Thermochemistry practice problems

1) How can energy be transferred to or from a system?

    A) Energy can only be transferred as potential energy being converted to kinetic energy.

    B) Energy can be transferred only as heat.

    C) Energy can be transferred only as work.

    D) Energy can be transferred as heat and/or work.

1) _____

2) Which of the following is an example of a state function?

    A) The length of time it takes to go from New York to Los Angeles

    B) The mileage traveled going from San Francisco to Los Angeles

    C) The amount of time it takes to change the channel when *Gossip Girl* comes on.

    D) The difference in altitude between Chicago and Denver

2) _____

3) Which of the following is NOT a state property?

    A) pressure

    B) temperature

    C) internal energy

    D) enthalpy

    E) work

3) _____

4) Which of the following is the best example of an isolated system?

    A) water in a styrofoam coffee cup

    B) liquid in a beaker with a watch glass over it

    C) soda in an unopened soft drink can

    D) coffee in a closed thermos bottle

4) _____

5) How does a closed system differ from an open system?

    A) A closed system does not do any work on the surroundings.

    B) A closed system cannot exchange heat with the surroundings.

    C) Energy is conserved in a closed system, but not in an open system.

    D) A closed system cannot exchange matter with the surroundings.

5) _____

6) A chemical reaction where heat is transferred to the surroundings is a(n) _____ reaction.

    EXOTHERMIC

7) Which of the following is an endothermic process?

    A) jet fuel burning in a jet engine   B) combustion of methane

    C) freezing of water   **D) vaporization of water**

7) _____

8) Which is true if $\Delta H = -95$ J?

    A) Both the system and the surroundings are gaining 95 J.

    B) Both the system and the surroundings are losing 95 J.

    C) The system is gaining 95 J, while the surroundings are losing 95 J.

    D) The system is losing 95 J, while the surroundings are gaining 95 J.

    E) The system is losing −95 J, while the surroundings are gaining 95 J.

8) _____

9) Which of the following signs on q and w represent a system that is doing work on the   9) _____
   surroundings, as well as losing heat to the surroundings?

   A) +q, +w
   B) −q, −w
   C) +q, −w
   D) −q, +w
   E) None of the above.

10) How much work in joules is done when a piston expands from a volume of 13.27 liters to   10) _____
    76.55 liters against a pressure of 14.89 atm?

$w = -P\Delta V$

$w = -(14.89\, atm)(76.55L - 13.27L)$

$w = -942.2\, L\cdot atm$

$-942.2\, L\cdot atm \times \dfrac{101.3\, J}{L\cdot atm} = -95450\, J$

11) How much work in joules is done on the system when a 1.15 atm external pressure causes   11) _____
    a piston to decrease in volume from 6.55 liters to 3.16 liters?

$w = -P\Delta V$

$w = -(1.15\, atm)(3.16L - 6.55L)$

$w = 3.90\, L\cdot atm$

$3.90\, L\cdot atm \times \dfrac{101.3\, J}{L\cdot atm} = 395\, J$

12) In a refrigeration system, the refrigerant gas absorbs 21.39 kJ of energy while expanding   12) _____
    against a 0.278 atmosphere pressure from a volume of 0.0423 liters to a volume of 1.876
    liters. What is the energy change of the gas?

$\Delta E = \Delta H - P\Delta V = (21390\, J) - (0.278\, atm)(1.876L - 0.0423L)\left(\dfrac{101.3\, J}{L\cdot atm}\right)$

$\Delta E = 21338\, J \Rightarrow 21.338\, kJ$

13) What is the energy change of the system if a chemical reaction transfers 32.146 kJ of heat to   13) _____
    the surroundings while it causes the expansion of a 1.465 liter vessel to 3.687 liters against a
    pressure of 3.64 atmospheres?

$\Delta E = -32.965\, kJ$

14) Lead, water, sulfur, and arsenic have specific heats of 0.128, 4.18, 0.706, and 0.329 J/g°C,   14) _____
    respectively. Which of these would require the smallest amount of heat to increase its
    temperature by 10 °C (assume all samples have the same mass)?

