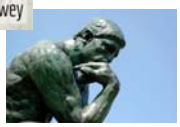
Reflection



After Action Report

What did I learn from this HW assignment?

Professional Program Application

- Meet with you advisor
  - Tan form
  - Pink Form
  - Excel course planning worksheet

Note: Any Bio class that satisfies GE can be used, not just Bio 100

- Due November 17!
  - Professors cannot do this all on the last day, so start early!!
- Application required before you can get an add code for ChEn 374 (Fluids)

Class 28

Enthalpies,
Heat Capacities
Heats of Formation,
Oh My!

Review of Energy Balances

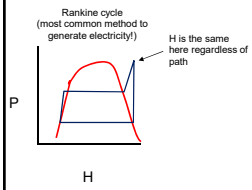
$$\Delta\dot{H} + \Delta\dot{E}_K + \Delta\dot{E}_P = \dot{Q} + \dot{W}_s$$

- Enthalpies needed to calculate heat or work terms
- Methods to calculate enthalpy (so far):
  - Steam tables
  - Graph (P-H diagram)
  - Interpolation from 2 given values
- Needed: Method to get enthalpies for any species as a function of T & P

Concepts

1. Enthalpy is a state function
2. Heat Capacities
3. Latent Heats (phase change)
4. Heat of Formation
5. Calculating ΔH as *f*(T,P)

Concept 1.
Enthalpy Is A State Function



- Enthalpy is independent of path
- Always talk about ΔH from some reference condition
  - Steam tables:
    $\hat{H} = 0$ at triple point
  - Other tables are different (e.g., in Table B.1, $\Delta\hat{H}_f^o$ for H_2 = 0 at 25°C)
  - Don't mix and match tables!!!

Concept 2.
Heat Capacities

- $\hat{H} = f(T,P)$ $\quad d\hat{H} = \left(\frac{\partial \hat{H}}{\partial T}\right)_P dT + \left(\frac{\partial \hat{H}}{\partial P}\right)_T dP$ Generally small
- $\hat{U} = f(T,\hat{V})$ $\quad d\hat{U} = \left(\frac{\partial \hat{U}}{\partial T}\right)_V dT + \left(\frac{\partial \hat{U}}{\partial \hat{V}}\right)_T d\hat{V}$
- Now define heat capacities:

$$C_P = \left(\frac{\partial \hat{H}}{\partial T}\right)_P, \quad C_V = \left(\frac{\partial \hat{U}}{\partial T}\right)_V$$

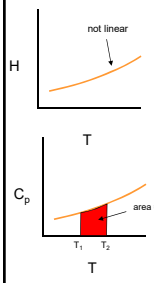
- For ideal gases:

$$d\hat{H} \equiv C_P dT, \qquad d\hat{U} \equiv C_V dT$$

- For solids and liquids:

$$d\hat{H} = C_P dT + \hat{V} dP$$

Concept 2.
Heat Capacities (cont.)



- $C_P = \left(\frac{\partial \hat{H}}{\partial T}\right)_P$ (like slope of H vs T curve, prob 7.51)
- $\Delta\hat{H} = \int_{T_1}^{T_2} C_P \, dT$
- $C_P = a + bT + cT^2 + dT^3 + \cdots$
- so

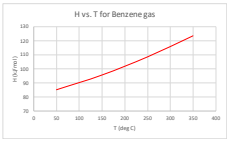
$$\Delta\hat{H}_{T_1 \to T_2} = \int_{T_1}^{T_2} (a + bT + cT^2 + dT^3)\, dT$$

$$= a(T_2 - T_1) + \frac{b}{2}({T_2}^2 - {T_1}^2) + \frac{c}{3}({T_2}^3 - {T_1}^3) + \frac{d}{4}({T_2}^4 - {T_1}^4)$$

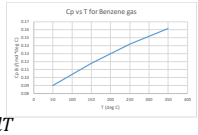
- For ideal gases: $C_p = C_v + R$
- For solids and liquids, $C_P \cong C_V$

A Practical View

- Wouldn't it be nice to have a polynomial equation for H!
- $H = a + bT + cT^2$



- This would not work for different reference enthalpies!
- Solution: Polynomial for C_p
  - $C_P = a + bT + cT^2 + dT^3$ (= dH/dT)
  - Fit to thermodynamic data
  - $\Delta\hat{H}_{T_1 \to T_2} = \int_{T_1}^{T_2} (a + bT + cT^2 + dT^3)\, dT$



