

**2016 AP<sup>®</sup> CHEMISTRY FREE-RESPONSE QUESTIONS**

2. A student designs an experiment to study the reaction between  $\text{NaHCO}_3$  and  $\text{HC}_2\text{H}_3\text{O}_2$ . The reaction is represented by the equation above. The student places 2.24 g of  $\text{NaHCO}_3$  in a flask and adds 60.0 mL of 0.875 M  $\text{HC}_2\text{H}_3\text{O}_2$ . The student observes the formation of bubbles and that the flask gets cooler as the reaction proceeds.
- (a) Identify the reaction represented above as an acid-base reaction, precipitation reaction, or redox reaction. Justify your answer.
- (b) Based on the information above, identify the limiting reactant. Justify your answer with calculations.
- (c) The student observes that the bubbling is rapid at the beginning of the reaction and gradually slows as the reaction continues. Explain this change in the reaction rate in terms of the collisions between reactant particles.
- (d) In thermodynamic terms, a reaction can be driven by enthalpy, entropy, or both.
- (i) Considering that the flask gets cooler as the reaction proceeds, what drives the chemical reaction between  $\text{NaHCO}_3(s)$  and  $\text{HC}_2\text{H}_3\text{O}_2(aq)$ ? Answer by drawing a circle around one of the choices below.
- Enthalpy only                      Entropy only                      Both enthalpy and entropy
- (ii) Justify your selection in part (d)(i) in terms of  $\Delta G^\circ$ .
- (e) The  $\text{HCO}_3^-$  ion has three carbon-to-oxygen bonds. Two of the carbon-to-oxygen bonds have the same length and the third carbon-to-oxygen bond is longer than the other two. The hydrogen atom is bonded to one of the oxygen atoms. In the box below, draw a Lewis electron-dot diagram (or diagrams) for the  $\text{HCO}_3^-$  ion that is (are) consistent with the given information.

- (f) A student prepares a solution containing equimolar amounts of  $\text{HC}_2\text{H}_3\text{O}_2$  and  $\text{NaC}_2\text{H}_3\text{O}_2$ . The pH of the solution is measured to be 4.7. The student adds two drops of 3.0 M  $\text{HNO}_3(aq)$  and stirs the sample, observing that the pH remains at 4.7. Write a balanced, net-ionic equation for the reaction between  $\text{HNO}_3(aq)$  and the chemical species in the sample that is responsible for the pH remaining at 4.7.

# AP<sup>®</sup> CHEMISTRY

## 2016 SCORING GUIDELINES

### Question 2



A student designs an experiment to study the reaction between  $\text{NaHCO}_3$  and  $\text{HC}_2\text{H}_3\text{O}_2$ . The reaction is represented by the equation above. The student places 2.24 g of  $\text{NaHCO}_3$  in a flask and adds 60.0 mL of 0.875 M  $\text{HC}_2\text{H}_3\text{O}_2$ . The student observes the formation of bubbles and that the flask gets cooler as the reaction proceeds.

- (a) Identify the reaction represented above as an acid-base reaction, precipitation reaction, or redox reaction. Justify your answer.

It is an acid-base reaction. The weak acid  $\text{HC}_2\text{H}_3\text{O}_2$  reacts with the weak base  $\text{HCO}_3^-$  with  $\text{HC}_2\text{H}_3\text{O}_2$  donating a proton.

OR

It is an acid-base reaction. No solid precipitates, so it is not a precipitation reaction. None of the oxidation numbers change, so it is not a redox reaction.

1 point is earned for identifying the reaction as acid-base.

1 point is earned for the justification.

- (b) Based on the information above, identify the limiting reactant. Justify your answer with calculations.

$$2.24 \text{ g NaHCO}_3 \times \frac{1 \text{ mol NaHCO}_3}{84.0 \text{ g}} = 0.0267 \text{ mol NaHCO}_3$$

$$60.0 \text{ mL} \times \frac{0.875 \text{ mol HC}_2\text{H}_3\text{O}_2}{1000 \text{ mL}} = 0.0525 \text{ mol HC}_2\text{H}_3\text{O}_2$$

The  $\text{NaHCO}_3(s)$  and  $\text{HC}_2\text{H}_3\text{O}_2(aq)$  react in a 1:1 ratio, so the limiting reactant is  $\text{NaHCO}_3(s)$ .

