UNIT 3 PERFORMANCE TASK: ENERGY AND RATES ANALYSIS OF CHEMICAL REACTIONS

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Prediction/Hypothesis

(a) $Mg_{(s)} + 2\,HCl_{(aq)} \rightarrow H_{2(g)} + MgCl_{2(aq)}$

$Mg_{(s)} + H_2SO_{4(aq)} \rightarrow H_{2(g)} + MgSO_{4(aq)}$

$Mg_{(s)} + 2\,HC_2H_3O_{2\,(aq)} \rightarrow H_{2(g)} + Mg(C_2H_3O_{2)2(aq)}$

(b) The molar enthalpy should be about the same for all three acids, since it is expressed "per mole" of magnesium. The largest rate should be with a dibasic strong acid (sulfuric acid) which yields 2 mol of hydrogen ion for each mole of acid, and the smallest with a weak acid (acetic acid) which yields a fraction of a mole of hydrogen ion for each mole of acid.

Experimental Design

(c) (Answers will vary.) Variables such as temperature and concentrations must be controlled. In the thermochemistry part, maximum temperature of the solution would be measured. In the kinetics part, time for the magnesium ribbon to be consumed might be a possibility, but a better method would be to measure the volume of hydrogen gas trapped in a gas measuring tube, over time.

Materials

(d) (Answers will vary.)
Styrofoam cups (for calorimetry)
stopwatches (for kinetics)

Procedure

(e) (Answers will vary. This is a student-designed experiment and considerable opportunity should be provided students to come up with their own procedures, in particular in the measurements of changes of gas production over time. The following is only one possible minimal design.)

1. Place 50 mL of 0.50 mol/L hydrochloric acid in a Styrofoam cup calorimeter. Measure the initial temperature of the acid. Add a measured mass of magnesium to the acid. Record the maximum temperature.
2. Repeat the previous step for separate samples of the other acids.
3. Place 50 mL of hydrochloric acid in an Erlenmeyer flask, stoppered with a one-hole rubber stopper and delivery tube leading to an inverted water-filled graduated cylinder. Measure the time taken for 20 mL of gas to be produced.
4. Repeat the previous step for separate samples of the other acids.

Evidence

(f) (Sample answers)

Thermochemistry

Acid	Initial *T* (°C)	Final *T* (°C)	Volume of Acid (mL)	Mass of Mg (g)
HCl	24.2	31.0	50	0.075
H_2SO_4	22.0	28.5	50	0.079
HAc	21.2	27.0	50	0.076

Kinetics

Acid	Time for 20 mL of Gas to Form (s)
HCl	31
H_2SO_4	15
HAc	160

Analysis

(g) The ΔH_r was about the same for all three acids. For example, for the hydrochloric acid,

$q = mc\Delta T$

$= 50\text{ g} \times (31.0 - 24.2)^\circ\text{C} \times 4.18\text{ J/g}\bullet^\circ\text{C}$

$q = 1.4\text{ kJ}$

The amount of Mg (in moles) was

$n = m/M$

$= \dfrac{0.075\text{ g}}{(24.3\text{ g/mol})}$

$n = 3.1 \times 10^{-3}\text{ mol}$

Thus, $H_{\text{hydrochloric acid}} = \dfrac{q}{n}$

$= \dfrac{1.4\text{ kJ}}{3.1 \times 10^{-3}\text{ mol}}$

$\Delta H_{\text{hydrochloric acid}} = -4.6 \times 10^2\text{ kJ/mol}$ (negative sign for exothermic reaction)

Similarly, for sulfuric acid,

$\Delta H_{\text{sulfuric acid}} = -4.2 \times 10^2\text{ kJ/mol}$

and for acetic acid,

$\Delta H_{\text{acetic acid}} = -4.5 \times 10^2\text{ kJ/mol}$

The rates of production of hydrogen gas, expressed as mL H_2 produced per s, varied considerably for the acids.

The rate for hydrochloric acid:

$r_{\text{hydrochloric acid}} = 20\text{ mL}/31\text{ s}$

$r_{\text{hydrochloric acid}} = 0.65\text{ mL/s}$

The rate for sulfuric acid:

$r_{\text{sulfuric acid}} = 20\text{ mL}/15\text{ s}$

$r_{\text{sulfuric acid}} = 1.3\text{ mL/s}$

The rate for acetic acid:

$r_{\text{acetic acid}} = 20\text{ mL}/60\text{ s}$

$r_{\text{acetic acid}} = 0.33\text{ mL/s}$

Evaluation

(h) The molar enthalpies of reaction are about the same for all three acids. The rate of reaction for sulfuric acid is about double the rate for hydrochloric acid and more than ten times the rate for acetic acid. (The student predictions will vary, but generally, students tend to expect the heat of reaction to be different for the acids.)

Synthesis

(i) The energy produced by the reaction is a function of the time taken for the roughly fixed mass of magnesium to be consumed. The dibasic sulfuric acid has twice the amount of H^+ as hydrochloric acid, and reacts roughly twice as fast. The weak organic acetic acid has a much smaller concentration of H^+ in solution, and reacts much more slowly.

(j) Possibilities could include solution conductivity, or volume or pressure of gas produced.

(k) As time passes, the rate increases because solution temperature increases but decreases as reactant concentration decreases.

(l) (Answers will vary.) The materials used are somewhat toxic for consumer products and the reaction occurs very quickly. Most consumer handwarmers use a slower reaction like the oxidation of iron filings.