NMSI Super Problem: Thermodynamics

Magnesium flakes were added to an open polystyrene cup filled with 50.0 mL of 1.00 *M* HCl solution. Assume the specific heat of the solution to be 4.18 J/g°C.

$$Mg(s) + 2\ HCl(aq) \rightarrow MgCl_2(aq) + H_2(g) \qquad \Delta H°_{rxn} = -316.0\ kJ\ mol^{-1}$$

a. If 0.650 g of the magnesium were added, determine the total amount of heat released into the calorimeter.

b. Determine the temperature change in the calorimeter.

c. Draw an energy profile diagram and label the enthalpy change, ΔH, for the reaction.

The hydrogen gas produced in the reaction of magnesium and HCl was captured and placed in a sealed container, which occupies a volume of 650 mL at a constant pressure of 1.0 atm. The temperature of the container and gas was changed by 15°C; the resulting volume of the gas in the container is 620 mL.

d. Is the temperature of the system increasing or decreasing. Justify your answer

e. Calculate the amount of work done, in Joules (J).

f. Is the statement in the box below correct? Justify your answer.

The gas collected in the container does work on the surroundings

Answer the following questions about the oxidation of magnesium metal.

$$Mg(s) + \tfrac{1}{2} O_2(g) \rightarrow MgO(s)$$

g. Determine the value of the standard enthalpy change for the reaction in the box above.

$Mg(s) + 2\ HCl(aq) \rightarrow MgCl_2(aq) + H_2(g)$ $\quad \Delta H°_{rxn} = -316.0\ kJ\ mol^{-1}$

$MgO(s) + 2\ HCl(aq) \rightarrow MgCl_2(aq) + H_2O(\ell)$ $\quad \Delta H°_{rxn} = -45.7\ kJ\ mol^{-1}$

$H_2(g) + \tfrac{1}{2} O_2(g) \rightarrow H_2O(\ell)$ $\quad \Delta H°_{rxn} = -286\ kJ\ mol^{-1}$

h. Determine the value of the standard entropy change, $\Delta S°_{rxn}$, for the oxidation of magnesium using the information in the following table.

Substance	$\Delta S°$ (J mol^{-1} K^{-1})
Mg	33
O_2	205
MgO	27

i. Calculate $\Delta G°_{rxn}$ for the oxidation of magnesium at 25°C

j. Indicate whether the reaction is thermodynamically favored at 25°C. Justify your answer.

The hydrogen gas collected and placed in the sealed container above is mixed with nitrogen gas to produce ammonia according to the Haber process shown below.

$N_2(g) + 3\ H_2(g) \rightleftharpoons 2\ NH_3(g)$ $\Delta G°_{rxn} = -34.1$ kJ mol^{-1} $\Delta H°_{rxn} = -92.2$ kJ mol^{-1}

k. In terms of the equilibrium constant, K for the above reaction at 25°C
   i. Predict whether K will be greater than, less than, or equal to one. Justify your choice.

   ii. Calculate its value.

l. In terms of the standard entropy change, $\Delta S°$
   i. Predict the sign of $\Delta S°$ for the above reaction. Justify your answer.

   ii. Calculate the value of $\Delta S°_{rxn}$ for the above reaction at 25°C.

m. Using the data in the table below and the enthalpy of reaction, $\Delta H°_{rxn}$, calculate the approximate bond energy of the nitrogen–hydrogen bond in ammonia.

Bonds	Approximate Bond Energy (kJ mol^{-1})
N—H	???
H—H	430
N≡N	960