# FE!M 2025

## Round 12

### TOSS UP

1) CHEMISTRY *Multiple Choice* Conventional phase diagrams plot the stability of different forms of an element at various temperatures and pressures. Similarly, what axes are used to represent redox stability in an electrochemical Pourbaix diagram?

W) Temperature, pH

X) Reduction potential, pH

Y) Temperature, oxidation state

Z) Reduction potential, oxidation state

ANSWER: X) Reduction potential, pH

### BONUS

1) CHEMISTRY *Short Answer* Constant-volume and pressure process A has a Helmholtz free energy of reaction of 500 kJ/mol at 100 K and 200 kJ/mol at 200 K at 1 bar. Another constant-volume and pressure process B has a Gibbs free energy of reaction of 600 kJ/mol at 100 K and 300 kJ/mol at 300 K, both at 1 bar. Rounding your answer to two significant figures, what is the ratio of the enthalpy of reaction for process A at 100 K to that of process B at 100 K, both at 1 bar?

ANSWER: 1.1

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**TOSS UP**

2) PHYSICS *Short Answer* A deep-water wave has angular frequency described by $\omega = \sqrt{k}$, where $\omega$ is the angular frequency and $k$ is the wavenumber. What is the ratio of group velocity to phase velocity for this wave?

ANSWER: $\frac{1}{2}$ [RoA]

**BONUS**

2) PHYSICS *Short Answer* A particle in a two-dimensional box has a ground state energy E. It is excited into a state with two quantum numbers 1 and 3. In terms of E, what is the new energy of the particle?

ANSWER: 5E [RuA]

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**TOSS UP**

3) ESS *Short Answer* During metamorphism, rhodochrosite can react with silica-rich fluids to form what mineral, releasing carbon dioxide as a byproduct?

ANSWER: Rhodonite [RoA]

**BONUS**

3) ESS *Short Answer* Order the following four carbonate minerals by increasing average specific gravity

1) Rhodochrosite
2) Aragonite
3) Calcite
4) Siderite

ANSWER: 3214 [RoA]

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**TOSS UP**

4) MATH *Short Answer* Identify all of the following three quantities that are preserved by conformal mappings

1) Lengths
2) Angles
3) Areas

ANSWER: 2 only [AdM]

**BONUS**

4) MATH *Short Answer* Identify all of the following three statements that are true about matrices:

1) Every real symmetric matrix is diagonalizable
2) Every complex matrix with distinct eigenvalues is diagonalizable
3) Every non-invertible matrix has a nontrivial nullspace

ANSWER: All [AdM]

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**TOSS UP**

5) BIOLOGY *Short Answer* Beanstalk Jack reaches into your brain and cuts the pituitary infundibulum. Identify all of the following three effects that would be observed as a result:

1) Increased blood osmolarity
2) Decreased prolactin levels
3) Decreased metabolic rate

ANSWER: 1 and 3

**BONUS**

5) BIOLOGY *Multiple Choice* A patient experiences a thalamic lesion due to a stroke. Which of the following senses would be unimpaired by this condition?

W) Olfaction

X) Gustation

Y) Vision

Z) Audition

ANSWER: W) Olfaction [TS]

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**TOSS UP**

6) CHEMISTRY *Multiple Choice* Which of the following statements is not true about the Krapcho decarboxylation?

W) It leads to the formation of $RCl$ and $CO_2$ as byproducts

X) It works best with tert-butyl esters due to the SN1 solvation step

Y) It removes a $CO_2$ group

Z) It uses water to convert the enolate back into the ester

ANSWER: X) It works best with tert-butyl esters due to the SN1 solvation step [AA]

**BONUS**

6) CHEMISTRY *Short Answer* The pKa of acetic acid is 4.76. To two significant figures, what is the pH of a 0.1 molar solution of acetic acid?

ANSWER: 2.9

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**TOSS UP**

7) PHYSICS *Short Answer* Icosahedrite is the only naturally occurring example of what type of crystal, which has a crystal structure that is ordered but not periodic?

ANSWER: Quasicrystal [RoA]

**BONUS**

7) PHYSICS *Multiple Choice* A massless ideal elastic rod stands upright with one of its ends fixed, allowing no translation or rotation about it. A force is applied to the other end of the rod such that it is always perpendicular to the rod. Which of the following curves best describes the shape of the rod at equilibrium?

