

Question 3: Long Answer**10 points**

(a) For the correct balanced equation (state symbols not required): **1 point**

Accept one of the following:

- $\text{CaCO}_3(s) + 2 \text{H}^+(aq) \rightarrow \text{Ca}^{2+}(aq) + \text{CO}_2(g) + \text{H}_2\text{O}(l)$
- $\text{CaCO}_3(s) + 2 \text{H}_3\text{O}^+(aq) \rightarrow \text{Ca}^{2+}(aq) + \text{CO}_2(g) + 3 \text{H}_2\text{O}(l)$

(b) For a correct explanation: **1 point**

Accept one of the following:

- *Even though the concentration of HCl is greater in trial 5 than in trial 2, the reaction time is significantly longer. Both trial 2 and 5 occur under otherwise identical conditions. The trend for trial 1 and 4 indicates that the higher concentration of HCl results in a shorter time of reaction.*
- *The time of reaction in trial 5, with small chunks of calcium carbonate, is longer than trial 6 with large chunks. Both trial 5 and 6 occur under otherwise identical conditions. The trend for trials 1, 2, and 3 shows that larger chunks of the solid result in longer time of reaction.*

(c) For a correct explanation of the effect of surface area on reaction time: **1 point**

The time of reaction in trial 2 is shorter than that in trial 3 because the calcium carbonate in trial 2 has a larger surface area (meaning that more particles of calcium carbonate are exposed to the H^+ particles in the solution).

For a correct explanation of the effect of particle collisions on reaction rate: **1 point**

The larger interface between the two reacting substances means there will be more collisions between the particles in a given amount of time, and thus, a higher frequency of successful collisions in which the particles react to form the products.

Total for part (c) 2 points

(d) For the correct answer and a valid justification: **1 point**

Accept one of the following:

- *Disagree. If the reaction was zeroth order with respect to HCl, then changing the concentration of HCl would not affect the rate of reaction, and the time of reaction would be the same for trials in which the only difference was [HCl]. The student's data for trials 1 and 4 (likewise for 3 and 6) show that changing [HCl] significantly alters the time of reaction.*
- *Disagree. The reaction appears to be first order, not zeroth order, with respect to [HCl]. Tripling [HCl] results in a reaction time that is 1/3 of that when [HCl] = 1.00 M, which means the reaction rate has also tripled, indicating a first-order process.*

(e) For the correct calculated moles of HCl reacted (may be implicit): **1 point**

$$1.00 \text{ g CaCO}_3 \times \frac{1 \text{ mol}}{100.09 \text{ g}} = 0.00999 \text{ mol CaCO}_3$$

$$0.00999 \text{ mol CaCO}_3 \times \frac{2 \text{ mol HCl}}{1 \text{ mol CaCO}_3} = 0.0200 \text{ mol HCl reacted}$$

For the correct calculated [HCl] remaining, consistent with the number of moles reacted: **1 point**

$$0.0500 \text{ L} \times \frac{1.00 \text{ mol HCl}}{1 \text{ L}} = 0.0500 \text{ mol HCl initially present}$$

$$0.0500 \text{ mol} - 0.0200 \text{ mol} = 0.0300 \text{ mol remaining}$$

$$\frac{0.0300 \text{ mol}}{0.0500 \text{ L}} = 0.600 \text{ M HCl remaining}$$

Total for part (e) 2 points

(f) For the correct answer and a valid justification: **1 point**

Exothermic. The solution temperature increases as the reaction proceeds.

(g)(i) For the correct calculated value (sign not required): **1 point**

$$q_{\text{surr}} = mc\Delta T = (51.0 \text{ g})(4.0 \frac{\text{J}}{\text{g}\cdot^\circ\text{C}})(21.90^\circ\text{C} - 21.20^\circ\text{C}) = 140 \text{ J}$$

(ii) For the correct calculated value, consistent with (g)(i), and the correct sign, consistent with (f): **1 point**

$$q_{\text{sys}} = -q_{\text{surr}} = -140 \text{ J} = -0.14 \text{ kJ}$$

$$1.00 \text{ g CaCO}_3 \times \frac{1 \text{ mol CaCO}_3}{100.09 \text{ g CaCO}_3} \times \frac{1 \text{ mol}_{\text{rxn}}}{1 \text{ mol CaCO}_3} = 0.00999 \text{ mol}_{\text{rxn}}$$

$$\Delta H_{\text{rxn}}^\circ = \frac{-0.14 \text{ kJ}}{0.00999 \text{ mol}_{\text{rxn}}} = -14 \text{ kJ/mol}_{\text{rxn}}$$

Total for part (g) 2 points

Total for question 3 10 points