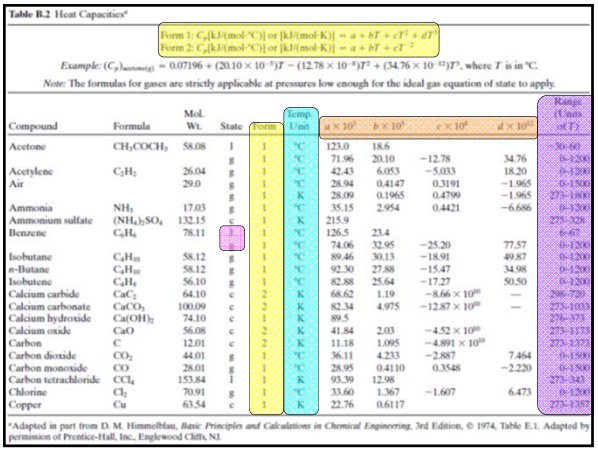


Table B.2 Heat Capacities[a]

Form 1: C_p[kJ/(mol·°C)] or [kJ/(mol·K)] $= a + bT + cT^2 + dT^3$
Form 2: C_p[kJ/(mol·°C)] or [kJ/(mol·K)] $= a + bT + cT^{-2}$

Example: $(C_p)_{\text{acetone}(g)} = 0.07196 + (20.10 \times 10^{-3})T - (12.78 \times 10^{-6})T^2 + (34.76 \times 10^{-12})T^3$, where T is in °C.

Note: The formulas for gases are strictly applicable at pressures low enough for the ideal gas equation of state to apply.

Compound	Formula	Mol. Wt.	State	Form	Temp. Unit	$a \times 10^{3}$	$b \times 10^{5}$	$c \times 10^{6}$	$d \times 10^{9}$	Range (Units of T)
Acetone	CH_3COCH_3	58.08	l	1	°C	123.0	18.6			30-60
			g	1	°C	71.96	20.10	−12.78	34.76	0-1200
Acetylene	C_2H_2	26.04	g	1	°C	42.43	6.053	−5.033	18.20	0-1200
Air		29.0	g	1	°C	28.94	0.4147	0.3191	−1.965	0-1500
			g	1	K	28.09	0.1965	0.4799	−1.965	273-1800
Ammonia	NH_3	17.03	g	1	°C	35.15	2.954	0.4421	−6.686	0-1200
Ammonium sulfate	$(NH_4)_2SO_4$	132.15	c	1	K	215.9				275-328
Benzene	C_6H_6	78.11	l	1	°C	126.5	23.4			7-67
			g	1	°C	74.06	32.95	−25.20	77.57	0-1200
Isobutane	C_4H_{10}	58.12	g	1	°C	89.46	30.13	−18.91	49.87	0-1200
n-Butane	C_4H_{10}	58.12	g	1	°C	92.30	27.88	−15.47	34.98	0-1200
Isobutene	C_4H_8	56.10	g	1	°C	82.88	25.64	−17.27	50.50	0-1200
Calcium carbide	CaC_2	64.10	c	2	K	68.62	1.19	-8.66×10^{10}	—	298-720
Calcium carbonate	$CaCO_3$	100.09	c	2	K	82.34	4.975	-12.87×10^{10}	—	273-1033
Calcium hydroxide	$Ca(OH)_2$	74.10	c	1	K	89.5				276-373
Calcium oxide	CaO	56.08	c	2	K	41.84	2.03	-4.52×10^{10}		273-1173
Carbon	C	12.01	c	2	K	11.18	1.095	-4.891×10^{10}		273-1373
Carbon dioxide	CO_2	44.01	g	1	°C	36.11	4.233	−2.887	7.464	0-1500
Carbon monoxide	CO	28.01	g	1	°C	28.95	0.4110	0.3548	−2.220	0-1500
Carbon tetrachloride	CCl_4	153.84	l	1	K	93.39	12.98			273-343
Chlorine	Cl_2	70.91	g	1	°C	33.60	1.367	−1.607	6.473	0-1200
Copper	Cu	63.54	c	1	K	22.76	0.6117			273-1357

[a]Adapted in part from D. M. Himmelblau, *Basic Principles and Calculations in Chemical Engineering*, 3rd Edition, © 1974, Table E.1. Adapted by permission of Prentice-Hall, Inc., Englewood Cliffs, NJ.

