

Chemical and Physical Foundations of Biological Systems Mock Test

Passage I (Questions 1–6)

A research team is studying the kinetics of a reversible isomerization reaction $A \rightleftharpoons B$ catalyzed by an enzyme. The forward rate constant k_f is 0.15 s^{-1} and the reverse rate constant k_r is 0.05 s^{-1} at 298 K. The reaction is carried out in a closed vessel of fixed volume. Initial concentrations are $[A]_0 = 2.0 \text{ mM}$ and $[B]_0 = 0$. When equilibrium is reached, the measured concentrations are $[A]_{\text{eq}} = 0.50 \text{ mM}$ and $[B]_{\text{eq}} = 1.50 \text{ mM}$.

In a separate experiment the same enzyme is studied under conditions where product inhibition becomes significant. A Lineweaver-Burk analysis shows that increasing product concentration raises both the apparent K_m and the apparent V_{max} by the same factor.

Question 1

The equilibrium constant K_{eq} for the isomerization is:

- a) 0.33
- b) 1.0
- c) 3.0
- d) 4.0

Correct Answer: c) 3.0

Explanation:

$K_{\text{eq}} = [B]_{\text{eq}} / [A]_{\text{eq}} = 1.50 / 0.50 = 3.0$. Alternatively $K_{\text{eq}} = k_f / k_r = 0.15 / 0.05 = 3$.

Question 2

The standard free-energy change ΔG° for the reaction at 298 K is closest to: ($R = 8.314 \text{ J mol}^{-1} \text{ K}^{-1}$)

- a) -2.7 kJ mol^{-1}
- b) $+2.7 \text{ kJ mol}^{-1}$
- c) -5.4 kJ mol^{-1}
- d) 0

Correct Answer: a) -2.7 kJ mol^{-1}

Explanation:

$\Delta G^\circ = -RT \ln K_{\text{eq}} = -(8.314 \times 10^{-3})(298) \ln 3 \approx -2.72 \text{ kJ mol}^{-1}$.

Question 3

At equilibrium the forward and reverse rates are:

- a) Both equal to zero
- b) Equal to each other but non-zero
- c) Unequal, with the forward rate larger
- d) Unequal, with the reverse rate larger

Correct Answer: b) Equal to each other but non-zero

Explanation:

At equilibrium the net rate is zero, but the individual forward and reverse rates remain equal and non-zero.

Question 4

The product-inhibition pattern described (both apparent K_m and V_{max} increased by the same factor) is characteristic of:

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

Correct Answer: c) Uncompetitive inhibition

Explanation:

Uncompetitive inhibitors bind only the ES complex and multiply both K_m and V_{max} by the factor $(1 + [I]/K_i)$.

Question 5

If the temperature is raised while keeping concentrations fixed, the equilibrium will:

- a) Shift toward A if the reaction is endothermic
- b) Shift toward B if the reaction is endothermic
- c) Remain unchanged because K_{eq} is temperature-independent
- d) Shift toward A regardless of enthalpy

Correct Answer: b) Shift toward B if the reaction is endothermic

Explanation:

Le Châtelier's principle: an endothermic reaction absorbs heat, so higher T favors the products.

Question 6

The enzyme's catalytic efficiency is best expressed by the ratio:

- a) K_m / V_{max}
- b) V_{max} / K_m
- c) K_{eq} / k_f
- d) $[E]_{total} / K_m$

Correct Answer: b) V_{max} / K_m

Explanation:

Catalytic efficiency under low-substrate conditions is given by k_{cat}/K_m (or V_{max}/K_m when enzyme concentration is fixed).

Passage II (Questions 7–11)

Physicists modeling blood flow treat a segment of artery as a rigid cylindrical tube of radius 2.0 mm and length 8.0 cm. Blood (viscosity 3.5×10^{-3} Pa·s) flows under a pressure difference of 400 Pa. The flow is assumed laminar and steady. In a follow-up calculation the same pressure difference is applied to a vessel whose radius is reduced by 20 % due to plaque deposition.

