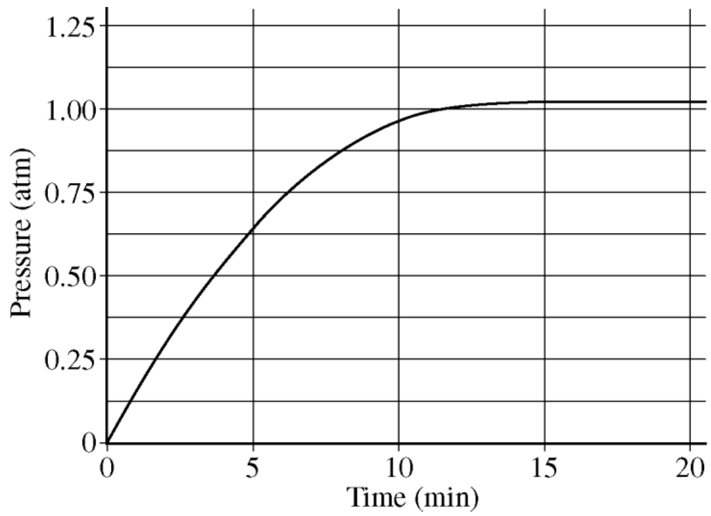
Question 4
(4 points)

$$CaCO_3(s) \rightleftarrows CaO(s) + CO_2(g)$$

When heated, calcium carbonate decomposes according to the equation above. In a study of the decomposition of calcium carbonate, a student added a 50.0 g sample of powdered $CaCO_3(s)$ to a 1.00 L rigid container. The student sealed the container, pumped out all the gases, then heated the container in an oven at 1100 K. As the container was heated, the total pressure of the $CO_2(g)$ in the container was measured over time. The data are plotted in the graph below.



The student repeated the experiment, but this time the student used a 100.0 g sample of powdered $CaCO_3(s)$. In this experiment, the final pressure in the container was 1.04 atm, which was the same final pressure as in the first experiment.

(a) Calculate the number of moles of $CO_2(g)$ present in the container after 20 minutes of heating.

$PV = nRT$ $\frac{PV}{RT} = n = \frac{(1.04 \text{ atm})(1.00 \text{ L})}{(0.0821 \frac{\text{L atm}}{\text{mol K}})(1100 \text{ K})} = 0.0115 \text{ mol } CO_2$	1 point is earned for the proper setup using the ideal gas law and an answer that is consistent with the setup.

Question 4 (continued)

(b) The student claimed that the final pressure in the container in each experiment became constant because all of the $CaCO_3(s)$ had decomposed. Based on the data in the experiments, do you agree with this claim? Explain.

Do not agree with claim Explanation I: In experiment 1, the moles of $CaCO_3$ = 50.0 g/100.09 g/mol = 0.500 mol $CaCO_3$. If the reaction had gone to completion, 0.500 mol of CO_2 would have been produced. From part (a) only 0.0115 mol was produced. Hence, the student's claim was false. Explanation II: The two different experiments (one with 50.0 g of $CaCO_3$ and one with 100.0 g of $CaCO_3$) reached the same constant, final pressure of 1.04 atm. Since increasing the amount of reactant did not produce more product, there is no way that all of the $CaCO_3$ reacted. Instead, an equilibrium condition has been achieved and there must be some solid $CaCO_3$ in the container.	1 point is earned for disagreement with the claim <u>and</u> for a correct justification using stoichiometry or a discussion of the creation of an equilibrium condition.

(c) After 20 minutes some $CO_2(g)$ was injected into the container, initially raising the pressure to 1.5 atm. Would the final pressure inside the container be less than, greater than, or equal to 1.04 atm? Explain your reasoning.

The final pressure would be equal to 1.04 atm. Equilibrium was reached in both experiments; the equilibrium pressure at this temperature is 1.04 atm. As the reaction shifts toward the reactant, the amount of $CO_2(g)$ in the container will decrease until the pressure returns to 1.04 atm.	1 point is earned for the correct answer with justification.