Caution!

- When getting a heat capacity coefficient from Table B.2, use the multiplier at the top of the column
- Example: Acetone
  - a = 123
  - multiplier = 10^3
    (i.e., the actual number was multiplied by 10^3 to make it look nicer in the table)
  - Therefore, **a = 123 × 10^{-3} kJ/(gmol·K)**

DIPPR Format

$$C_p = A + B\left[\frac{C/T}{\sinh(C/T)}\right]^2 + D\left[\frac{E/T}{\cosh(E/T)}\right]^2$$

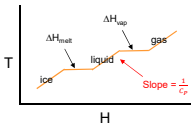
Integrated form:

$$\int_{T_1}^{T_2} C_p\, dT = A[T_2 - T_1] + BC\left[\coth\left(\frac{C}{T_2}\right) - \coth\left(\frac{C}{T_1}\right)\right] - DE\left[\tanh\left(\frac{E}{T_2}\right) - \tanh\left(\frac{E}{T_1}\right)\right]$$

Concepts

1. Enthalpy is a state function
2. Heat Capacities
3. Latent Heats (phase change)
4. Heat of Formation
5. Calculating ΔH as *f*(T,P)

Concept 3.
Phase Changes (pure substances)



$\Delta\hat{H}_{melt} = \hat{H}_{liq} - \hat{H}_{solid}$ (tabulated)

$\Delta\hat{H}_{vap} = \hat{H}_{gas} - \hat{H}_{liq}$ (tabulated)

$\Delta\hat{H}_{freezing} = -\Delta\hat{H}_{melt}$

$\Delta\hat{H}_{condens} = -\Delta\hat{H}_{vap}$

Also we could find $\Delta\hat{H}_{sub}$

Remember that for a pure substance, T is constant during a phase change

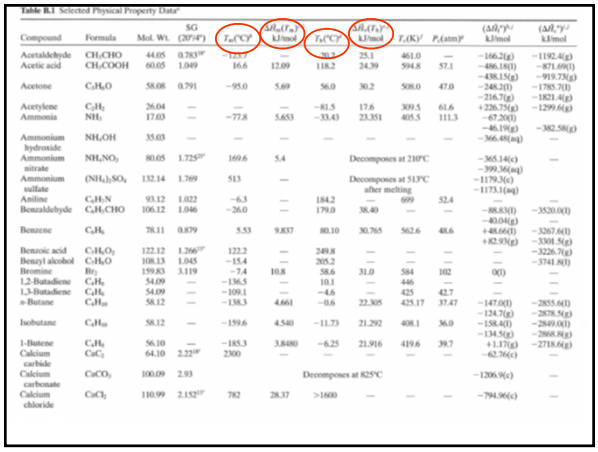
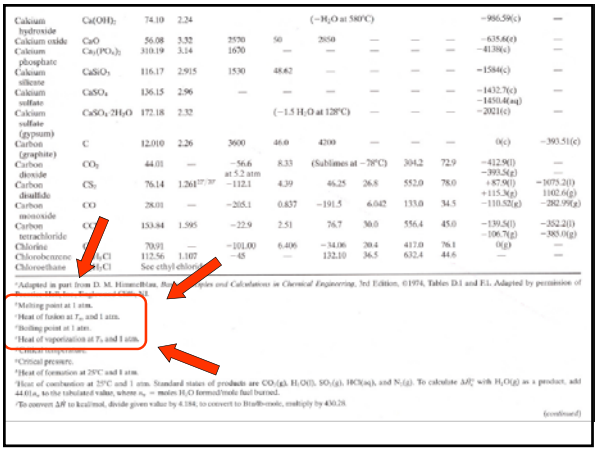


Table B.1 Selected Physical Property Data[a]