W) Catenary

X) Circular arc

Y) Parabola

Z) Sinusoid

ANSWER: X) Circular arc [RuA]

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**TOSS UP**

8) ESS *Short Answer* Identify all of the following three changes to a beach that would increase the rate of longshore drift on the beach: 1) Increasing the slope of the beach; 2) Replacing the sand with clay; 3) Replacing the sand with gravel

ANSWER: 1 only [RoA]

**BONUS**

8) ESS *Short Answer* Sputtering is a process of atmospheric escape in which energetic charged particles hit atmospheric molecules and knock them into space. Order the following four bodies by increasing effect of sputtering on their atmosphere:

1) Mars
2) Venus
3) Io
4) Earth

ANSWER: 4213 [RoA]

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**TOSS UP**

9) MATH *Short Answer* In homogenized barycentric coordinates, what are the coordinates of the centroid of the reference triangle?

ANSWER: $(\frac{1}{3}, \frac{1}{3}, \frac{1}{3})$[AdM]

**BONUS**

9) MATH *Short Answer* The multivariable function $f(x, y)$ is defined as $2xy + y^2$. Given that $x = t^2$ and $y = 2t$, what is the derivative of $f$ with respect to $t$?

ANSWER: $12t^2 + 8t$ [AdM]

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**TOSS UP**

10) BIOLOGY *Short Answer* Identify all of the following three hormone receptors that possess catalytic function:

1) Insulin receptor
2) Muscarinic acetylcholine receptor
3) Nitric oxide receptor

ANSWER: 1 and 3 [TS]

**BONUS**

10) BIOLOGY *Multiple Choice* Samples of body fluids are isolated and treated with equal amounts of 15-crown-5 and 18-crown-6. Which of the following fluids would have the highest ratio of bound 18-crown-6 to 15-crown-5?

W) Cerebrospinal fluid
X) Endolymph
Y) Aqueous humor
Z) Synovial fluid

ANSWER: X) Endolymph [TS]

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**TOSS UP**

11) CHEMISTRY *Multiple Choice* Which of the following statements is true about activity coefficients according to the Debye-Hückel limiting law for dilute electrolyte solutions?

W) Activity coefficients increase as ionic strength increases

X) Activity coefficients are independent of ionic charges

Y) Activity coefficients approach 1 as ionic strength approaches 0

Z) Activity coefficients approach 2 as ionic strength approaches 0

ANSWER: Y) Activity coefficients approach 1 as ionic strength approaches 0 [AA]

**BONUS**

11) CHEMISTRY *Short Answer* Identify all of the following three functional groups present in the reaction of 1,3-dicarbonyl group with an electrophilic carbonyl compound in the presence of an amine and acetic acid:

1) Alkene

2) Carbonyl

3) Ester

ANSWER: All

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**TOSS UP**

12) PHYSICS *Short Answer* A viscous fluid is flowing through the pipe when the pipe suddenly enlarges in size. Identify all of the following quantities that are conserved:

1) Flow velocity
2) Momentum per unit volume
3) Total fluid energy per unit volume

ANSWER: None [RuA]

**BONUS**

12) PHYSICS *Short Answer* What approximation in quantum mechanics states that the integral of wavenumber with respect to position over a closed loop equals an integer multiple of Planck's constant plus some phase difference?

ANSWER: WKB approximation [RoA]

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**TOSS UP**

13) ESS *Multiple Choice* Pandanus candelabrum is a tropical plant whose presence can indicate underground diamond deposits. Which of the following best describes the type of soil that this plant is commonly found in?

W) Pale, sandy soil with high silica content
X) Dark, heavy soil with high magnesium and iron content
Y) Moist, calcium-rich soil with high organic matter content
Z) Fine, clay-rich soil with high aluminum content

ANSWER: X) Dark, heavy soil rich in magnesium and iron minerals [RoA]

**BONUS**

13) ESS *Short Answer* Identify all of the following four paleocurrent indicators that indicate stream flow direction:

1) Clast imbrication
2) Groove casts
3) Flute casts
4) Primary lineations

ANSWER: 1 and 3 [RoA]

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**TOSS UP**

14) MATH *Short Answer* Identify all of the following three properties that are satisfied by the Hessian matrix of the function $f(x, y) = \frac{x^2 - y^2}{2}$ (read: *the quantity x squared minus y squared, all over 2*)

1) Invertible
2) Symmetric
3) Orthogonal

ANSWER: All [AdM]

**BONUS**

14) MATH *Short Answer* For a positive integer n, what function of n yields the smallest positive integer n such that $a^n \equiv 1 \pmod{m}$ for every integer $a$ coprime to $n$?