(d) Are there sufficient data obtained in the experiments to determine the value of the equilibrium constant, K_p, for the decomposition of $CaCO_3(s)$ at 1100 K? Justify your answer.

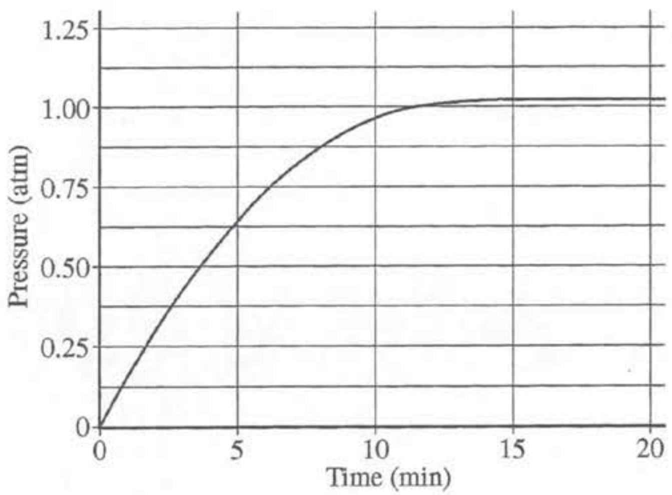
Question 4 (continued)

Yes. For the equilibrium reaction represented by the chemical equation in this problem, at a given temperature the equilibrium pressure of CO_2 determines the equilibrium constant. Since the measured pressure of CO_2 is also the equilibrium pressure of CO_2, $K_p = P_{CO_2} = 1.04$. Note: If the response in part (b) indicates "yes" , that all of the $CaCO_3(s)$ had decomposed, then the point can be earned by stating that the system did not reach equilibrium in either experiment and hence the value of K_p cannot be calculated from the data.	1 point is earned for correct explanation that is consistent with the student's answer to part (b).

4A1

$$CaCO_3(s) \rightleftarrows CaO(s) + CO_2(g)$$

4. When heated, calcium carbonate decomposes according to the equation above. In a study of the decomposition of calcium carbonate, a student added a 50.0 g sample of powdered $CaCO_3(s)$ to a 1.00 L rigid container. The student sealed the container, pumped out all the gases, then heated the container in an oven at 1100 K. As the container was heated, the total pressure of the $CO_2(g)$ in the container was measured over time. The data are plotted in the graph below.



The student repeated the experiment, but this time the student used a 100.0 g sample of powdered $CaCO_3(s)$. In this experiment, the final pressure in the container was 1.04 atm, which was the same final pressure as in the first experiment.

(a) Calculate the number of moles of $CO_2(g)$ present in the container after 20 minutes of heating.

(b) The student claimed that the final pressure in the container in each experiment became constant because all of the $CaCO_3(s)$ had decomposed. Based on the data in the experiments, do you agree with this claim? Explain.

(c) After 20 minutes some $CO_2(g)$ was injected into the container, initially raising the pressure to 1.5 atm. Would the final pressure inside the container be less than, greater than, or equal to 1.04 atm? Explain your reasoning.

(d) Are there sufficient data obtained in the experiments to determine the value of the equilibrium constant, K_p, for the decomposition of $CaCO_3(s)$ at 1100 K? Justify your answer.

a) $PV = nRT \quad n = \frac{PV}{RT} = \frac{1.04 * 1.00}{0.082059 * 1100} = 0.0115$ mol CO_2

b) $\frac{50g}{100.09 g/mol} = 0.500$ mol $CaCO_3$ initially

If $CaCO_3$ completely dissociated, 0.500 mol CO_2 would have been produced. However, only 0.0115 mol was

