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AP Chemistry

Name BRACKEN KEY
Period ____

AP Test Prep: Free-Response Practice Problems
Equilibrium

1977 D

For the system $2\ SO_{2(g)} + O_{2(g)} \leftrightarrows 2\ SO_{3(g)}$, ΔH is negative for the production of SO_3.

Assume that one has an equilibrium mixture of these substances. Predict the effect of each of the following changes on the value of the equilibrium constant and on the number of moles of SO_3 present in the mixture at equilibrium. Briefly account for each of your predictions.

(a) Decreasing the volume of the system.

★ LOWERING THE VOLUME OF SYSTEM CAUSES SYSTEM TO SHIFT RIGHT, INCREASING THE # MOLES OF SO_3

★ NO CHANGE TO K VALUE THOUGH.

(b) Adding oxygen to the equilibrium mixture.

★ SYSTEM WILL SHIFT RIGHT AND INCREASE # MOLES OF SO_3.

★ NO CHANGE TO K VALUE THOUGH

(c) Raising the temperature of the system.

WE'RE TOLD THE REACTION IS EXOTHERMIC BECAUSE ΔH IS NEGATIVE.

$$2\ SO_2 + O_2 \rightleftarrows 2\ SO_3 + \text{HEAT ENERGY}$$

RAISING TEMP CAUSES A SHIFT TO THE LEFT.

$$K = \frac{[SO_3]^2 \;\curvearrowleft \text{decreases}}{[SO_2]^2[O_2] \;\leftarrow \text{increases}}$$

K VALUE WILL
DECREASE IF
TEMP GOES UP

1992 A

$$2\,NaHCO_{3(s)} \leftrightarrows Na_2CO_{3(s)} + H_2O_{(g)} + CO_{2(g)}$$

Solid sodium hydrogen carbonate, $NaHCO_3$, decomposes on heating according to the equation above.

(a) A sample of 100. grams of solid $NaHCO_3$ was placed in a previously evacuated rigid 5.00-Liter container and heated to 160°C. Some of the original solid remained and the total pressure in the container was 7.76 atmospheres when equilibrium was reached. Calculate the number of moles of $H_2O_{(g)}$ present at equilibrium.

TOTAL PRESSURE IS DUE TO FORMATION OF H_2O AND CO_2 GASES.

$$P_{TOTAL} = P_{H_2O} + P_{CO_2}$$

$$7.76 = 2x \qquad \boxed{x = 3.88 \text{ atm}}$$

$PV = nRT$

$$(3.88)(5.00) = n(.0821)(433) \qquad \boxed{n = .546 \text{ moles } H_2O}$$

(b) How many grams of the original solid remain in the container under the conditions described in (a)?

.546 moles H_2O formed from the decomposition of

$$(2)(.546) = \boxed{1.09 \text{ moles } NaHCO_3 \text{ reacted}}$$

$$1.09 = \frac{x}{84} \qquad \boxed{x = 91.7 \text{ grams } NaHCO_3 \text{ reacted}}$$

$$\begin{array}{r} 100. \\ -\ 91.7 \\ \hline \end{array}$$

$\boxed{8 \text{ grams } NaHCO_3 \text{ unreacted}}$

(c) Write the equilibrium expression for the equilibrium constant, K_P, and calculate its value for the reaction under the conditions in (a).

$$K_p = P_{H_2O} \cdot P_{CO_2}$$

$$K_p = (3.88)(3.88)$$

$$\boxed{K_p = 15.0}$$

(d) If 110. grams of solid $NaHCO_3$ had been placed in the 5.00-Liter container and heated to 160°C, what would the total pressure have been at equilibrium? Explain.

AN EXCESS OF THE SOLID WILL NOT CAUSE ANY DIFFERENCE. THERE WAS EXCESS $NaHCO_3$ THAT HAD NOT REACTED SO NO EFFECT.

2000 A

$2H_2S_{(g)}$	⇆	$2H_{2(g)}$	+	$S_{2(g)}$
$.080\ M$		0		0
$-2x$		$+2x$		$+x$
$.080-2x$		$2x$		x

$$X = \frac{.0372}{1.25} = \underline{\underline{.0298\ M}}$$

When heated, hydrogen sulfide gas decomposes according to the equation above. A 3.40 g sample of $H_2S_{(g)}$ is introduced into an evacuated rigid 1.25 L container. The sealed container is heated to 483 K, and 0.0372 moles of $S_{2(g)}$ is present at equilibrium. $\frac{3.40}{34} = .10$ moles $H_2S \div 1.25 \underset{\text{LITERS}}{} = .080M$

(a) Write the expression for the equilibrium constant, K_c, for this decomposition reaction.

$$K_c = \frac{[H_2]^2[S_2]}{[H_2S]^2}$$

(b) Calculate the equilibrium concentrations of the following gases in the container at 483 K.

