

Chemical and Physical Foundations of Biological Systems Sample Paper 2

Passage I (Questions 1–5)

A research group is examining the thermodynamics of ATP hydrolysis under cellular conditions. The reaction $\text{ATP} + \text{H}_2\text{O} \rightarrow \text{ADP} + \text{P}_i$ has a standard free-energy change $\Delta G^\circ = -30.5 \text{ kJ mol}^{-1}$ at pH 7.0. In a typical eukaryotic cell the actual concentrations are $[\text{ATP}] = 8.0 \text{ mM}$, $[\text{ADP}] = 0.9 \text{ mM}$ and $[\text{P}_i] = 5.0 \text{ mM}$. Temperature is maintained at 310 K.

The group also measures the effect of Mg^{2+} ions, which form complexes with ATP and ADP and thereby alter the observed free-energy change. Parallel experiments track the rate of an ATP-dependent ion pump that hydrolyzes one ATP molecule for every two K^+ ions transported against a 30-fold concentration gradient.

Question 1

Under the stated cellular concentrations, the actual free-energy change ΔG for ATP hydrolysis is more negative than ΔG° primarily because:

- a) The reaction quotient Q is less than 1
- b) The reaction quotient Q is greater than 1
- c) The temperature is higher than the standard temperature of 298 K
- d) Mg^{2+} binding always increases the magnitude of ΔG

Correct Answer: a) The reaction quotient Q is less than 1

Explanation:

$\Delta G = \Delta G^\circ + RT \ln Q$. With the given millimolar concentrations $Q = ([\text{ADP}][\text{P}_i])/[\text{ATP}]$ is substantially less than 1, so the $RT \ln Q$ term is negative and ΔG becomes more negative than ΔG° .

Question 2

If the ion pump moves two K^+ ions against a 30-fold gradient at 310 K, the minimum free energy required per mole of ATP hydrolyzed (ignoring membrane potential) is closest to: ($R = 8.314 \text{ J mol}^{-1} \text{ K}^{-1}$)

- a) 5 kJ mol^{-1}
- b) 10 kJ mol^{-1}
- c) 17 kJ mol^{-1}
- d) 35 kJ mol^{-1}

Correct Answer: c) 17 kJ mol^{-1}

Explanation:

$\Delta G = nRT \ln([\text{out}]/[\text{in}]) = 2 \times 8.314 \times 10^{-3} \times 310 \times \ln(30) \approx 2 \times 8.314 \times 0.310 \times 3.40 \approx 17.5 \text{ kJ mol}^{-1}$.

Question 3

Binding of Mg^{2+} to ATP typically:

- a) Increases the magnitude of the observed free-energy release upon hydrolysis
- b) Decreases the magnitude of the observed free-energy release upon hydrolysis
- c) Has no effect on the free-energy change
- d) Converts the reaction from exergonic to endergonic

Correct Answer: a) Increases the magnitude of the observed free-energy release upon hydrolysis

Explanation:

Mg^{2+} binds more tightly to ATP than to ADP, stabilizing the reactant relative to the products and thereby making the observed ΔG of hydrolysis more negative.

Question 4

At constant temperature and pressure the criterion for spontaneous ATP hydrolysis is:

- a) $\Delta G < 0$
- b) $\Delta G^\circ < 0$
- c) $\Delta H < 0$
- d) $\Delta S > 0$

Correct Answer: a) $\Delta G < 0$

Explanation:

Under constant T and P the Gibbs free-energy change ΔG (not the standard value ΔG°) determines spontaneity.

Question 5

Raising the cellular $[P_i]$ while holding $[ATP]$ and $[ADP]$ fixed would:

- a) Make ΔG more negative
- b) Make ΔG less negative
- c) Leave ΔG unchanged
- d) Reverse the sign of ΔG°

Correct Answer: b) Make ΔG less negative

Explanation:

Increasing $[P_i]$ raises Q, which increases the $RT \ln Q$ term and therefore makes ΔG less negative.

Independent Questions (Questions 6–9)

Question 6

A photon of wavelength 450 nm strikes a retinal molecule. The energy of this photon is closest to: ($h = 6.626 \times 10^{-34}$ J s, $c = 3.00 \times 10^8$ m s⁻¹)

- a) 2.2×10^{-19} J
- b) 4.4×10^{-19} J
- c) 6.6×10^{-19} J
- d) 8.8×10^{-19} J

Correct Answer: b) 4.4×10^{-19} J

Explanation:

$$E = hc/\lambda = (6.626 \times 10^{-34} \times 3.00 \times 10^8) / 4.50 \times 10^{-7} \approx 4.42 \times 10^{-19} \text{ J.}$$

Question 7

Which functional group is most likely to participate in a nucleophilic acyl substitution under physiological conditions?

- a) An ether linkage
- b) A secondary alcohol
- c) A thioester
- d) An alkane side chain

Correct Answer: c) A thioester

Explanation:

Thioesters are activated acyl derivatives that readily undergo nucleophilic acyl substitution; ethers, alcohols and alkanes do not.

Question 8

In a galvanic cell the salt bridge serves primarily to:

- a) Provide a path for electron flow between the electrodes
- b) Maintain electrical neutrality in the half-cells
- c) Increase the cell potential above its standard value
- d) Prevent the electrodes from dissolving

Correct Answer: b) Maintain electrical neutrality in the half-cells

Explanation:

Ions migrate through the salt bridge to balance the charge that develops as electrons flow through the external circuit.

Question 9

The boiling point of a pure solvent is elevated by the addition of a non-volatile solute. This elevation is directly proportional to:

- a) The mole fraction of the solvent
- b) The molality of the solute
- c) The molar mass of the solute alone
- d) The vapor pressure of the pure solute

Correct Answer: b) The molality of the solute

Explanation:

Boiling-point elevation is a colligative property: $\Delta T_b = K_b \cdot m$, where m is the molality of the solute particles.