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produced. Therefore, $CaCO_3$ was not completely consumed; the reaction merely reached equilibrium

c) $K_p = P_{CO_2}$

According to this equilibrium constant, only the amount of CO_2 ~~[illegible]~~ affects the equilibrium. Addition of CO_2 would initially shift the reaction to produce more reactants, but once the pressure of CO_2 is 1.04, the reaction would have reached equilibrium. ∴ Final pressure is equal to 1.04 atm

d) Yes, because only P_{CO_2} ~~required~~ at equilibrium is required to calculate K_p. ∴ $K_p = 1.04$

Solid reactant and product is not involved in the calculation of K_p

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4B, 1

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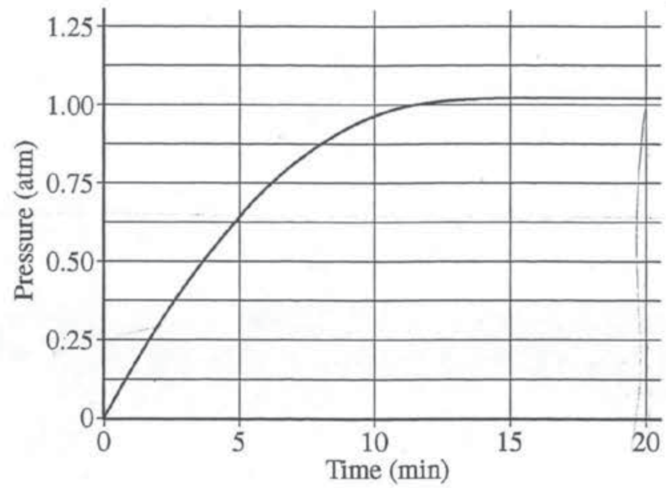

The student repeated the experiment, but this time the student used a 100.0 g sample of powdered $CaCO_3(s)$. In this experiment, the final pressure in the container was 1.04 atm, which was the same final pressure as in the first experiment.

(a) Calculate the number of moles of $CO_2(g)$ present in the container after 20 minutes of heating.

(b) The student claimed that the final pressure in the container in each experiment became constant because all of the $CaCO_3(s)$ had decomposed. Based on the data in the experiments, do you agree with this claim? Explain.

(c) After 20 minutes some $CO_2(g)$ was injected into the container, initially raising the pressure to 1.5 atm. Would the final pressure inside the container be less than, greater than, or equal to 1.04 atm? Explain your reasoning.

(d) Are there sufficient data obtained in the experiments to determine the value of the equilibrium constant, K_p, for the decomposition of $CaCO_3(s)$ at 1100 K? Justify your answer.

a) $PV = nRT$

$(1.04)(1\ L) = n(.08206)(1100\ K)$

.012 moles

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b) No. The pressure is constant because after 20 minutes, the reaction is at equilibrium. which is shown by the leveling off of the pressure in the graph

c) The final pressure would be equal to 1.04 because the increase in CO_2 would cause the reaction to shift to the reactants. The CO_2 would be used to make $CaCO_3$ to reestablish equilibrium.

d) Yes there is sufficient data because in this case the K_p would only be the pressure for the $CO_2(g)$ because the solids would be omitted from the equation.

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4C1

$$CaCO_3(s) \rightleftarrows CaO(s) + CO_2(g)$$

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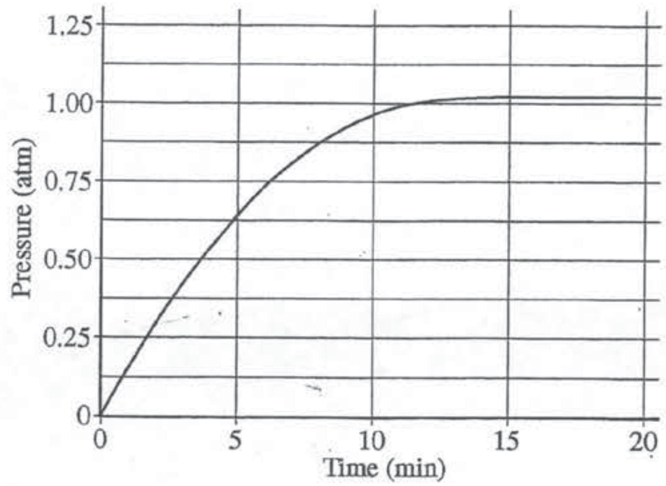

The student repeated the experiment, but this time the student used a 100.0 g sample of powdered $CaCO_3(s)$. In this experiment, the final pressure in the container was 1.04 atm, which was the same final pressure as in the first experiment.