ANSWER: Carmichael function [AdM]

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**TOSS UP**

15) BIOLOGY *Multiple Choice* Kian is studying a speech-impaired patient with an astrocytoma. When he images the tumor with PET, in what area will he see the tumor and which radioactive tracer should he use, respectively?

W) Left Temporal Lobe, fluorodeoxyglucose

X) Left Temporal Lobe, fluoroethyltyrosine

Y) Left Frontal Lobe, fluorodeoxyglucose

Z) Left Frontal Lobe, fluoroethyltyrosine

ANSWER: Z) Left Frontal Lobe, fluoroethyltyrosine [TS]

**BONUS**

15) BIOLOGY *Short Answer* Brianna is a dedicated worker bee with one sister and three brothers. Assuming each individual has equal reproductive potential, what is the minimum probability that Brianna's death would be justified from an evolutionary perspective if she sacrifices herself to save her family?

ANSWER: $\frac{1}{3}$

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**TOSS UP**

16) CHEMISTRY *Short Answer* What principle explains how the product ratio from a reaction with fast, reversible equilibrium between reactants is determined by the difference in free energy of the transition states, not the starting material's equilibrium?

ANSWER: Curtin-Hammett principle [AA]

**BONUS**

16) CHEMISTRY *Short Answer* The standard Born equation allows one to find the enthalpy of solvation. The radius of the $Ca^{2+}$ ion is A nanometers and the radius of the $Al^{3+}$ ion is B nanometers. Expressing your answer in terms of A and B, what is the ratio of the solvation enthalpy of $Ca^{2+}$ to that of $Al^{3+}$?

ANSWER: $\frac{4B}{9A}$ [AA]

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**TOSS UP**

17) PHYSICS *Short Answer* An object moving in the presence of a central mass is subject to a form of precession on its spin axis, predicted by general relativity. What is the name of this effect?

ANSWER: Geodetic effect [RuA]

**BONUS**

17) PHYSICS *Short Answer* An object orbits around a star with a semimajor axis of 4 AU, distance from focus to center of 2 AU, and a period of 1 year. If the object is on the latus rectum of its orbit, then in degrees, what is the angle between its position vector and its Laplace-Runge-Lenz vector?

ANSWER: 90 [RuA]

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**TOSS UP**

18) ESS *Multiple Choice* Which of the following best explains the difference between classical novae and dwarf novae?

W) Classical novae occur due to hydrogen detonation whereas dwarf novae occur due to helium detonation

X) Classical novae occur in binary star systems whereas dwarf novae occur in isolated white dwarves

Y) Classical novae exhibit periodic variability whereas dwarf novae exhibit irregular variability

Z) Classical novae occur due to runaway fusion whereas dwarf novae occur due to instabilities in the accretion disk

ANSWER: Z) Classical novae occur due to runaway fusion whereas dwarf novae occur due to instabilities in the accretion disk [RoA]

**BONUS**

18) ESS *Multiple Choice* Which of the following best describes the feedback effect of isostasy on the erosion rates of mountain ranges?

W) Positive feedback because erosion causes uplift

X) Positive feedback because erosion causes subsidence

Y) Negative feedback because erosion causes uplift

Z) Negative feedback because erosion causes subsidence

ANSWER: W) Positive feedback because erosion causes uplift [RoA]

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**TOSS UP**

19) MATH *Multiple Choice* The Gauss-Markov theorem states that, under certain conditions, the least-squares estimator is the best linear unbiased estimator. Which of the following is not a condition needed for the Gauss-Markov theorem to hold?

W) The error terms have constant variance

X) The expected value of the error terms is zero

Y) The error terms are normally distributed

Z) The error terms are uncorrelated with the explanatory variables

ANSWER: Y) The error terms are normally distributed [AdM]

**BONUS**

19) MATH *Short Answer* What is the area of the region that satisfies the inequalities $x^2 + y^2 \leq 100$ and $y \geq 5$?