Compound	Formula	Mol. Wt.	SG (20°/4°)	T_m(°C)[b]	$\Delta\hat{H}_m(T_m)$ kJ/mol	T_b(°C)[c]	$\Delta\hat{H}_v(T_b)$ kJ/mol	T_c(K)[d]	P_c(atm)[e]	$(\Delta\hat{H}_f^\circ)$ kJ/mol	$(\Delta\hat{G}_f^\circ)$ kJ/mol
Acetaldehyde	CH_3CHO	44.05	0.783[18°]	−123.5	—	20.2	25.1	461.0	—	−166.2(g)	−1192.4(g)
Acetic acid	CH_3COOH	60.05	1.049	16.6	12.09	118.2	24.39	594.8	57.1	−486.18(l)	−871.69(l)
										−438.15(g)	−919.73(g)
Acetone	C_3H_6O	58.08	0.791	−95.0	5.69	56.0	30.2	508.0	47.0	−248.2(l)	−1785.7(l)
										−216.7(g)	−1821.4(g)
Acetylene	C_2H_2	26.04	—	—	—	−81.5	17.6	309.5	61.6	+226.75(g)	−1299.6(g)
Ammonia	NH_3	17.03	—	−77.8	5.653	−33.43	23.351	405.5	111.3	−67.20(l)	
										−46.19(g)	−382.58(g)
Ammonium hydroxide	NH_4OH	35.03	—	—	—	—	—	—	—	−366.48(aq)	—
Ammonium nitrate	NH_4NO_3	80.05	1.725[20°]	169.6	5.4	Decomposes at 210°C				−365.14(c)	—
										−399.36(aq)	
Ammonium sulfate	$(NH_4)_2SO_4$	132.14	1.769	513	—	Decomposes at 513°C after melting				−1179.3(c)	
										−1173.1(aq)	
Aniline	C_6H_7N	93.12	1.022	−6.3	—	184.2	—	699	52.4	—	—
Benzaldehyde	C_6H_5CHO	106.12	1.046	−26.0	—	179.0	38.40	—	—	−88.83(l)	−3520.0(l)
										−40.04(g)	—
Benzene	C_6H_6	78.11	0.879	5.53	9.837	80.10	30.765	562.6	48.6	+48.66(l)	−3267.6(l)
										+82.93(g)	−3301.5(g)
Benzoic acid	$C_7H_6O_2$	122.12	1.266[15°]	122.2	—	249.8	—	—	—	—	−3226.7(g)
Benzyl alcohol	C_7H_8O	108.13	1.045	−15.4	—	205.2	—	—	—	—	−3741.8(l)
Bromine	Br_2	159.83	3.119	−7.4	10.8	58.6	31.0	584	102	0(l)	—
1,2-Butadiene	C_4H_6	54.09	—	−136.5	—	10.1	—	446	—	—	—
1,3-Butadiene	C_4H_6	54.09	—	−109.1	—	−4.6	—	425	42.7	—	—
n-Butane	C_4H_{10}	58.12	—	−138.3	4.661	−0.6	22.305	425.17	37.47	−147.0(l)	−2855.6(l)
										−124.7(g)	−2878.5(g)
Isobutane	C_4H_{10}	58.12	—	−159.6	4.540	−11.73	21.292	408.1	36.0	−158.4(l)	−2849.0(l)
										−134.5(g)	−2868.8(g)
1-Butene	C_4H_8	56.10	—	−185.3	3.8480	−6.25	21.916	419.6	39.7	+1.17(g)	−2718.6(g)
Calcium carbide	CaC_2	64.10	2.22[18°]	2300	—	—	—	—	—	−62.76(c)	—
Calcium carbonate	$CaCO_3$	100.09	2.93			Decomposes at 825°C				−1206.9(c)	—
Calcium chloride	$CaCl_2$	110.99	2.152[15°]	782	28.37	>1600	—	—	—	−794.96(c)	—


Calcium hydroxide $Ca(OH)_2$ 74.10 2.24 (−H_2O at 580°C) −986.59(c)

Calcium oxide CaO 56.08 3.32 2570 50 2850 −635.6(c)

Calcium phosphate $Ca_3(PO_4)_2$ 310.19 3.14 1670 −4138(c)

Calcium silicate $CaSiO_3$ 116.17 2.915 1530 48.62 −1584(c)

Calcium sulfate $CaSO_4$ 136.15 2.96 −1432.7(c) −1450.4(aq)

Calcium sulfate (gypsum) $CaSO_4 \cdot 2H_2O$ 172.18 2.32 (−1.5 H_2O at 128°C) −2021(c)

Carbon (graphite) C 12.010 2.26 3600 46.0 4200 0(c) −393.51(c)

Carbon dioxide CO_2 44.01 −56.6 at 5.2 atm 8.33 (Sublimes at −78°C) 304.2 72.9 −412.9(l) −393.5(g)

