• Explain the following terms or concepts.	**Marks**
Le Châtelier's principle	**1**

Marks
4

- At 700 °C, hydrogen and iodine react according to the following equation.

$$H_2(g) + I_2(g) \rightleftharpoons 2HI(g) \qquad K_c = 49.0$$

If 0.250 mol of HI(g) is introduced into a 2.00 L flask at 700 °C, what will be the concentration of $I_2(g)$ at equilibrium?

Answer:

Hydrogen also reacts with sulfur at 700 °C:

$$2H_2(g) + S_2(g) \rightleftharpoons 2H_2S(g) \qquad K_c = 1.075 \times 10^8$$

Determine K_c for the following overall equilibrium reaction at 700 °C.

$$2I_2(g) + 2H_2S(g) \rightleftharpoons S_2(g) + 4HI(g)$$

Answer:

Marks
5

- Methane, CH_4, reacts with hydrogen sulfide, H_2S, according the following equilibrium:

$$CH_4(g) + 2H_2S(g) \rightleftharpoons CS_2(g) + 4H_2(g)$$

In an experiment 1.00 mol of CH_4, 2.00 mol of H_2S, 1.00 mol of CS_2 and 2.00 mol of H_2 are mixed in a 250 mL vessel at 960 °C. At this temperature, $K_c = 0.034$ (based on a standard state of 1 mol L^{-1}).

Calculate the reaction quotient, Q, and hence predict in which direction the reaction will proceed to reach equilibrium? Explain your answer.

Show that the system is at equilibrium when $[CH_4(g)] = 5.56$ M.

Marks
3

- Ammonia is synthesised according to the following reaction.

$$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$$

At 500 °C this reaction has a K_c of 6.0×10^{-2}. $\Delta H°$ for this reaction is –92 kJ mol^{-1}. Calculate the value of K_c at 200 °C.

Answer:

Marks 4

- One of the most important reactions in living cells is the splitting of adenosine triphosphate (ATP) to adenosine diphosphate (ADP) and free phosphate (P_i):

$$ATP \rightleftharpoons ADP + P_i$$

Based on a standard state of 1 M, the value of $\Delta G°$ for this reaction at 37 °C is –33 kJ mol^{-1}. Calculate the value of the equilibrium constant for the reaction at this temperature.

Answer:

The following concentrations are typical in a living cell.

ATP: 5 mM	ADP: 0.1 mM	P_i: 5 mM

Under these conditions, calculate the energy per mole that is available from the splitting of ATP.

Answer:

- The electron transfer reaction between NADH and oxygen is a spontaneous reaction at 37 °C

  $$NADH + \tfrac{1}{2}O_2 + H^+ \rightarrow NAD^+ + H_2O \qquad \Delta G = -220 \text{ kJ mol}^{-1}$$

  When this reaction is carried out in solution in a test tube via direct mixing of NADH with dissolved oxygen, the reaction releases a significant amount of heat. However, when the reaction occurs in mitochondria during respiration, it produces very little heat. Explain why the heat evolved is much less in mitochondria.

3

Marks 4

- Consider the following reaction.

$$SO_2(g) + NO_2(g) \rightleftharpoons SO_3(g) + NO(g)$$

An equilibrium mixture in a 1.00 L vessel was found to contain $[SO_2(g)] = 0.800$ M, $[NO_2(g)] = 0.100$ M, $[SO_3(g)] = 0.600$ M and $[NO(g)] = 0.400$ M. If the volume and temperature are kept constant, what amount (in mol) of NO(g) needs to be added to the reaction vessel to give an equilibrium concentration of $NO_2(g)$ of 0.300 M?

Answer:

Marks

- Calculate $\Delta G°$ for the reaction: $2N_2O(g) + 3O_2(g) \rightarrow 4NO_2(g)$ **2**

  Data: $4NO(g) \rightarrow 2N_2O(g) + O_2(g)$ $\Delta G° = -139.56$ kJ mol^{-1}

  $2NO(g) + O_2(g) \rightarrow 2NO_2(g)$ $\Delta G° = -69.70$ kJ mol^{-1}

Answer:

- Good wine will turn to vinegar if it is left exposed to air because the alcohol is oxidised to acetic acid. The equation for the reaction is: **2**

$$CH_3CH_2OH(l) + O_2(g) \rightarrow CH_3COOH(l) + H_2O(l)$$

Calculate $\Delta S°$ for this reaction in J K^{-1} mol^{-1}.

Data:

	$S°$ (J K^{-1} mol^{-1})		$S°$ (J K^{-1} mol^{-1})
$C_2H_5OH(l)$	161	$CH_3COOH(l)$	160.
$O_2(g)$	205.0	$H_2O(l)$	69.96

Answer:

Page Total:

Marks 5

- Consider the following reaction.

$$SO_2(g) + NO_2(g) \rightleftharpoons NO(g) + SO_3(g)$$

At 460 °C this reaction has a value of $K_c = 85.0$. Suppose 0.100 mol of SO_2, 0.0600 mol of NO_2, 0.0800 mol of NO and 0.120 mol of SO_3 are placed in a 10.0 L container at this temperature. What are the concentrations of all of the gases when the system reaches equilibrium?