ANSWER: $\frac{100}{3}\pi - 25\sqrt{3}$ [AdM]

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**TOSS UP**

20) BIOLOGY *Short Answer* The partial thromboplastin time is defined as the time taken for the intrinsic pathway to clot a sample of plasma. Identify all of the following three substances that would increase the partial thromboplastin time if elevated in a plasma sample:

1) Tissue factor pathway inhibitor

2) Warfarin

3) EDTA

ANSWER: 2 and 3 [TS]

**BONUS**

20) BIOLOGY *Multiple Choice* Roshan expresses GFP-coupled catalase in a colony of HeLa cells and notices a lack of fluorescence localization to COPI-coated vesicles. Which of the following signal sequences is likely located on this protein?

W) Peroxisome signal sequence

X) ER signal sequence

Y) Nuclear localization sequence

Z) Mitochondrial signal sequence

ANSWER: W) Peroxisome signal sequence [TS]

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**TOSS UP**

21) CHEMISTRY *Short Answer* Identify all of the following three coupling reactions that normally have nickel as a catalyst:

1) Sonogashira Coupling

2) Buchwald–Hartwig Amination

3) Negishi Coupling

ANSWER: 3 only

**BONUS**

21) CHEMISTRY *Short Answer* Identify all of the following statements that are true regarding the preference for SN2 substitution over SN2' substitution

1) Bulky groups at the γ-carbon force the reaction to proceed via SN2 attack
2) SN2 attack is kinetically favored for simple primary allylic halides
3) Gilman reagents favor SN2' attack

ANSWER: ALL [AA]

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**TOSS UP**

22) PHYSICS *Multiple Choice* Which of the following best describes the IV graph of a Zener diode?

W) Zero, then increases indefinitely
X) Increases to zero, then zero
Y) Increases to zero, stays at zero, then increases indefinitely
Z) Decreases to zero, stays at zero, then decreases indefinitely

ANSWER: Y) Increases to zero, stays at zero, then increases indefinitely [RuA]

**BONUS**

22) PHYSICS *Short Answer* In the multipole expansion used to describe the potential due to a distribution of charges or masses, the moments of the distribution are expressed using a specific set of polynomials inside a volume integral. What set of polynomials are commonly used in this expansion?

ANSWER: Legendre polynomials [RuA]

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**TOSS UP**

23) ESS *Multiple Choice* Which of the following stars has the lowest Eddington limit?

W) Red supergiant

X) Wolf-Rayet star

Y) White dwarf

Z) Neutron star

ANSWER: Y) White dwarf [AS]

**BONUS**

23) ESS *Multiple Choice* Theenash develops a new model of Jupiter's evolution dubbed the "Grand Crack Hypothesis". His model predicts Jupiter formed at a distance of 2 AU from the Sun and migrated inwards to a distance of 1.5 AU before reversing direction and settling at its current distance of 5.4 AU. Which of the following best explains why this model must be incorrect?

W) 2 AU was inside the early solar system's frost line so refractories couldn't have accreted

X) 2 AU was inside the early solar system's frost line so volatiles couldn't have accreted

Y) 2 AU was outside the early solar system's frost line so refractories couldn't have accreted

Z) 2 AU was outside the early solar system's frost line so volatiles couldn't have accreted

ANS: X) 2 AU was inside the early solar system's frost line so volatiles couldn't have accreted [RoA]

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**TOSS UP**

24) MATH *Short Answer* In logic, it is common to assume that either a given proposition or its negation is true. This is due to what law?

ANSWER: Law of excluded middle [AdM]

**BONUS**

24) MATH *Short Answer* Rutvik flips 6 coins. Two of these come up heads with probability $\frac{1}{3}$, another two come up heads with probability $\frac{1}{4}$, and the last two come up heads with probability $\frac{1}{5}$. What is the probability that an even number of coins come up heads?

ANSWER: $\frac{101}{200}$ [AdM]

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**TOSS UP**

25) BIOLOGY *Short Answer* In an epigenomic analysis, Advaith is attempting to identify all methylated regions in Roshan's genome. To do so, he can differentially sequence his DNA under treatment with what ion that reacts with unmethylated cytosine bases?

ANSWER: Bisulfite [TS]

**BONUS**

25) BIOLOGY *Multiple Choice* Roshan is taking Advaith's blood pressure and creates a plot of pulse pressure vs. cardiac output. Which of the following is the value of the slope of this graph?

W) Three times systolic blood pressure

X) Three times total peripheral resistance

Y) One third times systolic blood pressure

Z) One third times total peripheral resistance

ANSWER: X) Three times total peripheral resistance [TS]

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