Unit 5* HW problems
Thermodynamics

* Actually on unit 6

Specific Heat

① $m = 200.\,g$
$c = 4.184\ J/g°C$
$T_i = 5°C$
$T_f = 85°C$

$q = mc\Delta T$
$= (200.\,g)(4.184\ J/g°C)(85°C - 5°C)$
$= \boxed{67000\ J = 67\ kJ}$

② $c = .897\ J/g°C$

$= (200.\,g)(.897\ J/g°C)(85°C - 5°C)$
$= \boxed{14\,000\ J = 14\ kJ}$

③ $c = .385\ J/g°C$
$T_i = 20.°C$
$T_f = 75°C$
$q = 1200.\,J$

$q = mc\Delta T$
$m = \frac{q}{c\Delta T} = \frac{1200.\,J}{(.385\ J/g°C)(75° - 20.°C)}$
$= \boxed{57\ g}$

④ $q = 750\ J$
$m = 100.\,g$
$T_i = 90.°C$
$T_f = 135°C$

$c = \frac{q}{m\Delta T} = \frac{750\ J}{(100.\,g)(135°C - 90°C)}$
$= \boxed{.17\ J/g°C}$

⑤ $q = 500.\,J$
$m = 150\,g$
$c = 2.06\ J/g°C$
$T_i = 90.°C$

$q = mc(T_f - T_i)$
$\frac{q}{mc} = T_f - T_i$
$\frac{q}{mc} + T_i = T_f = \frac{500.\,J}{(150g)(2.06\ J/g°C)} + {-90.°C}$
$\boxed{T_f = -88°C}$

⑥ $m = 90.\,g$
$c = .449\ J/g°C$
$q = -200\ J$

$q = mc\Delta T$
$\Delta T = \frac{q}{mc} = \frac{-200\ J}{(90.\,g)(.449\ J/g°C)}$
$\boxed{= -4.9°C}$

(7) $q = 500.\ J$

$m = 250.\ g$

$c = .14\ J/g°C$

$T_f = 50.°C$

$q = mc\Delta T = mc(T_f - T_i)$

$\frac{q}{mc} = T_f - T_i \qquad T_i = T_f - \frac{q}{mc}$

$= 50°C - \frac{(500\ J)}{(250.\ g)(.14\ J/g°C)}$

$T_i = 36°C$

Phase Change

(1) T doesn't change during phase change

(2) heat required to melt substance (usually kJ/mol)

(3) heat required to boil 1 mol substance

(4) $\frac{30.\ g\ Cu}{} \left| \frac{1\ mol}{63.55\ g} \right| \frac{13.3\ kJ}{1\ mol} =$ **6.3 kJ**

(5) $\frac{63\ g\ EtOH}{} \left| \frac{1\ mol}{46.07\ g} \right| \frac{38.6\ kJ}{1\ mol} =$ **53 kJ**

(6) $\frac{6.3\ g\ CO_2}{} \left| \frac{1\ mol}{44.01\ g} \right. = .14\ mol \qquad \Delta H_{fus} = \frac{1200\ J}{.14} =$ **8.4 kJ/mol**

(7) $\frac{.14\ g\ CO_2}{} \left| \frac{1\ mol}{44.01\ g} \right. = .0032\ mol \qquad \Delta H_{vap} = \frac{50.\ J}{.0032\ mol}$ **= 16 kJ/mol**

(8) $\frac{700.\ J}{} \left| \frac{1\ kJ}{1000\ J} \right| \frac{1\ mol}{13.05\ kJ} \left| \frac{63.55\ g}{1\ mol} \right. =$ **3.41 g**

(9) $\frac{8000.\ J}{} \left| \frac{1\ kJ}{1000\ J} \right| \frac{1\ mol}{40.7\ kJ} \left| \frac{18.02\ g}{1\ mol} \right. =$ **3.54 g**