Carbon disulfide CS_2 76.14 1.261[17.3°] −112.1 4.39 46.25 26.8 552.0 78.0 +87.9(l) +115.3(g) −1075.2(l) 1102.6(g)

Carbon monoxide CO 28.01 −205.1 0.837 −191.5 6.042 133.0 34.5 −110.52(g) −282.99(g)

Carbon tetrachloride CCl_4 153.84 1.595 −22.9 2.51 76.7 30.0 556.4 45.0 −139.5(l) −106.7(g) −352.2(l) −385.0(g)

Chloroform $CHCl_3$ 70.91 — −101.00 6.406 −34.06 20.4 417.0 76.1 0(g)

Chlorobenzene C_6H_5Cl 112.56 1.107 −45 — 132.10 36.5 632.4 44.6 — —

Chloroethane C_2H_5Cl See ethyl chloride

[a] Adapted in part from D. M. Himmelblau, *Basic Principles and Calculations in Chemical Engineering*, 3rd Edition, ©1974, Tables D.1 and F.1. Adapted by permission of

[b] Melting point at 1 atm.

[c] Heat of fusion at T_m and 1 atm.

[d] Boiling point at 1 atm.

[e] Heat of vaporization at T_b and 1 atm.

[f] Critical pressure.

[g] Critical temperature.

[h] Heat of formation at 25°C and 1 atm.

[i] Heat of combustion at 25°C and 1 atm. Standard states of products are CO_2(g), H_2O(l), SO_2(g), HCl(aq), and N_2(g). To calculate $\Delta\hat{H}_f^\circ$ with H_2O(g) as a product, add 44.01n_w, to the tabulated value, where n_w = moles H_2O formed/mole fuel burned.

[j] To convert $\Delta\hat{H}$ to kcal/mol, divide given value by 4.184, to convert to Btu/lb-mole, multiply by 430.28.

(continued)

Table B.10 Atomic Heat Capacities for Kopp's Rule[a]

Element	C_{pa}[J/(g-atom·°C)] Solids	Liquids
C	7.5	12
H	9.6	18
B	11	20
Si	16	24
O	17	25
F	21	29
P	23	31
S	26	31
All Others	26	33

[a] D. M. Himmelblau, *Basic Principles and Calculations in Chemical Engineering*, 3rd Edition, Prentice-Hall, Englewood Cliffs, NJ, 1974, p. 270.

Kopp's Rule:

$$C_p = \sum_{k=element} \nu_k C_{p,k}$$

where ν_k = moles of element *k* in molecule

So for solid phenol, C_6H_5OH,

$\nu_C = 6$

$\nu_H = 6$

$\nu_O = 1$

$C_p = 6*7.5 + 6*9.6 + 17 = 119.6$ J/(mol·°C)

(Dippr = 129 J/(mol·°C) at 25°C)

Only use this out of desperation!

Other Estimation Formulas

- Trouton's rule (8.4-3)
  $\Delta H_v = f(T_b)$
- Chen's equation (8.4-4)
  $\Delta H_v = f(T_b, T_c, P_c)$
- Clapeyron equation (8.4-7)
  $\Delta H_v = f(P^*)$
- Watson's correlation (8.4-8)
  ΔH_v vs. T using T_c

Only use these equations out of desperation!

Simplifications

- Sometimes we get lazy and assume an average heat capacity for some temperature range

$$\hat{H}_2 - \hat{H}_1 = \overline{C_P}(T_2 - T_1)$$

- We will use this on exams!
  - I am not testing you on integration skills

Concepts

1. Enthalpy is a state function
2. Heat Capacities
3. Latent Heats (phase change)
4. Heat of Formation
5. Calculating ΔH as *f*(T,P)