LEAD ⇒ SMALLEST SPECIFIC HEAT

15) When power was turned off to a 30.0 gal. water heater, the temperature of the water   15) _____
    dropped from 75.0 °C to 22.5 °C. How much heat was lost to the surroundings? (1 gal =
    3.785 L)

$-q = mC\Delta T$

$30.0\, gal \times \dfrac{3.785L}{gal} \times \dfrac{mL}{10^{-3}L} \times \dfrac{1.00g}{mL} = 113550\, g$

$q = -(113550\, g)(4.184\,\tfrac{J}{g°C})(22.5°C - 75.0°C)$

$q = 2.49 \times 10^7\, J$

2

$2.49 \times 10^4\, kJ$

$$5.28 \text{ gal} \times \frac{3.785 \text{ L}}{\text{gal}} \times \frac{\text{mL}}{10^{-3} \text{ L}} \times \frac{1.00 \text{ g}}{\text{mL}} = 19984.8 \text{ g}$$

16) How much heat is needed to raise the temperature of 5.28 gal of water from 25.0 °C to 88.0 °C (1 gal = 3.785 L)?

16) _____

$$q = (19984 \text{ g})(4.184 \tfrac{J}{g°c})(88.0°c - 25.0°c)$$

$$q = 5270 \text{ kJ}$$

17) 14.0 g of metal at 24.0 °C has 250 joules of heat added to it. The metal's specific heat is 0.105 J/g °C. What is its final temperature?

17) _____

$$q = mC\Delta T \Rightarrow \quad 250 J = (14.0 \text{ g})(0.105 \tfrac{J}{g°c})(T_f - 24.0°c)$$

$$T_f = 28.3 °c$$

18) 1219 joules of heat raise the temperature of 250 g of metal by 64 °C. What is the specific heat in J/g °C?

18) _____

$$c = \frac{q}{m\Delta T} = \frac{(1219 J)}{(250 \text{ g})(64°c)}$$

$$c = 0.076 \tfrac{J}{g°c}$$

19) 1674 J of heat are absorbed by 25.0 mL of an aqueous solution of NaOH ($d = 1.10$ g/mL, specific heat = 4.10 J/g °C). The temperature of the solution goes up how many degrees?

19) _____

$$\Delta T = \frac{q}{mC} = \frac{(1674 J)}{(25.0 \text{ mL} \times \frac{1.10 \text{ g}}{\text{mL}})(4.10 \tfrac{J}{g°c})} = 14.8°c$$

20) What is the final temperature when 150.0 mL of water at 90.0 °C is added to 100.0 mL of water at 30.0 °C?

20) _____

$$-q_{HOT} = q_{COLD} \Rightarrow -(m_{HOT} C_{H_2O} \Delta T_{HOT}) = (m_{COLD} C_{H_2O} \Delta T_{COLD}) \leftarrow C_{H_2O} \text{ CANCELS}$$

$$-(150.0 \text{ g})(T_f - 90.0°c) = (100.0 \text{ g})(T_f - 30.0°c)$$

$$T_f = 66.0°c$$

21) 50.0 g of iron that has an initial temperature of 225 °C and 50.0 g of gold that has an initial temperature of 25.0 °C are brought into contact with one another. Assuming no heat is lost to the surroundings, what will be the temperature when the two metals reach thermal equilibrium? The specific heat capacity of iron = 0.449 J/g°C and gold = 0.128 J/g°C.

21) _____

$$-q_{Fe} = q_{Au} \Rightarrow -(m_{Fe} C_{Fe} \Delta T_{Fe}) = (m_{Au} C_{Au} \Delta T_{Au})$$

$$-(50.0 \text{ g})(0.449 \tfrac{J}{g°c})(T_f - 225°c) = (50.0 \text{ g})(0.128 \tfrac{J}{g°c})(T_f - 25.0°c)$$

$$-22.45 \tfrac{J}{°c}(T_f) + 5051.25 J = 6.40 \tfrac{J}{°c}(T_f) - 1.60 \times 10^2 J$$

$$T_f = 181°C$$

22) 100.0 g of nickel at 150 °C was placed in 1.00 L of water at 25.0 °C. The final temperature of the water was 26.3 °C. What is the specific heat of nickel?   22) _____

$$-q_{Ni} = q_{H_2O} \implies -(m_{Ni} C_{Ni} \Delta T_{Ni}) = (m_{H_2O} C_{H_2O} \Delta T_{H_2O})$$

$$C_{Ni} = \frac{(m_{H_2O} C_{H_2O} \Delta T_{H_2O})}{-(m_{Ni} \Delta T_{Ni})} = 0.44 \frac{J}{g\,°C}$$