1 point is earned for calculating the number of moles of each reactant.

1 point is earned for identifying the limiting reactant consistent with the calculations.

- (c) The student observes that the bubbling is rapid at the beginning of the reaction and gradually slows as the reaction continues. Explain this change in the reaction rate in terms of the collisions between reactant particles.

As the reaction proceeds, both reactants are consumed and their concentrations decrease. Collisions between reactant particles become less likely as their concentrations decrease, thus the reaction rate slows.

1 point is earned for a valid explanation.

- (d) In thermodynamic terms, a reaction can be driven by enthalpy, entropy, or both.

- (i) Considering that the flask gets cooler as the reaction proceeds, what drives the chemical reaction between  $\text{NaHCO}_3(s)$  and  $\text{HC}_2\text{H}_3\text{O}_2(aq)$ ? Answer by drawing a circle around one of the choices below.

Enthalpy only

Entropy only

Both enthalpy and entropy

Entropy only should be circled.

1 point is earned for circling Entropy only.

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**Question 2 (continued)**

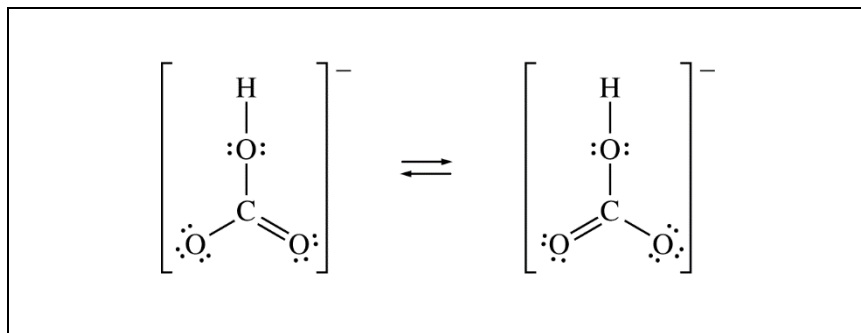
(ii) Justify your selection in part (d)(i) in terms of  $\Delta G^\circ$ .

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

Reactions are thermodynamically favorable when  $\Delta G^\circ$  is negative. Since the reaction is endothermic (the flask gets cooler,  $\Delta H^\circ$  is positive), the reaction is not driven by enthalpy, because enthalpy does not help make  $\Delta G^\circ$  negative. Because there are no gases in the reactants and one of the products is a gas,  $\Delta S^\circ$  must be positive, which helps make  $\Delta G^\circ$  negative.

1 point is earned for a valid justification.

- (e) The  $\text{HCO}_3^-$  ion has three carbon-to-oxygen bonds. Two of the carbon-to-oxygen bonds have the same length and the third carbon-to-oxygen bond is longer than the other two. The hydrogen atom is bonded to one of the oxygen atoms. In the box below, draw a Lewis electron-dot diagram (or diagrams) for the  $\text{HCO}_3^-$  ion that is (are) consistent with the given information.

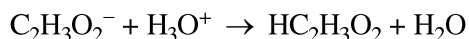


See diagram above.

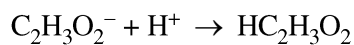
1 point is earned for a correct Lewis structure of  $\text{HCO}_3^-$ .

1 point is earned for indicating resonance (e.g., two diagrams, or one diagram with an arrow between the two appropriate oxygen atoms).

- (f) A student prepares a solution containing equimolar amounts of  $\text{HC}_2\text{H}_3\text{O}_2$  and  $\text{NaC}_2\text{H}_3\text{O}_2$ . The pH of the solution is measured to be 4.7. The student adds two drops of 3.0 M  $\text{HNO}_3(aq)$  and stirs the sample, observing that the pH remains at 4.7. Write a balanced, net-ionic equation for the reaction between  $\text{HNO}_3(aq)$  and the chemical species in the sample that is responsible for the pH remaining at 4.7.



OR



1 point is earned for a correct equation.