Concept 4.
Heat of Formation

- Wanted: Common reference state for all species!
- Can use $\Delta\hat{H}_f^o$ as a reference at 25°C, 1 atm
- Good for reaction chemistry
- $\Delta\hat{H}_f^o$ = 0 for species whose natural state is 25°C, 1 atm
  - N_2, O_2, H_2, C(graphite)

$$\hat{H}_i = \Delta\hat{H}_{f,i}^o + \int_{25°C}^{T_2} C_{P,i}\, dT$$

Tabulated in Table B.1

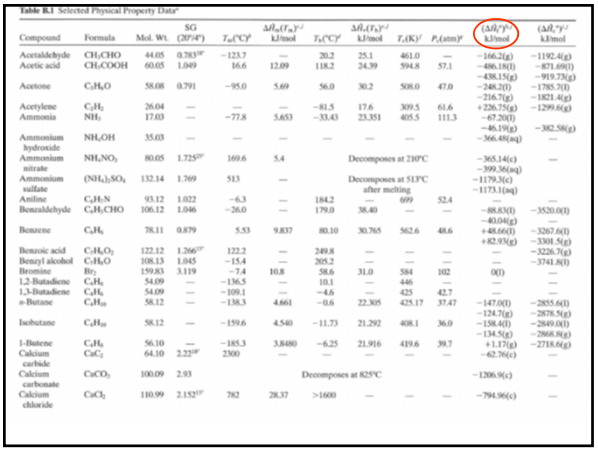


Table B.1 Selected Physical Property Data[a]

Compound	Formula	Mol. Wt.	SG (20°/4°)	T_m(°C)[d]	$\Delta\hat{H}_m(T_m)$[c,d] kJ/mol	T_b(°C)[d]	$\Delta\hat{H}_v(T_b)$[c,d] kJ/mol	T_c(K)[f]	P_c(atm)[g]	$(\Delta\hat{H}_f^o)^o$[h] kJ/mol	$(\Delta\hat{H}_c^o)^o$[i] kJ/mol
Acetaldehyde	CH_3CHO	44.05	0.783[20]	−123.7	—	20.2	25.1	461.0	—	−166.2(g)	−1192.4(g)
Acetic acid	CH_3COOH	60.05	1.049	16.6	12.09	118.2	24.39	594.8	57.1	−486.18(l)	−871.69(l)
										−438.15(g)	−919.73(g)
Acetone	C_3H_6O	58.08	0.791	−95.0	5.69	56.0	30.2	508.0	47.0	−248.2(l)	−1785.7(l)
										−216.7(g)	−1821.4(g)
Acetylene	C_2H_2	26.04	—	—	—	−81.5	17.6	309.5	61.6	+226.75(g)	−1299.6(g)
Ammonia	NH_3	17.03	—	−77.8	5.653	−33.43	23.351	405.5	111.3	−67.20(l)	
										−46.19(g)	−382.58(g)
Ammonium hydroxide	NH_4OH	35.03	—	—	—	—	—	—	—	−366.48(aq)	—
Ammonium nitrate	NH_4NO_3	80.05	1.725[25]	169.6	5.4	Decomposes at 210°C				−365.14(c)	—
										−399.36(aq)	
Ammonium sulfate	$(NH_4)_2SO_4$	132.14	1.769	513	—	Decomposes at 513°C after melting				−1179.3(c)	
										−1173.1(aq)	
Aniline	C_6H_7N	93.12	1.022	−6.3	—	184.2	—	699	52.4	—	—
Benzaldehyde	C_6H_5CHO	106.12	1.046	−26.0	—	179.0	38.40	—	—	−88.83(l)	−3520.0(l)
										−40.04(g)	—
Benzene	C_6H_6	78.11	0.879	5.53	9.837	80.10	30.765	562.6	48.6	+48.66(l)	−3267.6(l)
										+82.93(g)	−3301.5(g)
Benzoic acid	$C_7H_6O_2$	122.12	1.266[15]	122.2	—	249.8	—	—	—	—	−3226.7(g)
Benzyl alcohol	C_7H_8O	108.13	1.045	−15.4	—	205.2	—	—	—	—	−3741.8(l)
Bromine	Br_2	159.83	3.119	−7.4	10.8	58.6	31.0	584	102	0(l)	—
1,2-Butadiene	C_4H_6	54.09	—	−136.5	—	10.1	—	446	—	—	—
1,3-Butadiene	C_4H_6	54.09	—	−109.1	—	−4.6	—	425	42.7	—	—
n-Butane	C_4H_{10}	58.12	—	−138.3	4.661	−0.6	22.305	425.17	37.47	−147.0(l)	−2855.6(l)
										−124.7(g)	−2878.5(g)
Isobutane	C_4H_{10}	58.12	—	−159.6	4.540	−11.73	21.292	408.1	36.0	−158.4(l)	−2849.0(l)
										−134.5(g)	−2868.8(g)
1-Butene	C_4H_8	56.10	—	−185.3	3.8480	−6.25	21.916	419.6	39.7	+1.17(g)	−2718.6(g)
Calcium carbide	CaC_2	64.10	2.22[18]	2300	—	—	—	—	—	−62.76(c)	—
Calcium carbonate	$CaCO_3$	100.09	2.93	Decomposes at 825°C						−1206.9(c)	—
Calcium chloride	$CaCl_2$	110.99	2.152[15]	782	28.37	>1600	—	—	—	−794.96(c)	—