23) A 25.0 g piece of iron at 398 K is placed in a styrofoam coffee cup containing 25.0 mL of water at 298 K. Assuming that no heat is lost to the cup or the surroundings, what will the final temperature of the water be? The specific heat capacity of iron = 0.449 J/g°C and water = 4.18 J/g°C.   23) _____

$$-q_{Fe} = q_{H_2O} \implies -(m_{Fe} C_{Fe} \Delta T_{Fe}) = (m_{H_2O} C_{H_2O} \Delta T_{H_2O})$$

$$\downarrow \text{ SOLVE FOR } T_f$$

$$T_F = 34.6\,°C$$

24) What is the molar mass of a metal predicted by the Dulong–Petit law if the metal has a specific heat capacity of 0.128 J/g°C?   24) _____

$$C = \frac{3R}{M} \implies M = \frac{3R}{C} = \frac{(3)(8.3145 \frac{J}{mol\,K})}{(0.128 \frac{J}{g\,K})} = 195 \text{ g/mol}$$

25) A 75.0 g sample of a metal at is heated by adding 450 J of heat. Its temperature increased from 22.0 °C to 37.0 °C. What is the molar mass of the metal?   25) _____

FIRST DETERMINE SPECIFIC HEAT CAPACITY:

$$q = mC\Delta T \implies C = \frac{q}{m\Delta T} = \frac{450 J}{(75.0 g)(15.0°C)} = 0.40 \frac{J}{g\,°C}$$

THEN USE DULONG-PETIT LAW:

$$M = \frac{3R}{C} = \frac{(3)(8.3145 \frac{J}{mol\,K})}{(0.40 \frac{J}{g\,K})} = 62 \text{ g/mol}$$

26) A 10.0 g sample of a metal at 78.0 °C is submerged in 50.0 mL of water at 25.0 °C. the final 26) _____
temperature of the water is measured to be 26.1 °C. Assuming no heat is lost to the
surroundings, what is the approximate molar mass of the metal?

$$-q_m = q_{H_2O} \Rightarrow -(m_m C_m \Delta T_m) = (m_{H_2O} C_{H_2O} \Delta T_{H_2O}) \quad \longleftarrow \text{ SOLVE FOR } C_m$$

$$C_m = \frac{(m_{H_2O} C_{H_2O} \Delta T_{H_2O})}{-(m_m \Delta T_m)} = \frac{(50.0_g)(4.184 \frac{J}{g \cdot C})(1.1 °C)}{-(10.0_g)(-51.9 °C)} = 0.44 \frac{J}{g \cdot C}$$

$$M = \frac{3R}{C} = \frac{(3)(8.3145 \frac{J}{mol \cdot K})}{(0.44 \frac{J}{g \cdot K})} = 56 \ g/mol$$

27) Two aqueous solutions at room temperature are mixed in a coffee cup calorimeter. The reaction 27) _____
causes the temperature of the resulting solution to fall below room temperature. Which of the
following statements is TRUE?
   A) Energy is leaving the system during reaction.
   B) The products have a lower potential energy than the reactants.
   C) This type of experiment directly yields ΔE_{rxn}.
   D) The mixing is endothermic.
   E) The solution has special properties that enable it to violate the first and second law of
   thermodynamics.

28) A 21.8 g sample of ethanol (C_2H_5OH) is burned in a bomb calorimeter. If the temperature 28) _____
rises from 25.0 °C to 62.3 °C, determine the heat capacity of the calorimeter. The molar
mass of ethanol is 46.07 g/mol.

$$C_2H_5OH(l) + 3 \ O_2(g) \rightarrow 2 \ CO_2(g) + 3 \ H_2O(g) \qquad \Delta H_{rxn} = -1235 \ kJ$$
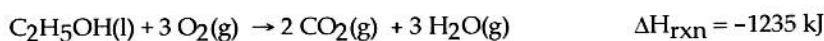
$$q = C_{cal} \Delta T \Rightarrow C_{cal} = \frac{q}{\Delta T} = \frac{584 \ kJ}{37.3 °C} = 15.7 \ \frac{kJ}{°C}$$

$$21.8_g \times \frac{mol \ C_2H_5OH}{46.07_g} \times \frac{1235 \ kJ}{mol \ C_2H_5OH} = 584 \ kJ$$

29) A 35.6 g sample of ethanol (C_2H_5OH) is burned in a bomb calorimeter that has a heat 29) _____
capacity of 23.3 kJ/°C. If the temperature rose from 35.0 °C to 76.0 °C, what is the value of
ΔH_{rxn}? The molar mass of ethanol is 46.07 g/mol.