$[SO_2(g)] =$	$[NO_2(g)] =$

Page Total:

- Consider the ammonia synthesis reaction shown below.

$$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g) \qquad K_c = 6.0 \times 10^{-2} \text{ at } 500\ ^\circ C$$

ΔH° for this reaction is –92 kJ mol^{-1}. Calculate the value of K_c at 200 °C.

Marks 2

Answer:

Page Total:

Marks 3

- Consider the following reaction.

$H_2O(g) + Cl_2O(g) \rightleftharpoons 2HOCl(g)$ $\quad K_p = 0.090$ at 298 K

Calculate $\Delta G°$ (in J mol^{-1}) for this reaction.

$\Delta G° =$

Calculate ΔG (in J mol^{-1}) at 25 °C when $p(H_2O)$ = 18 mmHg, $p(Cl_2O)$ = 2.0 mmHg and $p(HOCl)$ = 0.10 mmHg.

Answer:

Explain the following terms or concepts.	**Marks** **3**
a) Lewis acid	
b) 3rd Law of Thermodynamics	
c) Brownian motion	

• $\Delta_{vap}H°$ = 34.0 kJ mol^{-1} for benzene, which has a boiling point of 80.1 °C. What is the entropy change for the vaporisation of benzene in J K^{-1} mol^{-1}?	**2**
Answer:	

- A mixture of NaCl (5.0 g) and $AgNO_3$ (5.0 g) was added to 1.0 L of water. What are the concentrations of $Ag^+(aq)$, $Cl^-(aq)$ and $Na^+(aq)$ ions in solution after equilibrium has been established? $K_{sp}(AgCl) = 1.8 \times 10^{-10}$.

Marks 3

$[Ag^+(aq)]$ =	$[Cl^-(aq)]$ =	$[Na^+(aq)]$ =

Marks 5

- At 700 °C, hydrogen and iodine react according to the following equation.

$$H_2(g) + I_2(g) \rightleftharpoons 2HI(g) \qquad K_c = 49.0$$

Hydrogen also reacts with sulfur at 700 °C:

$$2H_2(g) + S_2(g) \rightleftharpoons 2H_2S(g) \qquad K_c = 1.075 \times 10^8$$

Determine K_c for the following overall equilibrium reaction at 700 °C.

$$2I_2(g) + 2H_2S(g) \rightleftharpoons S_2(g) + 4HI(g)$$

K_c =

What is the standard free energy change at 700 °C for this overall equilibrium reaction?

Answer:

If 0.250 mol of HI(g) is introduced into a 2.00 L flask at 700 °C, what will be the concentration of $I_2(g)$ at equilibrium?

Marks 5

Answer:

If 0.274 g of H_2S were now introduced into the same flask, what would be the concentration of $S_2(g)$ at equilibrium?

Answer:

Marks 5

- Consider the reaction $2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g)$

  $\Delta H° = -198.4$ kJ mol^{-1} and $\Delta S° = -187.9$ J K^{-1} mol^{-1} at 25 °C.

  Show that this reaction is spontaneous at 25 °C.

If the volume of the reaction system is increased at 25 °C, in which direction will the reaction move?

Calculate the value of the equilibrium constant, K, at 25 °C.

K =

Assuming $\Delta H°$ and $\Delta S°$ are independent of temperature, in which temperature range is the reaction non-spontaneous?

Answer:

Marks 6

- The first step in the metabolism of glucose in biological systems is the addition of a phosphate group in a dehydration-condensation reaction:

$$\text{glucose(aq)} + H_2PO_4^-\text{(aq)} \rightleftharpoons [\text{glucose phosphate}]^-\text{(aq)} + H_2O\text{(l)}$$

The free energy change associated with this reaction is $\Delta G° = 13.8$ kJ mol^{-1}. The reaction is driven forwards by harnessing the free energy associated with the hydrolysis of adenosine triphosphate, ATP^{4-}, to adenosine diphosphate, ADP^{3-}:

$$ATP^{4-}\text{(aq)} + H_2O\text{(l)} \rightleftharpoons ADP^{3-}\text{(aq)} + H_2PO_4^-\text{(aq)} \qquad \Delta G° = -30.5 \text{ kJ mol}^{-1}$$

The overall reaction is thus:

$$\text{glucose(aq)} + ATP^{4-}\text{(aq)} \rightleftharpoons [\text{glucose phosphate}]^-\text{(aq)} + ADP^{3-}\text{(aq)}$$

Calculate the equilibrium constant associated with this overall reaction at body temperature (37 ºC).

Answer:

This overall equilibrium reaction is investigated by adding 0.0100 mol of ATP^{4-} to a flask containing 175 mL of a 0.0500 M aqueous solution of glucose at 37 ºC. What percentage of the ATP^{4-} will have been consumed when the system reaches equilibrium?

Answer:

Suggest two simple ways of further reducing the remaining percentage of ATP^{4-}.