Combo Problems

① $(C_2H_5)_2O(l)$ → $(C_2H_5)_2O(l)$ → $(C_2H_5)_2O(g)$

5.0°C → 34.6°C → 34.6°C

$q = mc\Delta T$

$= (200.\ g)(2.33\ J/g°C)(34.6°C - 5°C)$

$= 13800\ J = 13.8\ kJ$

$\frac{200.\ g}{} \left| \frac{357\ J}{1\ g} \right.$

$= 71400\ J = 71.4\ kJ$

$q_{total} = 13800\ J + 71400\ J = \boxed{85200\ J = 85.2\ kJ}$

② $C_6H_6(l)$ → $C_6H_6(l)$ → $C_6H_6(g)$ → $C_6H_6(g)$

20°C → 80°C → 80°C → 150°C

$q = mc\Delta T$

$= (400)(1.74)(80-20)$

$= 42\ kJ$

$400\ g \left| \frac{1\ mol}{78.11\ g} \right| \frac{30.7\ kJ}{1\ mol}$

$= 157\ kJ$

$q = mc\Delta T$

$= (400)(1.06)(150-80)$

$= 29.7\ kJ$

$q_{total} = 42\ kJ + 157\ kJ + 29.7\ kJ = \boxed{229\ kJ}$

③ $H_2O(s)$ →① $H_2O(s)$ →② $H_2O(l)$ →③ $H_2O(l)$ →④ $H_2O(g)$ →⑤ $H_2O(g)$

−40.0°C → 0°C → 0°C → 100°C → 100°C → 250°C

① $q = mc\Delta T$

$= (75g)(2.1)(0 - -40)$

$= 6300\ J = 6.3\ kJ$

② $75g \left| \frac{1\ mol}{18.02g} \right| \frac{6.01\ kJ}{1\ mol}$

$= 25\ kJ$

③ $q = mc\Delta T$

$= (75)(4.184)(100-0)$

$= 31\ kJ$

④ $75g \left| \frac{1\ mol}{18.02g} \right| \frac{40.7\ kJ}{1\ mol}$

$= 170\ kJ$

⑤ $q = mc\Delta T$

$= (75)(2.0)(250-100)$

$= 23\ kJ$

$q_{total} = 6.3\ kJ + 25\ kJ + 31\ kJ + 170\ kJ + 23\ kJ = 255 \boxed{= 260\ kJ}$

④ Boiling the H_2O

Molar heat combo

① $H_2O(s)$ →① $H_2O(l)$ →② $H_2O(l)$ →③ $H_2O(g)$

0°C 0°C 100°C 150.0°C

① 33.30g | 1 mol / 18.02g | 6.01 kJ / 1 mol = 11.1 kJ

② $q = mc\Delta T$ = (33.30)(4.184)(100 − 0) = 13.9 kJ

③ 33.30g | 1 mol / 18.02g | 40.7 kJ / 1 mol = 75.2 kJ

q_{tot} = 11.1 kJ + 13.9 kJ + 75.2 kJ = **103.6 kJ**

② $H_2O(g)$ →① $H_2O(l)$ →② $H_2O(l)$ →③ $H_2O(s)$ →④ $H_2O(s)$

100°C 100°C 0°C 0°C −15.0°C

① 105.0g | 1 mol / 18.02g | −40.7 kJ / 1 mol = −237 kJ

② 105.0g = 5.83 mol
$q = mc\Delta T$ = (5.83)(75.4)(0 − 100) = −43.9 kJ

③ 5.83 mol | −6.01 kJ / 1 mol = −35.0 kJ

④ $q = mc\Delta T$ = (5.83)(36.4)(−15 − 0) = −3.18 kJ

q_{tot} = −237 − 43.9 − 35.0 − 3.18 = **−319 kJ**

Heating curve

① a) fusion (melting)
b) vaporization (boiling)
c) deposition
d) sublimation
e) solidification (freezing)
f) condensation