$$C_2H_5OH(l) + 3 \ O_2(g) \rightarrow 2 \ CO_2(g) + 3 \ H_2O(g) \qquad \Delta H_{rxn} = ?$$
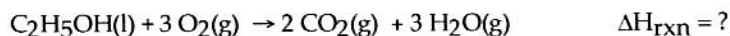
$$35.6_g \times \frac{mol \ C_2H_5OH}{46.07_g} = 0.773 \ mol \ C_2H_5OH \qquad -q_{rxn} = C_{cal} \Delta T = (23.3 \frac{kJ}{°C})(41.0 °C)$$

$$q_{rxn} = -955 \ kJ$$

$$\Delta E \approx \Delta H = \frac{-955 \ kJ}{0.773 \ mol} = -1240 \ \frac{kJ}{mol}$$

30) A 12.8 g sample of ethanol (C_2H_5OH) is burned in a bomb calorimeter that has a heat   30) _____
capacity of 5.65 kJ/°C. If the initial temperature is 25.0 °C, determine the final temperature
of the calorimeter. The molar mass of ethanol is 46.07 g/mol.

$$C_2H_5OH(l) + 3\,O_2(g) \rightarrow 2\,CO_2(g) + 3\,H_2O(g) \qquad \Delta H_{rxn} = -1235\ kJ$$
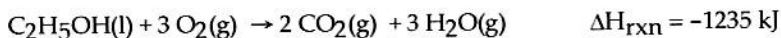
$$-q_{rxn} = q_{cal} = C_{cal}\,\Delta T = C_{cal}(T_F - T_i) \implies T_f = \left(\frac{q_{cal}}{C_{cal}}\right) + T_i = \left(\frac{343\ KJ}{5.65\frac{KJ}{°C}}\right) + 25.0°C$$

$$12.8\,g \times \frac{mol\ C_2H_5OH}{46.07\,g} \times \frac{1235\ KJ}{mol\ C_2H_5OH} = 343\ KJ \qquad\qquad T_f = 85.7\ °C$$

31) A 100.0 mL sample of 0.300 M NaOH is mixed with a 100.0 mL sample of 0.305 M HNO3   31) _____

LIMITING   in a coffee cup calorimeter. If both solutions were initially at 35.0 °C and the temperature
of the resulting solution was recorded as 37.0 °C, determine the ΔH_{rxn} (in units of kJ/mol).
Assume that no heat is lost to the calorimeter or the surroundings. $NaOH + HNO_3 \rightarrow NaNO_3 + H_2O$
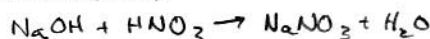
$$-q_{rxn} = q_{soln} \implies q_{rxn} = -(200.0\,g)\left(4.184\frac{J}{g°C}\right)(37.0°C - 35.0°C)$$

$$q_{rxn} = -1673.6\ J$$

$$0.1000\,L \times \frac{0.300\ mol\ NaOH}{L} = 0.0300\ mol$$

$$\Delta H_{rxn} = \frac{q_{rxn}}{mol\ NaOH} = \frac{-1673.6\ J}{0.0300\ mol} = -56000\ J/mol$$
$$-56\ KJ/mol$$

32) A student is preparing to perform a series of calorimetry experiments. She first wishes to   32) _____
determine the heat capacity of the calorimeter (C_{cal}) for her coffee cup calorimeter. She
pours a 50.0 mL sample of water at 72.0 °C into the calorimeter containing a 50.0 mL
sample of water at 25.0 °C. She carefully records the final temperature of the water as 44.0
°C. What is the value of C_{cal} for the calorimeter?

$$-q_{HOT} = q_{COLD} + q_{CAL} \implies -(50.0\,g)\left(4.184\frac{J}{g°C}\right)(-28.0°C) = (50.0\,g)\left(4.184\frac{J}{g°C}\right)(19.0°C) + C_{cal}(19.0°C)$$

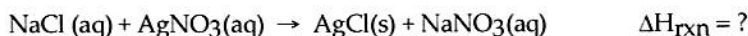$$C_{cal} = 99.1\ \frac{J}{°C}$$

33) Two solutions, initially at 24.60 °C, are mixed in a coffee cup calorimeter (C_{cal} = 15.5 J/°C).   33) _____
When a 100.0 mL volume of 0.100 M AgNO3 solution is mixed with a 100.0 mL sample of
0.200 M NaCl solution, the temperature in the calorimeter rises to 25.30 °C. Determine the
LIMITING ΔH_{rxn} for the reaction as written below.

