Question 1

$$C(s) + CO_2(g) \rightleftarrows 2\,CO(g)$$

Solid carbon and carbon dioxide gas at 1,160 K were placed in a rigid 2.00 L container, and the reaction represented above occurred. As the reaction proceeded, the total pressure in the container was monitored. When equilibrium was reached, there was still some $C(s)$ remaining in the container. Results are recorded in the table below.

Time (hours)	Total Pressure of Gases in Container at 1,160 K (atm)
0.0	5.00
2.0	6.26
4.0	7.09
6.0	7.75
8.0	8.37
10.0	8.37

(a) Write the expression for the equilibrium constant, K_p, for the reaction.

$K_p = \dfrac{(P_{CO})^2}{P_{CO_2}}$	One point is earned for the correct expression.

(b) Calculate the number of moles of $CO_2(g)$ initially placed in the container. (Assume that the volume of the solid carbon is negligible.)

$n = \dfrac{PV}{RT} = \dfrac{(5.00\text{ atm})(2.00\text{ L})}{(0.0821\ \frac{\text{L atm}}{\text{mol K}})(1{,}160\text{ K})} = 0.105\text{ mol}$	One point is earned for the correct setup. One point is earned for the correct answer.

(c) For the reaction mixture at equilibrium at 1,160 K, the partial pressure of the $CO_2(g)$ is 1.63 atm. Calculate

(i) the partial pressure of $CO(g)$, and

$P_{CO_2} + P_{CO} = P_{total}$ $P_{CO} = P_{total} - P_{CO_2} = 8.37\text{ atm} - 1.63\text{ atm} = 6.74\text{ atm}$	One point is earned for the correct answer supported by a correct method.

Question 1 (continued)

(ii) the value of the equilibrium constant, K_p.

$K_p = \frac{(P_{CO})^2}{P_{CO_2}} = \frac{(6.74\text{ atm})^2}{1.63\text{ atm}} = 27.9$	One point is earned for a correct setup that is consistent with part (a). One point is earned for the correct answer according to the setup.

(d) If a suitable solid catalyst were placed in the reaction vessel, would the final total pressure of the gases at equilibrium be greater than, less than, or equal to the final total pressure of the gases at equilibrium without the catalyst? Justify your answer. (Assume that the volume of the solid catalyst is negligible.)

The total pressure of the gases at equilibrium with a catalyst present would be equal to the total pressure of the gases without a catalyst. Although a catalyst would cause the system to reach the same equilibrium state more quickly, it would not affect the extent of the reaction, which is determined by the value of the equilibrium constant, K_p.	One point is earned for the correct answer with justification.

In another experiment involving the same reaction, a rigid 2.00 L container initially contains 10.0 g of C(s), plus CO(g) and $CO_2(g)$, each at a partial pressure of 2.00 atm at 1,160 K.

(e) Predict whether the partial pressure of $CO_2(g)$ will increase, decrease, or remain the same as this system approaches equilibrium. Justify your prediction with a calculation.

$Q = \frac{(P_{CO})^2}{P_{CO_2}} = \frac{(2.00\text{ atm})^2}{2.00\text{ atm}} = 2.00 < K_p\ (= 27.9)$, therefore P_{CO_2} will decrease as the system approaches equilibrium.	One point is earned for a correct calculation involving Q or ICE calculation. One point is earned for a correct conclusion based on the calculation.

(d) If a suitable solid catalyst were placed in the reaction vessel, would the final total pressure of the gases at equilibrium be greater than, less than, or equal to the final total pressure of the gases at equilibrium without the catalyst? Justify your answer. (Assume that the volume of the solid catalyst is negligible.)

1A

In another experiment involving the same reaction, a rigid 2.00 L container initially contains 10.0 g of C(*s*), plus CO(*g*) and $CO_2(g)$, each at a partial pressure of 2.00 atm at 1,160 K.

(e) Predict whether the partial pressure of $CO_2(g)$ will increase, decrease, or remain the same as this system approaches equilibrium. Justify your prediction with a calculation.

a) $K_p = \frac{P_{CO}^2}{P_{CO_2}}$

b) Use the gas law $PV = nRT$

$5.00\,atm \cdot 2.00\,L = n \cdot 0.0821\,L\,atm\,mol^{-1}K^{-1} \cdot 1160\,K$

(solve) $\frac{5.00\,atm \cdot 2.00\,L}{0.0821\,L\,atm\,mol^{-1}K^{-1} \cdot 1160\,K} = n$

$n = .105$ mol

c) i. full pressure is 8.37 atm subtract $CO_2(g)$ partial pressure to find CO(g) partial pressure

$8.37\,atm - 1.63\,atm = 6.74\,atm$

CO(g) partial pressure = 6.74 atm

ii. $K_p = \frac{(6.74\,atm)^2}{1.63\,atm}$ $K_p = 27.9$

d) the solid catalyst would cause more CO(g) to be produced therefore raising the final pressure.

e) the pressure of $CO_2(g)$ will decrease as the new system approches equilibrium.