② freezing pt

③ boiling pt

④ see graph

⑤ a) −30°C
b) 40°C
c) X
d) Y
e) Z

⑥ both steam & H_2O are at 100°C. when steam condenses on skin, it releases heat as $H_2O(g) \rightarrow H_2O(l)$ in addition to heat from 100°C H_2O

Calorimetry ① $4.184\ J/g°C$

② ice gains energy from air
air loses energy

③ $m_h = 100.\ g$ | $-q_h = q_c$
$T_{ih} = 80.°C$ | $-m_h c_h \Delta T_h = m_c c_c \Delta T_c$
$m_c = 100.\ g$ | $-\Delta T_h = \Delta T_c$
$T_{ic} = 20°C$ | $-(T_f - T_{ih}) = T_f - T_{ic}$
$T_f = ?$ | $-T_f + 80 = T_f - 20$ | $T_f = 50.°C$

④ $m_h = 100.\ g$ | $-q_h = q_c$
$T_{ih} = 80°C$ | $-m_h c_h \Delta T_h = m_c c_c \Delta T_c$
$m_c = 50.\ g$ | $-(100.g)(T_f - 80.) = (50.)(T_f - 20.)$
$T_{ic} = 20.°C$ | $-2(T_f - 80) = (T_f - 20)$
$T_f = ?$ | $180 = 3T_f$ | $T_f = 60.°C$

⑤ $m_m = 25g$ | $-q_m = q_w$
$T_{im} = 97°C$ | $-m_m c_m \Delta T_m = m_w c_w \Delta T_w$
$m_w = 35g$ | $-(25g)(c_m)(22-97) = (35)(4.184)(22-19)$
$T_{iw} = 19°C$ | $c_m = .2\ J/g°C$
$T_f = 22°C$
$c_m = ?$

⑥ $m_m = 75g$ | $-q_m = q_w$
$T_{im} = 100.°C$ | $-m_m c_m \Delta T_m = m_w c_w \Delta T_w$
$m_w = 50.\ g$ | $-(75)(c_m)(30-100) = (50)(4.184)(30-22)$
$T_{iw} = 22°C$ | $c_m = .3\ J/g°C$
$T_f = 30.°$
$c_m = ?$

(7) $m_{cu} = 120\,g$
$C_{cu} = .385\,J/g°C$
$T_{i\,cu} = 75°C$
$m_w = 20.\,g$
$T_{iw} = 10°C$
$T_f = ?$

$-(120)(.385)(T_f - 75) = (20)(4.184)(T_f - 10)$
$-46(T_f - 75) = 84(T_f - 10)$
$3500 - 46T_f = 84T_f - 840$
$4300 = 130\,T_f$
$\boxed{T_f = 33°C}$

(8) $m_w = 100.\,g$
$T_{iw} = 22°C$
$m_i = 20.\,g$
$T_f = 6°C$
$\Delta H_{fus} = ?$

$-q_w = q_{ice}$
$-m_w C_w \Delta T = q_{ice}$
$-(100.)(4.184)(6 - 22)$
$\frac{6700\ J}{20.\,g} = q_{ice}$
$330\,J/g$

(9) $M_w = 200.\,g$
$T_{iw} = 22°C$
$m_i = 15\,g$
$\Delta H_{fus} = 333\,J/g$

$-q_w = q_{ice}$
$-m_w C_w \Delta T_w = 15\,g \times \frac{333\,J}{1\,g}$
$-(200)(4.184)(T_f - 22) = 5.00 \cdot 10^3\,J$
$\boxed{T_f = 16°C}$

(10) $m_{Ag} = 50.\,g$
$T_{i\,Ag} = 99.8°C$
$m_i = 3.54\,g$
$T_{f\,Ag} = 0°C$
$C_{Ag} = ?$

$-q_{Ag} = q_{ice}$
$-m_{Ag} C_{Ag} \Delta T_{Ag} = 3.54\,g \times \frac{333\,J}{1\,g}$
$-(50.)(C_{Ag})(0 - 99.8) = 1180\,J$
$\boxed{C_{Ag} = .24\,J/g°C}$