$$NaCl\,(aq) + AgNO_3(aq) \rightarrow AgCl(s) + NaNO_3(aq) \qquad \Delta H_{rxn} = ?$$

$$0.1000\,L \times \frac{0.100\ mol\ AgNO_3}{L} = 0.0100\ mol$$

$$-q_{rxn} = q_{soln} + q_{cal}$$

$$q_{rxn} = -\left[(200.0\,g)\left(4.184\frac{J}{g°C}\right)(0.70°C) + \left(15.5\frac{J}{°C}\right)(0.70°C)\right]$$

$$q_{rxn} = -596.61\ J$$

$$\Delta H_{rxn} = \frac{q_{rxn}}{mol\ AgNO_3} = \frac{-596.61\ J}{0.0100\ mol\ AgNO_3} = -59700\ J/mol$$

$$-59.7\ KJ/mol$$

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34) Use the $\Delta H°_f$ information provided to calculate $\Delta H°_{rxn}$ for the following: 34) _____

$$SO_2Cl_2\,(g) + 2\,H_2O(l) \rightarrow 2\,HCl(g) + H_2SO_4(l) \qquad \Delta H°_{rxn} = \;?$$
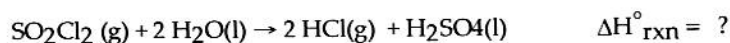
	$\Delta H°_f$ (kJ/mol)
$SO_2Cl_2(g)$	−364
$H_2O(l)$	−286
$HCl(g)$	−92
$H_2SO_4(l)$	−814

$$\Delta H°_{rxn} = \left[(2mol)(-92\tfrac{KJ}{mol}) + (1mol)(-814\tfrac{KJ}{mol})\right] - \left[(1mol)(-364\tfrac{KJ}{mol}) + (2mol)(-286\tfrac{KJ}{mol})\right] = -62\;KJ$$

35) Use the information provided to determine $\Delta H°_{rxn}$ for the following reaction: 35) _____

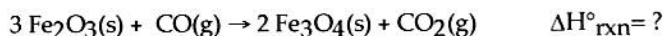$$CH_4(g) + 4\,Cl_2(g) \rightarrow CCl_4(g) + 4\,HCl(g) \qquad \Delta H°_{rxn} = \;?$$
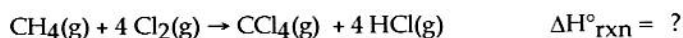
	$\Delta H°_f$ (kJ/mol)
$CH_4(g)$	−75
$CCl_4(g)$	−96
$HCl(g)$	−92

$$\Delta H°_{rxn} = \left[(1mol)(-96\tfrac{KJ}{mol}) + (4mol)(-92\tfrac{KJ}{mol})\right] - \left[(1mol)(-75\tfrac{KJ}{mol})\right] = -389\;KJ$$

36) Use the information provided to determine $\Delta H°_{rxn}$ for the following reaction: 36) _____

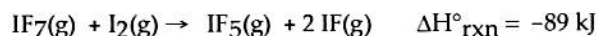$$3\,Fe_2O_3(s) + CO(g) \rightarrow 2\,Fe_3O_4(s) + CO_2(g) \qquad \Delta H°_{rxn} = \;?$$

	$\Delta H°_f$ (kJ/mol)
$Fe_2O_3(s)$	−824
$Fe_3O_4(s)$	−1118
$CO(g)$	−111
$CO_2(g)$	−394

$$\Delta H°_{rxn} = \left[(2mol)(-1118\tfrac{KJ}{mol}) + (1mol)(-394\tfrac{KJ}{mol})\right] - \left[(3mol)(-824\tfrac{KJ}{mol}) + (1mol)(-111\tfrac{KJ}{mol})\right] = -47\;KJ$$

37) Use the $\Delta H°_f$ and $\Delta H°_{rxn}$ information provided to calculate $\Delta H°_f$ for IF: 37) _____

$$IF_7(g) + I_2(g) \rightarrow IF_5(g) + 2\,IF(g) \qquad \Delta H°_{rxn} = -89\;kJ$$

