

Chemical and Physical Foundations of Biological Systems Sample Paper 1

Passage I (Questions 1–5)

Researchers are investigating a novel enzyme inhibitor intended to slow a metabolic reaction that is over-active in certain tumor cells. The enzyme obeys Michaelis-Menten kinetics. Without inhibitor the enzyme exhibits a K_m of 12 μM and a V_{max} of 48 $\mu\text{mol min}^{-1}$.

Addition of the inhibitor at a constant concentration of 5 μM raises the apparent K_m to 36 μM while V_{max} is unchanged.

Assays are performed in aqueous buffer at pH 7.4 and 37 °C. The substrate is a small polar molecule that must cross a lipid bilayer by passive diffusion before it can bind the enzyme. Initial rates are measured at several substrate concentrations in the presence and absence of inhibitor, and the data are displayed as Lineweaver-Burk plots.

Question 1

The experimental results indicate that the inhibitor is best classified as:

- a) Competitive
- b) Noncompetitive
- c) Uncompetitive
- d) Irreversible

Correct Answer: a) Competitive

Explanation:

Competitive inhibitors raise the apparent K_m because higher substrate concentrations are required to achieve half-maximal velocity, yet they leave V_{max} unaltered. These are precisely the changes reported. Noncompetitive inhibitors lower V_{max} without affecting K_m ; uncompetitive inhibitors lower both parameters; irreversible inhibitors permanently disable the enzyme.

Question 2

When the substrate concentration equals the uninhibited K_m (12 μM), the initial velocity in the absence of inhibitor is approximately:

- a) 12 $\mu\text{mol min}^{-1}$
- b) 24 $\mu\text{mol min}^{-1}$
- c) 36 $\mu\text{mol min}^{-1}$
- d) 48 $\mu\text{mol min}^{-1}$

Correct Answer: b) 24 $\mu\text{mol min}^{-1}$

Explanation:

By definition, velocity equals half of V_{max} when $[S] = K_m$. Therefore the initial rate is $48 / 2 = 24 \mu\text{mol min}^{-1}$.

Question 3

Which change would be expected to increase the rate at which the polar substrate reaches the intracellular enzyme?

- a) Lowering the temperature from 37 °C to 25 °C
- b) Increasing the thickness of the lipid bilayer
- c) Steepening the concentration gradient of substrate across the membrane
- d) Reducing the surface area of the membrane

Correct Answer: c) Steepening the concentration gradient of substrate across the membrane

Explanation:

Fick's law states that the rate of passive diffusion is directly proportional to the concentration gradient and membrane surface area and inversely proportional to membrane thickness. Increasing the gradient therefore accelerates delivery of substrate to the enzyme.

Question 4

On a Lineweaver-Burk plot the x-intercept obtained in the presence of the inhibitor is:

- a) More negative than the uninhibited intercept
- b) Less negative than the uninhibited intercept
- c) Identical to the uninhibited intercept
- d) Equal to zero

Correct Answer: b) Less negative than the uninhibited intercept

Explanation:

The x-intercept equals $-1/K_m$. Because the apparent K_m is larger under competitive inhibition, the intercept moves closer to the origin (becomes less negative).

Question 5

Suppose instead that both K_m and V_{max} decrease by the same factor upon addition of inhibitor. The inhibitor would then be classified as:

- a) Competitive
- b) Noncompetitive
- c) Uncompetitive
- d) Mixed with $\alpha > \alpha'$

Correct Answer: c) Uncompetitive

Explanation:

Uncompetitive inhibitors bind exclusively to the enzyme-substrate complex and lower both apparent K_m and V_{max} by the identical factor $(1 + [I]/K_i)$. Competitive inhibitors raise only K_m ; pure noncompetitive inhibitors lower only V_{max} .

Independent Questions (Questions 6–9)

Question 6

A 0.15 M aqueous solution of a weak monoprotic acid HA has a pH of 3.2. The approximate acid-dissociation constant K_a is:

- a) 2.5×10^{-4}
- b) 4.0×10^{-6}
- c) 6.3×10^{-7}
- d) 1.6×10^{-3}

Correct Answer: b) 4.0×10^{-6}

Explanation:

For a dilute weak acid, $[H^+] \approx \sqrt{(K_a \cdot C)}$. With $[H^+] = 10^{-3.2} \approx 6.3 \times 10^{-4}$ M one obtains $K_a \approx (6.3 \times 10^{-4})^2 / 0.15 \approx 2.6 \times 10^{-6}$, closest to the listed value 4.0×10^{-6} .

Question 7

One mole of an ideal gas occupies 2.0 L at 1.0 atm and 300 K. The gas is heated at constant pressure until its volume doubles. The work performed by the gas is closest to: ($R = 8.314 \text{ J mol}^{-1} \text{ K}^{-1}$)

- a) -200 J
- b) +200 J
- c) -400 J
- d) +400 J

Correct Answer: b) +200 J

Explanation:

Expansion work at constant pressure has magnitude $P\Delta V$. $\Delta V = +2.0 \text{ L} = 0.002 \text{ m}^3$ and $P \approx 1.013 \times 10^5 \text{ Pa}$, so $P\Delta V \approx 203 \text{ J}$. The work done by the system is therefore approximately +200 J.

Question 8

Which of the following compounds is expected to exhibit the highest boiling point?

- a) $\text{CH}_3\text{CH}_2\text{OCH}_2\text{CH}_3$
- b) $\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{OH}$
- c) $\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_3$
- d) $\text{CH}_3\text{CH}_2\text{CH}_2\text{CHO}$

Correct Answer: b) $\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{OH}$

Explanation:

1-Butanol forms intermolecular hydrogen bonds through its hydroxyl group, requiring substantially more thermal energy to enter the vapor phase. The ether, alkane and aldehyde interact only through weaker dipole–dipole or London forces and therefore boil at lower temperatures.

Question 9

In any electrochemical cell the half-reaction that takes place at the anode is:

- a) Always an oxidation
- b) Always a reduction
- c) An oxidation only when the cell is galvanic
- d) A reduction only when the cell is electrolytic

Correct Answer: a) Always an oxidation

Explanation:

Oxidation (loss of electrons) occurs at the anode by definition, whether the cell operates galvanically or electrolytically. Reduction always occurs at the cathode.