

2. A chemical reaction between maleic acid ($\text{H}_2\text{C}_4\text{H}_2\text{O}_4$) and sodium bicarbonate (NaHCO_3) occurs in the presence of water to produce carbon dioxide and sodium maleate ($\text{Na}_2\text{C}_4\text{H}_2\text{O}_4$), as represented by the following equation.



(a) A student combines equal masses of $\text{H}_2\text{C}_4\text{H}_2\text{O}_4(s)$ chunks and $\text{NaHCO}_3(s)$ chunks with sufficient water at 20.0°C . The student determines that 0.0114 mol of $\text{CO}_2(g)$ is produced after the reaction goes to completion.

(i) Calculate the number of grams of $\text{CO}_2(g)$ produced.

(ii) The $\text{CO}_2(g)$ produced from the reaction at 20.0°C was collected and found to have a pressure of 1.25 atm . Calculate the volume of $\text{CO}_2(g)$, in liters.

(b) The student performs a second experiment that is identical to the first except that the student grinds the chunks of $\text{H}_2\text{C}_4\text{H}_2\text{O}_4(s)$ and $\text{NaHCO}_3(s)$ into powder before combining the powder with water.

(i) What happens to the surface area of the reactants when the student grinds the chunks into powder?

(ii) The rate-determining step for the overall reaction is the dissolving of the solids. Would the time required for the dissolving of the solids in the second experiment be longer than, shorter than, or the same as the time required in the first experiment? Justify your answer based on the collisions between particles.

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(iii) When the reaction is complete, will the volume of $\text{CO}_2(g)$ at the end of the second experiment be greater than, less than, or equal to the volume at the end of the first experiment? Justify your answer.

The student conducts additional trials of the experiment and produces the following data table.

Trial	Mass of $\text{H}_2\text{C}_4\text{H}_2\text{O}_4$ (grams)	Mass of NaHCO_3 (grams)	Moles of CO_2 Produced (mol)
3	1.543	1.251	0.01489
4	1.543	1.686	0.02007

(c) Based on the student’s data, identify the limiting reactant in trial 3. Justify your answer.

(d) The reaction has a value of ΔS° greater than zero. Using particle-level reasoning, explain why the entropy increases as the reaction progresses.

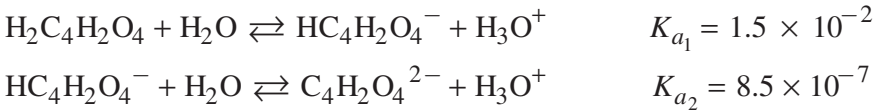
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The student notices that the temperature of the reaction mixture decreases as the reaction takes place and correctly determines that the reaction is endothermic.

(e) The student claims that the reaction is thermodynamically favorable at all temperatures because $\Delta S_{rxn}^\circ > 0$ and the reaction is endothermic. Do you agree or disagree with the student’s claim? Justify your answer.

Next, the student investigates the acid-base behavior of maleic acid. The student notes that maleic acid is a diprotic acid. The two acid dissociation processes that occur are represented by the following equations.



(f) Calculate the $\text{p}K_{a_2}$ value for the $\text{HC}_4\text{H}_2\text{O}_4^-$ ion.

(g) A buffer solution with a pH of 7.00 is prepared using $\text{C}_4\text{H}_2\text{O}_4^{2-}$ and $\text{HC}_4\text{H}_2\text{O}_4^-$. Calculate the ratio

$$\frac{[\text{C}_4\text{H}_2\text{O}_4^{2-}]}{[\text{HC}_4\text{H}_2\text{O}_4^-]} \text{ in this solution.}$$

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