ONE METHOD

(i) $H_{2(g)}$ $(.0372)(2) = .0744$ moles H_2 $\quad \frac{.0744}{1.25} = \boxed{.0595\ M\ H_2}$

(ii) $H_2S_{(g)}$ $.080 - 2x$

$$.080 - (2)(.0298) = \boxed{.0205\ M\ H_2S}$$

(c) Calculate the value of the equilibrium constant, K_c, for the decomposition reaction at 483 K.

$$K_c = \frac{[.0595]^2[.0298]}{[.0205]^2} = \boxed{.251}$$

(d) Calculate the partial pressure of $S_{2(g)}$ in the container at equilibrium at 483 K.

moles S_2 gas $= .0372$

$PV = nRT$

$(P)(1.25) = (.0372)(.0821)(483)$ $\quad \boxed{P = 1.18\ \text{atm}}$

(e) For the reaction $H_{2(g)} + \frac{1}{2}S_{2(g)} \leftrightarrows H_2S_{(g)}$ at 483 K, calculate the value of the equilibrium constant, K_c.

REVERSED + DIVIDED ALL COEFFS BY 2

$$\left(\frac{1}{.251}\right)^{1/2} = \boxed{2.00}$$

2007 B

A sample of solid U_3O_8 is placed in a rigid 1.500 L flask. Chlorine gas, $Cl_{2(g)}$, is added, and the flask is heated to 862°C. The equation for the reaction that takes place and the equilibrium-constant expression for the reaction are given below.

$$U_3O_{8(s)} + 3\,Cl_{2(g)} \leftrightarrows 3\,UO_2Cl_{2(g)} + O_{2(g)} \qquad K_P = \frac{(P_{UO_2Cl_2})^3(P_{O_2})}{(P_{Cl_2})^3}$$

some some 0 0

$-x$ $-3x$ $+3x$ $+x$

$3x$ x

When the system is at equilibrium, the partial pressure of $Cl_{2(g)}$ is 1.007 atm and the partial pressure of $UO_2Cl_{2(g)}$ is 9.734×10^{-4} atm.

(a) Calculate the partial pressure of $O_{2(g)}$ at equilibrium at 862°C.

Based on coeffs, the pressure of O_2 will be $\frac{1}{3}$ rd the pressure of UO_2Cl_2

$$\frac{9.734 \times 10^{-4}}{3} = \boxed{3.245 \times 10^{-4}\ \text{atm}}$$

(b) Calculate the value of the equilibrium constant, K_P, for the system at 862°C.

$$K_p = \frac{[9.734 \times 10^{-4}]^3[3.245 \times 10^{-4}]}{[1.007]^3} = \boxed{2.931 \times 10^{-13}}$$

(c) Calculate the Gibbs free-energy change, $\Delta G°$, for the reaction at 862°C.

$\Delta G = -RT \ln K_{eq}$ T = Kelvin so 862 + 273 = 1135 Kelvin

$$\Delta G = -(8.314)(1135)\ln(2.931 \times 10^{-13})$$

$$\boxed{\Delta G = +272318 \text{ Joules} = +272 \text{ kJ}}$$

(d) State whether the entropy change, $\Delta S°$ for the reaction at 862°C is positive, negative, or zero. Justify your answer.

1 solid + 3 gas → 4 gas

$\Delta S > 0$ because you will have more moles of the highly disordered gas @ the end

(e) State whether the enthalpy change, $\Delta H°$, for the reaction at 862°C is positive, negative, or zero. Justify your answer.

$$\Delta G = \Delta H - T\Delta S$$

$\oplus$ $\oplus$ $\oplus$

FOR ΔG TO BE POSITIVE, WE MUST HAVE A POSITIVE ΔH BECAUSE WE KNOW WE HAVE A POSITIVE ΔS. ONLY WAY TO GET A $+\Delta G$ IS TO HAVE A $+\Delta H$.

(f) After a certain period of time, 1.000 mol of $O_{2(g)}$ is added to the mixture in the flask. Does the mass of $U_3O_{8(s)}$ in the flask increase, decrease, or remain the same? Justify your answer.

ADDITION OF O_2 WOULD CAUSE THE EQUILIBRIUM TO SHIFT TO THE LEFT, INCREASING THE MASS OF U_3O_8