(11) $m_{Pt} = 9.36\,g$
$T_{i\,Pt} = 98.6°C$
$T_{f\,Pt} = 0°C$
$m_{ice} = .37\,g$
$C_{Pt} = ?$

$-m_{Pt} C_{Pt} \Delta T_{Pt} = .37\,g \times \frac{333\,J}{1\,g}$
$-(9.36)(C_{Pt})(0 - 98.6) = 120\,J$
$\boxed{C_{Pt} = .13\,J/g°C}$

(12) A) exo
b) endo
c) exo
d) exo
e) exo
f) endo

Enthalpy (1) $\frac{-16.7\ kJ}{1.0g\ Mg} \cdot \frac{24.31g}{1\ mol}$ = **-410 kJ/mol**

(2) $\frac{-3.57\ kJ}{3.0g\ (NH_4)_2Cr_2O_7} \cdot \frac{252.08g}{1\ mol}$ = **-300. kJ/mol**

(3) $m_{Na} = 5.0g$
$m_w = 100.g$
$T_{i\,w} = 20.°C$
$T_f = 27$

$q = mc\Delta T$
$= (105g)(4.184\ J/g°C)(27-20°C)$
$= \frac{3075J}{5.0g} \cdot \frac{22.99g}{1\ mol}$ = **-14 kJ**

heat gained by H_2O is released by Na

(4) $m_{Ca} = 2.0g$
75mL 2.0M HCl - excess
$T_{i\,HCl} = 18°C$
$T_f = 23°C$

$q = mc\Delta T$
$= (77g)(4.18\ J/g°C)(23°C - 18°C)$
$= \frac{1609J}{2.0g} \cdot \frac{40.08g}{1\ mol}$ = **-32. kJ/mol**

(5) 20.g $NaNO_3$
200. g H_2O
$T_i = 22°C$
$T_f = 12°C$

$q = mc\Delta T$
$= (220g)(4.184\ J/g°C)(12°C - 22°C)$
$= \frac{-9205J}{20g} \cdot \frac{85g}{1\ mol}$ = 39000 = **+40 kJ/mol**

Bond energies

(1) $CO + Cl_2 \rightarrow Cl_2CO$

$:C \equiv O:$ $\quad$ $Cl-Cl$ $\rightarrow$ $Cl_2C{=}O$ (Cl–C(=O)–Cl)

1072 $\quad$ 242 $\quad\quad$ $2 \cdot 328 + 799$

* used #s from Bond energy activity

$\Delta H = \Sigma$ bonds breaking $- \Sigma$ bonds forming

$= (1072 + 242) - (2 \cdot 328 + 799) = \boxed{-141 \text{ kJ/mol}}$

* slightly diff C≡O from other key

(2) $O_2 + 2H_2 \rightarrow 2H_2O$

$O=O + 2\ H-H \rightarrow 2\ H-O-H$

495 $\quad$ $2 \cdot 436$ $\rightarrow$ $2 \cdot 2 \cdot 463$

$\Delta H = (495 + 2 \cdot 436) - (2 \cdot 2 \cdot 463) = \boxed{-485 \text{ kJ/mol}}$

(3) $OF_2 + H_2O \rightarrow O_2 + 2HF$ $\quad$ $\Delta H_{rxn} = -318$ kJ

$F-O-F + H-O-H \rightarrow O=O + 2\ H-F$

$2 \cdot O-F$ $\quad$ $2 \cdot 463$ $\quad$ 495 $\quad$ $2 \cdot 567$

$-318 = (2 \cdot O\text{-}F + 2 \cdot 463) - (495 + 2 \cdot 567)$

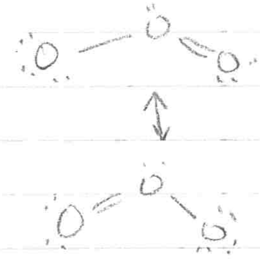
$O-F = \boxed{193 \text{ kJ/mol}}$

(4) a) $O_3 + O \rightarrow 2\ O_2$ $\quad$ $\Delta H_{rxn} = -394$ kJ

$O-O=O \quad O \rightarrow 2\ O=O$

(see explanation at right) $\quad$ $2 \cdot 495$

BUT O_3 has resonance



therefore O_3 bond is between single + double

b) $-394 = (2 \cdot O\text{⋯}O) - (2 \cdot 495)$

each O⋯O is $\boxed{298 \text{ kJ/mol}}$

c) 1.5 (between single + double)