Balances

$$\Delta H_{sys} = H_{out} - H_{in}$$

$$\Delta H_{sys} = \left(\sum n_i \hat{H}_i\right)_{out} - \left(\sum n_i \hat{H}_i\right)_{in}$$

$$\hat{H}_i = \Delta\hat{H}_{f,i}^o + \int_{25°C}^{T_2} C_{P,i}\, dT$$

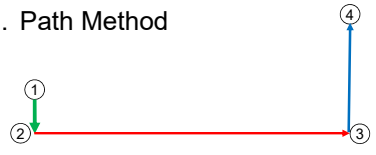
$$\sum n_i \hat{H}_i = \sum n_i \Delta\hat{H}_{f,i}^o + \left(\sum n_i a_i\right)(T - 298) + \left(\sum n_i b_i\right)\frac{T^2 - 298^2}{2} + \left(\sum n_i c_i\right)\frac{T^3 - 298^3}{3} + \cdots$$

where a_i, b_i, and c_i are the heat capacity coefficients for species i

Note that for a chemical reaction, the number of moles of each species (n_i) changes

Two Methods to Get ΔH

1. Path Method



$$H_4 - H_1 = (H_2 - H_1) + (H_3 - H_2) + (H_4 - H_3)$$

2. ΔH_f^0 method

$$\hat{H}_i = \Delta\hat{H}_{f,i}^o + \int_{25°C}^{T_2} C_{P,i}\, dT$$

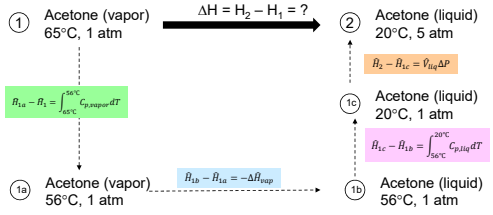
So compute H_4 and H_1 and subtract

Example

Calculate the enthalpy change for acetone going from a vapor at 65°C and 1 atm to a liquid at 20 °C and 5 atm

A. Path method using ΔH_{vap} at 1 atm and $T_{boiling}$
B. Heat of formation method

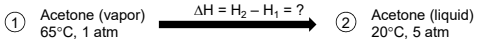
Example: Find ΔH for acetone vapor at 65°C forming a liquid at 20 °C and 5 atm (Path method)



$$\hat{H}_2 - \hat{H}_1 = \Delta\hat{H}_{1a-1} + \Delta\hat{H}_{1b-1a} + \Delta\hat{H}_{1c-1b} + \Delta\hat{H}_{2-1c}$$

$$\hat{H}_2 - \hat{H}_1 = \int_{65°C}^{56°C} C_{p,vapor}\,dT + \left(-\Delta\hat{H}_{vap,56°C}\right) + \int_{56°C}^{20°C} C_{p,liq}\,dT + \hat{V}_{liq}\Delta P$$

Example: Find ΔH for acetone vapor at 65°C forming a liquid at 20 °C and 5 atm (ΔH_f° method)



$$\hat{H}_1 = \Delta H^\circ_{f,vapor} + \int_{25°C}^{65°C} C_{p,vapor}\,dT$$

$$\hat{H}_2 = \Delta H^\circ_{f,liq} + \int_{25°C}^{20°C} C_{p,liq}\,dT + \hat{V}_{liq}\Delta P$$

$$\hat{H}_2 - \hat{H}_1 = \left(\Delta H^\circ_{f,liq} + \int_{25°C}^{20°C} C_{p,liq}\,dT + \hat{V}_{liq}\Delta P\right) - \left(\Delta H^\circ_{f,vapor} + \int_{25°C}^{65°C} C_{p,vapor}\,dT\right)$$

$$\hat{H}_2 - \hat{H}_1 = \Delta H^\circ_{f,liq} - \Delta H^\circ_{f,vapor} + \int_{25°C}^{20°C} C_{p,liq}\,dT + \hat{V}_{liq}\Delta P - \int_{25°C}^{65°C} C_{p,vapor}\,dT$$

