that Rutvik is trying to synthesize, respectively?

W) Reformatsky reaction; Isoquinoline

X) Hantzsch synthesis; Quinoline

Y) Skraup reaction; Quinoline

Z) Knorr synthesis; Isoquinoline

ANSWER: Y) Skraup reaction; Quinoline [TS]

VISUAL BONUS

21) CHEMISTRY *Short Answer* Shown in the image is the structure of an organometallic complex. Answer the following three questions regarding this image:

1) What is the name of the compound?
2) What is the most common aggregation state for this compound?
3) Which of the following coordinating additives is commonly used with n-butyllithium to disrupt its aggregated structure, increase its basicity, and make it a more effective deprotonating agent?

W) CuI

X) TMEDA

Y) t-BuOK

Z) DIPEA

ANSWER: 1) N-butyllithium; 2) Tetramer; 3) X) TMEDA [AA]

TOSS UP

22) PHYSICS *Multiple Choice* Which of the following is NOT a valid way to find the normal modes of an AC circuit?

W) Short two terminals not connected by wires and solve for the angular frequency

X) Set the impedance of any two terminals not connected by wires to infinity

Y) Find the eigenvalues of the coefficient matrix

Z) Set the phase of all independent loops equal, then solve for the shared angular frequency

ANSWER: Z) Set the phase of all independent loops equal, then solve for the shared angular frequency [RuA]

BONUS

22) PHYSICS *Multiple Choice* An object is dropped from rest at a very high height h » R, where R is the radius of the Earth. Which of the following is closest to the ratio of the time it takes to hit the ground to the period of a circular orbit at that same height?

W) $\frac{1}{4}$

X) $\frac{1}{2}$

Y) $\frac{\sqrt{2}}{4}$

Z) $\frac{\sqrt{2}}{8}$

ANSWER: Z) $\frac{\sqrt{2}}{8}$ [RuA]

TOSS UP

23) ESS *Short Answer* Identify all of the following four attributes that accurately describe cold-core rings:

1) Warm
2) Shallow
3) Rotating clockwise
4) Zone of downwelling

ANSWER: None [RoA]

BONUS

23) ESS *Short Answer* Order the following three lava types by increasing average viscosity:

1) Carbonatitic
2) Kimberlitic
3) Basaltic

ANSWER: 123 [RoA]

TOSS UP

24) MATH *Multiple Choice* For which of the following numbers n is $n - 1$ a quadratic residue modulo n?

W) 23
X) 45
Y) 99
Z) 103

ANSWER: X) 45 [AdM]

BONUS

24) MATH *Multiple Choice* The Hairy Ball Theorem states that any continuous tangent vector field on a 2-sphere must vanish at one or more points. For which of the following manifolds is it possible for there to exist a nonvanishing continuous tangent vector field?

W) 4-sphere

X) Real projective plane

Y) Klein bottle

Z) Torus

ANSWER: Z) Torus [AdM]

TOSS UP

25) BIOLOGY *Multiple Choice* Activation-induced cytidine deaminase is responsible for immunoglobulin class switching in plasma cells. Production of which of the following isotypes would be unaffected under AID knockout?

W) IgA

X) IgE

Y) IgG

Z) IgM

ANSWER: Z) IgM [TS]

BONUS

25) BIOLOGY *Short Answer* Advaith uses a cell-free system to synthesize a peptide with sequence MOP-URI. Answer the following two questions about this peptide:

1) Identify all of the following three NMR techniques that may be used to study the structure of this peptide:
    1) 77Se-NMR
    2) 31P-NMR
    3) 33S-NMR

4) Which of the following modifications can this peptide undergo?
    W) Methylation
    X) Ubiquitination
    Y) Phosphorylation
    Z) Glycosylation

ANSWER: 1) 1 and 3; 2) W) Methylation [TS]