(a) Calculate the number of moles of $CO_2(g)$ present in the container after 20 minutes of heating.

(b) The student claimed that the final pressure in the container in each experiment became constant because all of the $CaCO_3(s)$ had decomposed. Based on the data in the experiments, do you agree with this claim? Explain.

(c) After 20 minutes some $CO_2(g)$ was injected into the container, initially raising the pressure to 1.5 atm. Would the final pressure inside the container be less than, greater than, or equal to 1.04 atm? Explain your reasoning.

(d) Are there sufficient data obtained in the experiments to determine the value of the equilibrium constant, K_p, for the decomposition of $CaCO_3(s)$ at 1100 K? Justify your answer.

a.) $PV = nRT$

$(1.04)(1.00) = (n)(.0821)(1100)$

$n = .012$ mol CO_2

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4C2

ADDITIONAL PAGE FOR ANSWERING QUESTION 4

b.) Yes because even though in the second experiment, we used more of the powdered sample, the pressure was the same. The latter rxn may have taken longer but after all of the powdered $CaCO_3(s)$ was gone, all thats left is the pressure resulting from the $CO_2(g)$. which is in constant amounts btwn the 2 experiment trials

c.) Greater than because of the additional pressure, the container would increase the number of collisions occuring w/i the gaseous molecules and thus after the powdered $CaCO_3$ is gone, the resulting container will still contain the increased velocities of the gas particles (more pressure)

d.) Yes because we know the pressure of the container after $CaCO_3$ is fully deteriorated so calculation of Kp would only require P_{CO_2} which we know is 1.04 as the other reactants and products are solids so they do not contribute to the calculation of Kp.

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Question 4

Overview

This question was designed to evaluate student understanding of a dynamic equilibrium system undergoing a reversible reaction. Students are presented with a graphical relationship of the variables pressure and time for the chemical reaction represented by: $CaCO_3(s) \rightleftarrows CaO(s) + CO_2(g)$. This question also addresses the relationship between K_p and P_{CO_2}. In part (a), the student is asked to apply a mathematical relationship (the ideal gas law) to natural phenomena (decomposition of a solid to form a gas). Given data, students calculated one unknown variable in the ideal gas law. In part (b), the student is asked to analyze data and construct explanations of phenomena based on experimental evidence presented in graphical form. Data from two experiments are presented and students are asked to agree or disagree with a student claim based on the given data. Students must recognize and explain that the decomposition has not gone to completion so the system is at equilibrium. Students may use either mathematical or nonmathematical explanations to refute the claim in the question. Part (c) describes a response to the disturbance of a system at equilibrium. In this part, the student is asked to evaluate the effect on the equilibrium when additional $CO_2(g)$ is injected into the system. Students are expected to claim, based on knowledge of scientific theories, whether the final pressure will be less than, greater than, or equal to the pressure at equilibrium and to give a rationale for their prediction. In part (d), students were asked if there were sufficient experimental data to determine the value of K_p and were also asked to justify their answer.

Sample: 4A
Score: 4

This response earned all four points: 1 point in part (a), 1 point in part (b), 1 point in part (c), and 1 point in part (d).

Sample: 4B
Score: 3

The points were earned in parts (a), (c), and (d). In part (b) the explanation is insufficient to earn the point.

Sample: 4C
Score: 1

The point was earned in part (a). In part (b) the point was not earned because the student agrees with the claim, which is inconsistent with the explanation given. In part (c) the point was not earned for stating that the pressure would be greater. In part (d) the point was not earned because the student stated in part (b) that all of the $CaCO_3(s)$ had decomposed, and the answer in part (d) is not correct for a system that is not at equilibrium.