$-\Delta H_{vaporization}$ at 25°C

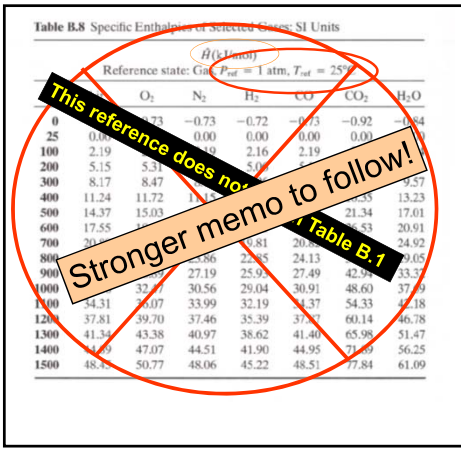
Bottom Line

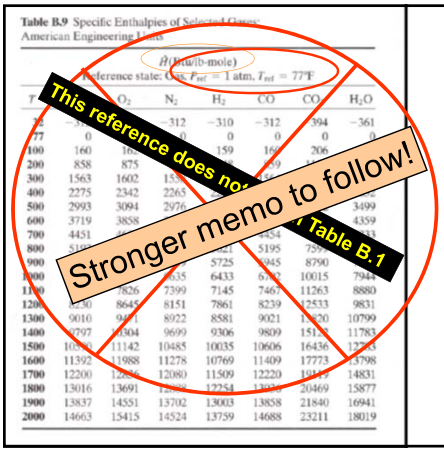
You Should Know Both Methods to Get ΔH

1. Path Method
2. ΔH_f° method

Remember that ΔH is just part of energy balance

$$\Delta\dot{H} + \Delta\dot{E}_K + \Delta\dot{E}_P = \dot{Q} + \dot{W}_s$$





Taboo Equations

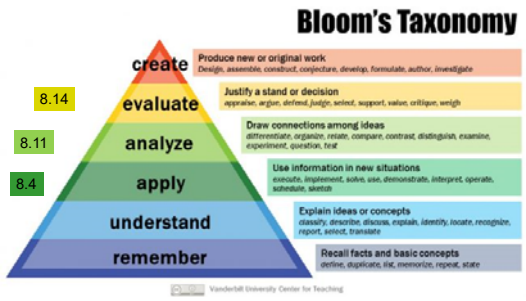
3rd Edition
- Page 451: 9.5-1a and 9.5-1b
- 1st Eqn. on page 457
- Page 463: last equation (under section 5)

- 4th Edition
- Page 506: 9.5-1a and 9.5-1b
- 1st Eqn. on page 511
- Page 519: last equation (under section 5)

Problem Solving (pp. 361-362)

1. Solve material balances (mass or moles)
2. Write energy balance (drop appropriate terms)
3. Choose reference state(s)
4. Table of n_i & H_i in and out (or m_i, U_i, etc.)
5. Find ΔH_{sys} or ΔU_{sys}
6. Find W, W_s, ΔE_k, ΔE_p as needed
7. Solve energy balance

Homework Problems



https://cft.vanderbilt.edu/guides-sub-pages/blooms-taxonomy/

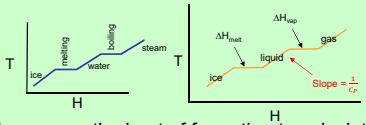
Hint on Prob 8.11

- $\Delta U = \Delta H - \Delta PV$
- PV = nRT

QUIZ

1. What is meant by the statement that "enthalpy is a state function?"
2. What is a heat capacity?
3. For water, draw a graph with temperature on the *y* axis and enthalpy on the *x* axis, starting from ice and proceeding to steam, labeling the different portions of the line.
4. How do you use the heat of formation to calculate enthalpy? (eqn. needed)

1. What is meant by the statement that "enthalpy is a state function?"
   - H is not dependent on T & P path
2. What is a heat capacity?
   - Change in enthalpy with temperature
3. For water, draw a graph with temperature on the *y* axis and enthalpy on the *x* axis, starting from ice and proceeding to steam, labeling the different portions of the line.



1. How do you use the heat of formation to calculate enthalpy?

$$H(at\ T_2) = \Delta H_f^0 + \int_{T_1}^{T_2} C_p dT$$