d) O⋯O $\quad$ O−O $\quad$ O=O

298 kJ/mol $\quad$ 146 kJ/mol $\quad$ 495 kJ/mol

O⋯O bond energy in O_3 is between O−O + O=O

a 1.5 bond order is stronger than single but weaker than O=O

Hess's law

①

$\frac{1}{2}(2H_2O \rightarrow 2H_2 + O_2)$ — $\Delta H = +572\ kJ \cdot \frac{1}{2}$ — Reverse $\times \frac{1}{2}$

$2HNO_3 \rightarrow N_2O_5 + H_2O$ — $\Delta H = +74\ kJ$ — Reverse

$2(\frac{1}{2}N_2 + \frac{3}{2}O_2 + \frac{1}{2}H_2 \rightarrow HNO_3)$ — $\Delta H = -174\ kJ \cdot 2$ — $\times 2$

$N_2 + \frac{5}{2}O_2 \rightarrow N_2O_5$ — $\boxed{\Delta H_{rxn} = 12\ kJ}$

②

$\frac{1}{2}(N_2 + 3H_2 \rightarrow 2NH_3)$ — $\Delta H = -92 \cdot \frac{1}{2}$ — $\times \frac{1}{2}$

$\frac{1}{4}(4NH_3 + 5O_2 \rightarrow 4NO + 6H_2O)$ — $\Delta H = -906 \cdot \frac{1}{4}$ — $\times \frac{1}{4}$

$\frac{3}{2}(H_2O \rightarrow H_2 + \frac{1}{2}O_2)$ — $\Delta H = +242 \cdot \frac{3}{2}$ — Reverse $\times 3/2$

$\frac{1}{2}N_2 + \frac{1}{2}O_2 \rightarrow NO$ — $\Delta H = 90.5 = \boxed{91\ kJ}$

③

$Sr + \frac{1}{2}O_2 \rightarrow SrO$ — $\Delta H = -592$ — no changes

$SrO + CO_2 \rightarrow SrCO_3$ — $\Delta H = -234$

$C + O_2 \rightarrow CO_2$ — $\Delta H = -394$

$Sr + C + \frac{3}{2}O_2 \rightarrow SrCO_3$ — $\boxed{\Delta H = -1220\ kJ}$

④

$CH_4 \rightarrow C + 2H_2$ — $\Delta H = +75\ kJ$ — Reverse

$C + 2Cl_2 \rightarrow CCl_4$ — $\Delta H = -96$

$2(H_2 + Cl_2 \rightarrow 2HCl)$ — $\Delta H = -92 \cdot 2$ — $\times 2$

$CH_4 + 4Cl_2 \rightarrow CCl_4 + 4HCl$ — $\boxed{\Delta H = -205\ kJ}$

⑤

$5CO_2 + 6H_2O \rightarrow C_5H_{12} + 8O_2$ — $\Delta H = +3506$ — Reverse

$5(C + O_2 \rightarrow CO_2)$ — $\Delta H = -394 \cdot 5$

$3(2H_2 + O_2 \rightarrow 2H_2O)$ — $\Delta H = -484 \cdot 3$

$5C + 6H_2 \rightarrow C_5H_{12}$ — $\boxed{\Delta H = 84\ kJ}$

ΔH_f°

① a) $2Al + \frac{3}{2}O_2 \rightarrow Al_2O_3$ — $\Delta H_f^\circ = -1669.8\ kJ/mol$