Question 7

The volume flow rate through the original vessel is closest to: (Poiseuille's law)

- a) $1.1 \times 10^{-7} \text{ m}^3 \text{ s}^{-1}$
- b) $2.3 \times 10^{-7} \text{ m}^3 \text{ s}^{-1}$
- c) $4.5 \times 10^{-7} \text{ m}^3 \text{ s}^{-1}$
- d) $9.0 \times 10^{-7} \text{ m}^3 \text{ s}^{-1}$

Correct Answer: b) $2.3 \times 10^{-7} \text{ m}^3 \text{ s}^{-1}$

Explanation:

$$Q = \frac{\pi r^4 \Delta P}{8\eta L}. \quad r = 2 \times 10^{-3} \text{ m}, \quad L = 0.08 \text{ m} \rightarrow Q \approx 2.24 \times 10^{-7} \text{ m}^3 \text{ s}^{-1}.$$

Question 8

After the 20 % reduction in radius the new flow rate is approximately what fraction of the original?

- a) 0.80
- b) 0.64
- c) 0.41
- d) 0.25

Correct Answer: c) 0.41

Explanation:

Flow scales as r^4 . $(0.80)^4 = 0.4096 \approx 0.41$.

Question 9

The Reynolds number for the original flow is most likely:

- a) Much less than 1, confirming laminar flow
- b) Approximately 2000, near the onset of turbulence
- c) Greater than 10^4 , fully turbulent
- d) Undefined because blood is non-Newtonian

Correct Answer: a) Much less than 1, confirming laminar flow

Explanation:

With the given small radius and moderate velocity, Re is well below the laminar–turbulent transition.

Question 10

If the pressure difference is doubled while radius and length remain constant, the flow rate:

- a) Remains the same
- b) Doubles
- c) Quadruples
- d) Increases by a factor of 16

Correct Answer: b) Doubles

Explanation:

Poiseuille's law is linear in ΔP ; doubling the driving pressure doubles Q .

Question 11

The primary reason blood-flow calculations often treat plasma viscosity as constant is that:

- a) Blood is an ideal gas
- b) Under physiological shear rates plasma behaves approximately as a Newtonian fluid
- c) Viscosity has no effect on laminar flow
- d) The vessel walls are perfectly elastic

Correct Answer: b) Under physiological shear rates plasma behaves approximately as a Newtonian fluid

Explanation:

Although whole blood is non-Newtonian at very low shear, plasma itself is nearly Newtonian in the physiologic range.

Independent Questions (Questions 12–15)

Question 12

Which of the following molecules can form the greatest number of hydrogen bonds with water?

- a) CH_4
- b) CH_3CH_3
- c) CH_3OH
- d) CCl_4

Correct Answer: c) CH_3OH

Explanation:

Methanol possesses both a hydrogen-bond donor ($-OH$) and acceptor (oxygen lone pairs); the others cannot donate hydrogen bonds.

Question 13

In an electrolytic cell used to plate copper onto a key, the key is the:

- a) Anode and is the site of oxidation
- b) Cathode and is the site of reduction
- c) Anode and is the site of reduction
- d) Cathode and is the site of oxidation

Correct Answer: b) Cathode and is the site of reduction

Explanation:

Metal cations are reduced and deposited at the cathode; the object to be plated is therefore made the cathode.

Question 14

The pH of a solution prepared by mixing equal volumes of 0.10 M HCl and 0.10 M NaOH is:

- a) 1
- b) 7
- c) 13
- d) Undefined

Correct Answer: b) 7

Explanation:

Equimolar strong acid and strong base neutralize completely, producing a neutral salt solution of pH 7.

Question 15

A photon whose energy equals the work function of a metal is incident on the metal surface. The maximum kinetic energy of the emitted photoelectron is:

- a) Equal to the photon energy
- b) Zero
- c) Twice the photon energy
- d) Dependent on the intensity of the light

Correct Answer: b) Zero

Explanation:

When $h\nu = \phi$ the residual kinetic energy is zero; the electron is just liberated.