	$\Delta H°_f$ (kJ/mol)
$IF_7(g)$	−941
$IF_5(g)$	−840

$$-89KJ = \left[(1mol)(-840\tfrac{KJ}{mol}) + (2mol)(\Delta H°_{f\,IF})\right] - \left[(1mol)(-941\tfrac{KJ}{mol})\right]$$

$$\Delta H°_{f\,IF} = -95\;\tfrac{KJ}{mol}$$

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38) Use the standard reaction enthalpies given below to determine $\Delta H°_{rxn}$ for the following reaction: 38) _____

$$2\,NO(g) + O_2(g) \rightarrow 2\,NO_2(g) \qquad \Delta H°_{rxn} = \,?$$
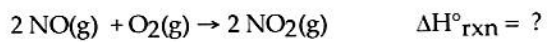
Given:

$$N_2(g) + O_2(g) \rightarrow 2\,NO(g) \qquad \Delta H°_{rxn} = 183\ kJ$$

$$1/2\ N_2(g) + O_2(g) \rightarrow NO_2(g) \qquad \Delta H°_{rxn} = 33\ kJ$$

FLIP

$\underline{\hspace{1cm}\Delta H°}$

$\rightarrow$ $2NO \rightarrow N_2 + O_2$ $-183\ kJ$

$\times 2$

$\rightarrow$ $N_2 + 2O_2 \rightarrow 2NO_2$ $66\ kJ$

$2NO + O_2 \rightarrow 2NO_2$ $-117\ kJ$

39) Use the standard reaction enthalpies given below to determine $\Delta H°_{rxn}$ for the following reaction: 39) _____

$$P_4(g) + 10\,Cl_2(g) \rightarrow 4PCl_5(s) \qquad \Delta H°_{rxn} = \,?$$
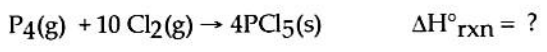
Given:

$$PCl_5(s) \rightarrow PCl_3(g) + Cl_2(g) \qquad \Delta H°_{rxn} = 157\ kJ$$

$$P_4(g) + 6\,Cl_2(g) \rightarrow 4\,PCl_3(g) \qquad \Delta H°_{rxn} = -1207\ kJ$$

FLIP
$\times 4$

$4PCl_3 + 4Cl_2 \rightarrow 4PCl_5$ $-628\ kJ$

$P_4 + 6Cl_2 \rightarrow 4PCl_3$ $-1207\ kJ$

$P_4 + 10Cl_2 \rightarrow 4PCl_5$ $-1835\ kJ$

40) How much energy is released during the formation of 98.7 g of Fe, according to the reaction below?   40) _____

$$Fe_2O_3(s) + 2\,Al(s) \rightarrow Al_2O_3(s) + 2\,Fe(s) \qquad \Delta H°_{rxn} = -852\ kJ$$

$$98.7\,g \times \frac{mol\ Fe}{55.847\,g} \times \frac{852\ kJ}{2\ mol\ Fe} = 753\ kJ$$

41) Using the following information, what mass of HF must react in order to produce 345 kJ of energy? Assume excess SiO_2.   41) _____

$$SiO_2(s) + 4\,HF(g) \rightarrow SiF_4(g) + 2\,H_2O(l) \qquad \Delta H°_{rxn} = -184\ kJ$$

$$345\ kJ \times \frac{4\ mol\ HF}{184\ kJ} \times \frac{20.006\,g}{mol\ HF} = 1.50 \times 10^2\,g$$

42) Using the following information, what mass of H_2O must form in order to produce 975 kJ of energy?   42) _____

$$SiO_2(s) + 4\,HF(g) \rightarrow SiF_4(g) + 2\,H_2O(l) \qquad \Delta H°_{rxn} = -184\ kJ$$

$$975\ kJ \times \frac{2\ mol\ H_2O}{184\ kJ} \times \frac{18.016\,g}{mol\ H_2O} = 191\,g$$

43) How much energy can be relased during the following reaction if 2.50 L B_2H_6 and 5.65 L Cl_2 (Both gases are initially at STP), are allowed to react?   43) _____

$$B_2H_6(g) + 6\,Cl_2(g) \rightarrow 2\,BCl_3(g) + 6\,HCl(g) \qquad \Delta H°_{rxn} = -1396\ kJ$$

$$2.50\,L \times \frac{mol\ B_2H_6}{22.41\,L} \times \frac{1396\ kJ}{mol\ B_2H_6} = 156\ kJ \qquad 5.65\,L \times \frac{mol\ Cl_2}{22.41\,L} \times \frac{1396\ kJ}{6\ mol\ Cl_2} = \boxed{58.7\ kJ}$$