b) $Mg + O_2 + H_2 \rightarrow Mg(OH)_2$ — $\Delta H_f^\circ = -942.7\ kJ/mol$

c) $12C + 11H_2 + \frac{11}{2}O_2 \rightarrow C_{12}H_{22}O_{11}$ — $\Delta H_f^\circ = -2221.2\ kJ/mol$ *

d) $Na + \frac{1}{2}H_2 + C + \frac{3}{2}O_2 \rightarrow NaHCO_3$ — $\Delta H_f^\circ = -947.7\ kJ/mol$

* webbook.nist.gov

other values found in Appendix C in book

(2) a) $SO_2 + \frac{1}{2} O_2 \rightarrow SO_3$

-296.9   0   -395.2

$\Delta H^o_{Rxn} = \Sigma \Delta H^o_f \text{ products} - \Sigma \Delta H^o_f \text{ Reactants}$

$= (-395.2) - (-296.9) = \boxed{-98.3 \text{ kJ/mol}}$

b) $4 NH_3 + 5 O_2 \rightarrow 4 NO + 6 H_2O$

-80.29   0   90.37   -241.82

$\Delta H^o_{Rxn} = [4(90.37) + 6(-241.82)] - [4(-80.29)] = \boxed{-768.3 \text{ kJ/mol}}$ *

* other key has much different value for NO

c) $NH_4NO_3 \rightarrow N_2O + 2 H_2O$

-365.6   81.6   -241.82

$\Delta H^o_{Rxn} = [81.6 + 2(-241.82)] - [-365.6] = \boxed{-36.4 \text{ kJ/mol}}$

(3) $C_3H_5(NO_3)_3 \rightarrow \frac{3}{2} N_2 + \frac{1}{4} O_2 + 3 CO_2 + \frac{5}{2} H_2O$ $\Delta H = -4200$ kJ

0   0   -393.5   -241.82

$\Delta H^o_{Rxn} = -4200 \text{ kJ} = [3(-393.5) + \frac{5}{2}(-241.82)] - [H^o_{f\ nitrog.}]$

$\Delta H^o_{f\ nitrog} = \boxed{2415.0 \text{ kJ/mol}}$

(4) $OF_2 + H_2O \rightarrow 2HF + O_2$ $\Delta H^o_{Rxn} = -318$ kJ

-241.82   -268.61   0

$\Delta H^o_{Rxn} = -318 \text{ kJ} = [2(-268.61)] - [\Delta H^o_{f\ OF_2} + (-241.82)]$ *

$\Delta H^o_{f\ OF_2} = \boxed{23 \text{ kJ/mol}}$ * slightly different in other key

(5) $SO_2 + 2 H_2O(g) + Br_2(g) \rightarrow H_2SO_4(l) + 2 HBr$

-296.9   -241.82   30.71   -814.0   -36.23 $\Delta H^o_{Rxn} = -136.6$ kJ/mol

$H_2SO_4(l) \longrightarrow H_2O(g) + SO_2 + \frac{1}{2} O_2$

-814.0   -241.82   -296.9   0 $\Delta H^o_{Rxn} = 275.3$ kJ/mol

$2HBr \longrightarrow H_2 + Br_2(g)$

-36.23   0   30.71 $\Delta H^o_{Rxn} = 103.17$ kJ/mol

~~SO2~~ + $\frac{1}{2} H_2O$ + ~~Br2~~ → ~~H2SO4~~ + ~~2HBr~~

~~H2SO4~~ → ~~H2O~~ + ~~SO2~~ + $\frac{1}{2} O_2$

2 ~~HBr~~ → H_2 + ~~Br2~~

$H_2O \rightarrow H_2 + \frac{1}{2} O_2$ endo $\Delta H^o_{Rxn} = \boxed{241.9 \text{ kJ/mol}}$

or (−) $\Delta H^o_f\ H_2O(g)$

(10)