Question 3: Long Answer — 10 points

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

Accept one of the following:

- $CaCO_3(s) + 2\,H^+(aq) \rightarrow Ca^{2+}(aq) + CO_2(g) + H_2O(l)$
- $CaCO_3(s) + 2\,H_3O^+(aq) \rightarrow Ca^{2+}(aq) + CO_2(g) + 3\,H_2O(l)$

(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**

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

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

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

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**

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

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

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

$$1.00\text{ g } CaCO_3 \times \frac{1\text{ mol } CaCO_3}{100.09\text{ g } CaCO_3} \times \frac{1\text{ mol}_{rxn}}{1\text{ mol } CaCO_3} = 0.00999\text{ mol}_{rxn}$$

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

Total for part (g) **2 points**

Total for question 3 **10 points**