$K_p = 27.9$ $Q = \frac{(2.0\,atm)^2}{2.0\,atm}$ $Q = 2$

$Q < K$ therefore we need more products and the pressure of CO(g) will increase and the $CO_2(g)$ will decrease

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(d) If a suitable solid catalyst were placed in the reaction vessel, would the final total pressure of the gases at equilibrium be greater than, less than, or equal to the final total pressure of the gases at equilibrium without the catalyst? Justify your answer. (Assume that the volume of the solid catalyst is negligible.) 1B1

In another experiment involving the same reaction, a rigid 2.00 L container initially contains 10.0 g of C(*s*), plus CO(*g*) and $CO_2(g)$, each at a partial pressure of 2.00 atm at 1,160 K.

(e) Predict whether the partial pressure of $CO_2(g)$ will increase, decrease, or remain the same as this system approaches equilibrium. Justify your prediction with a calculation.

a) $K_p = \frac{[CO]^2}{[CO_2]}$

b) t=0, P= 5.00 atm

PV=nRT

(5.00 atm)(2.00 L) = n · 0.0821 · 1,160

n= 0.105 mol

c) i) $P_T = P_{CO_2} + P_{CO}$

$8.37 = 1.63 + P_{CO}$

$P_{CO} = 6.74$

ii) $K_p = \frac{[6.74]^2}{[1.63]} = 27.87$

d) If a suitable solid catalyst were added, the final pressure at equilibrium would be equal to the final pressure at equilibrium without the catalyst (assuming that the volume of the catalyst is negligible). This is because a catalyst only speeds up a reaction and help the system reach equilibrium faster; it does not affect the final pressure or concentration at equilibrium.

e) The partial pressure of CO_2 as it approaches equilibrium will increase since the container begins with CO_2. Since $K_p \propto \frac{1}{[CO_2]}$, Kp will decrease and the partial pressure of CO_2 will increase.

1B2

ADDITIONAL PAGE FOR ANSWERING QUESTION 1

because not as much CO_2 will react to form CO.

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1C

(d) If a suitable solid catalyst were placed in the reaction vessel, would the final total pressure of the gases at equilibrium be greater than, less than, or equal to the final total pressure of the gases at equilibrium without the catalyst? Justify your answer. (Assume that the volume of the solid catalyst is negligible.)

In another experiment involving the same reaction, a rigid 2.00 L container initially contains 10.0 g of C(*s*), plus CO(*g*) and $CO_2(g)$, each at a partial pressure of 2.00 atm at 1,160 K.

(e) Predict whether the partial pressure of $CO_2(g)$ will increase, decrease, or remain the same as this system approaches equilibrium. Justify your prediction with a calculation.

a. $\frac{[CO]^2}{[C][CO_2]} = k_p$

b. $k_p = 5.00 = k_c(.0821 \frac{L\,atm}{mol\,k})(1160k)^{2-1}$

$k_c = 5.00\,atm / (.0821 \frac{L\,atm}{mol\,k})(1160k)^1$

$k_c = .0525 \frac{L}{mol} \cdot 2L$

$CO_2 = .105\,mol$

c. i $P_1 + P_2 + P_n \ldots = P_T$

$P_1 = CO_{2(g)}$ $P_2 = CO_{(g)}$ $P_T = 8.37$

$P_1 = 1.63\,atm$ $P_T - P_1 = P_2$

$8.37\,atm - 1.63\,atm = P_2 = CO_{(g)} = 6.74$

ii $k_p = \frac{6.74^2}{1.63} = 27.9$

d. they would be less than because the reaction would get to equilibrium faster so less gas pressure would found.

e. It would decrease because it is a 2 to 1 mole ratio so the partial pressure of $CO_{2(g)}$ will go down

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AP® CHEMISTRY
2008 SCORING COMMENTARY

Question 1

Overview

This question was designed to probe student understanding of gases and gaseous equilibria. Part (a) required students to write the expression for K_p. In part (b) students were asked to determine the number of moles of CO_2(*g*) given the volume, pressure, and temperature. This determination required the use of the ideal gas law. In part (c)(i) students had to select the correct data from the table and use Dalton's law of partial pressures to determine the pressure of CO(*g*) at equilibrium. In part (c)(ii) students were asked to determine the value of K_p using equilibrium pressures. In part (d) they had to explain the effect of a catalyst on the total pressure of gases at equilibrium. In part (e) students were given a new set of initial conditions and asked to determine the direction the reaction would proceed to reach equilibrium.

Sample: 1A
Score: 8

This response earned 8 out of 9 points: 1 for part (a), 2 for part (b), 1 for part (c)(i), 2 for part (c)(ii), and 2 for part (e). The point was not earned in part (d) because the response states that the pressure would increase.

Sample: 1B
Score: 6

The point was not earned in part (a) because the equilibrium-constant expression is given in terms of concentrations rather than pressures. The points were not earned in part (e) because the question states that the prediction needs to be justified with a calculation.

Sample: 1C
Score: 3

The point was not earned in part (a) because the equilibrium-constant expression is given in terms of concentrations rather than pressures (also, the concentration of solid carbon is included in the expression). The points were not earned in part (b) because there is an attempt to solve for the number of moles of CO_2 using the relationship between K_c and K_p. Note that the correct numerical value is obtained fortuitously with the assumed K_p = 5.00 atm and n = 1. The points were earned in parts (c)(i) and (c)(ii). The point was not earned in part (d) because the response states that the pressure would be less. The points were not earned in part (e) because the question states that the prediction needs to be justified with a calculation, and the response uses incorrect reasoning (the 2 to 1 mole ratio) to try to justify the correct prediction of a decrease in the partial pressure of CO_2.