Marks 3

- Acetylene, C_2H_2, is an important fuel in welding. It is produced in the laboratory when calcium carbide, CaC_2, reacts with water:

$$CaC_2(s) + 2H_2O(l) \rightarrow C_2H_2(g) + Ca(OH)_2(s)$$

For a sample of C_2H_2 collected over water, the total gas pressure was 748 mmHg and the volume was 543 mL. At the gas temperature (23 ^oC), the vapour pressure of water is 21 mmHg. What mass of acetylene was collected?

Answer:

The solubility of acetylene in water at 22.0 ^oC is small. If the temperature were raised, would you expect this solubility to increase or decrease?

Marks 6

- The isomerisation of glucose-6-phosphate (G6P) to fructose-6-phosphate (F6P) is a key step in the metabolism of glucose for energy.

$$\text{G6P} \rightleftharpoons \text{F6P}$$

At 298 K, the equilibrium constant for the isomerisation is 0.510. Calculate the value of $\Delta G°$ at 298 K.

Answer:

Calculate ΔG at 298 K when the [F6P] / [G6P] ratio = 10.

Answer:

In which direction will the reaction shift in order to establish equilibrium? Why?

Sketch a graph of G_{sys} *versus* "extent of reaction", with a curve showing how G_{sys} varies as G6P is converted to F6P. Indicate the position on this curve corresponding to the point where [F6P] / [G6P] ratio = 10. Indicate on the graph that section of the curve where $Q > K$.

Marks 4

The CO(g) in water gas can be reacted further with $H_2O(g)$ in the so-called "water-gas shift" reaction:

$$CO(g) + H_2O(g) \rightleftharpoons CO_2(g) + H_2(g)$$

At 900 K, $K_c = 1.56$ for this reaction. A sample of water gas flowing over coal at 900 K contains a 1:1 mole ratio of CO(g) and $H_2(g)$, as well as 0.250 mol L^{-1} $H_2O(g)$. This sample is placed in a sealed container at 900 K and allowed to come to equilibrium, at which point it contains 0.070 mol L^{-1} $CO_2(g)$. What was the initial concentration of CO(g) and $H_2(g)$ in the sample?

$[CO] = [H_2] =$

If the walls of the container are chilled to below 100 ºC, what will be the effect on the concentration of $CO_2(g)$?

Marks 6

- The isomerisation of glucose-6-phosphate (G6P) to fructose-6-phosphate (F6P) is a key step in the metabolism of glucose for energy. At 298 K,

$$\text{G6P} \rightleftharpoons \text{F6P} \qquad \Delta G^\circ = 1.67 \text{ kJ mol}^{-1}$$

Calculate the equilibrium constant for this process at 298 K.

Answer:

What is the free energy change (in kJ mol^{-1}) involved in a mixture of 3.00 mol of F6P and 2.00 mol of G6P reaching equilibrium at 298 K?

Answer:

Sketch a graph of G_{sys} *versus* "extent of reaction", with a curve showing how G_{sys} varies as G6P is converted to F6P. Indicate the position on this curve corresponding to 3.00 mol of F6P and 2.00 mol of G6P.

Marks 5

- A mixture of 0.500 mol of $NO_2(g)$ and 0.500 mol of $N_2O_4(g)$ is allowed to reach equilibrium in a 10.0 L vessel maintained at 298 K. The equilibrium is described by the equation below. $\Delta H° = -15$ kJ mol^{-1} for the forward reaction.

$$2NO_2(g) \rightleftharpoons N_2O_4(g) \qquad K_c = 1.2 \times 10^2 \text{ M}^{-1}$$

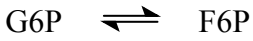
Show that the system is at equilibrium when the concentration of $NO_2(g)$ is 0.023 M.

Discuss the effect an increase in temperature, at constant volume, would have on the concentration of $NO_2(g)$.

State with a brief reason whether the concentration of $NO_2(g)$ is increased, decreased, or unchanged when argon gas (0.2 mol) is injected while the temperature and volume remain constant.

Marks

- A key step in the metabolism of glucose for energy is the isomerism of glucose-6-phosphate (G6P) to fructose-6-phosphate (F6P);



At 298 K, the equilibrium constant for the isomerisation is 0.510. Calculate $\Delta G°$ at 298 K.

4

Answer:

Calculate ΔG at 298 K when the [F6P] / [G6P] ratio = 10.

Answer:

In which direction will the reaction shift in order to establish equilibrium? Why?

- The specific heat capacity of water is 4.18 J g^{-1} K^{-1} and the specific heat capacity of copper is 0.39 J g^{-1} K^{-1}. If the same amount of energy were applied to a 1.0 mol sample of each substance, both initially at 25 °C, which substance would get hotter? Show all working.

2

Answer:

Marks 5

- For the reaction $2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g)$ at 25 °C

  $\Delta H° = -198.4$ kJ mol^{-1} and $\Delta S° = -187.9$ J K^{-1} mol^{-1}

  Show that this reaction is spontaneous at 25 °C.

If the volume of the reaction system is increased at 25 °C, in which direction will the reaction move?

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$K =$

Assuming $\Delta H°$ and $\Delta S°$ are independent of temperature, in which temperature range is the reaction non-spontaneous?

Answer: