# Energetics -2025

1. 50 mL of 1 mol dm^{-3} HCl and 50 mL of 1 mol dm^{-3} NaOH was allowed to react inside a polystyrene container which possesses a negligible heat capacity. Calculate the enthalpy change for the reaction for a mol of reaction if the change in the temperature is 6.6 K. Specific heat capacity of the solution is 4.2 J g^{-1} K^{-1}. **(-55.44 kJ mol^{-1})**

2. 15.3 g of a solid NaNO$_3$ was dissolved in water contained in a calorimeter. The temperature dropped from 25.00 ℃ to 21.50 ℃. The heat capacity of the solution and the calorimeter is 1071 J ℃$^{-1}$. Find the enthalpy change of the reaction if 1 mol of solid NaNO$_3$ is dissolved in water. **(+20.805 kJ mol^{-1})**

3. 250 mL of 0.4 mol dm^{-3} NaOH and 250 mL of 0.4 mol dm^{-3} HCl was allowed to react in a calorimeter. If the initial temperature of the initial solution is 17.05 ℃ and the final temperature of the solution is 19.55 ℃ find the enthalpy of neutralisation of the reaction. The mass of the calorimeter is 500 g. The specific heat capacities of the calorimeter and solutions are 400 J kg^{-1} K^{-1} and 4200 J kg^{-1} K^{-1} respectively. **(-57.50 kJ mol^{-1})**

4. Following data was obtained during a reaction to design the heat of combustion of ethanol.

   Volume of water inside the calorimeter = 400 mL
   Temperature of water   = 12 ℃
   Final temperature   = 22 ℃
   Mass of ethanol burned   = 0.92 g
   Specific heat capacity of water = 4.2 J g^{-1} K^{-1}

   (i) Calculate the heat required to increase the temperature of water from 12 ℃ to 22 ℃. (**16.8 kJ**)
   (ii) Calculate heat released when 1 mol of ethanol undergoes combustion. **(-840 kJ mol^{-1})**
   (iii) Standard enthalpy change of ethanol is -1368 kJ mol^{-1}. Explain why there is a significant difference in the experimental and theoretical value.

5. 50 mL of 1.25 mol dm^{-3} HCl and 50 mL of 1.25 mol dm^{-3} KOH was kept at 25 ℃ were allowed to react together inside a calorimeter. Mass of the calorimeter is 200 g and the specific heat capacity is 400 J kg^{-1} K^{-1}. If the temperature increases by 7 ℃ then calculate the standard enthalpy of neutralisation. Specific heat capacity of the solution is 4.2 J g^{-1} K^{-1}. **(-56 kJ mol^{-1})**

6. 20.00 mL of 0.5 mol dm^{-3} H$_2$SO$_4$ was required for the neutralisation of 50.00 mL of 0.4 mol dm^{-3} NaOH. The temperature of the mixture rises by 3.6 ℃. The heat capacity of the calorimeter is 39.0 J K^{-1} and the specific heat capacity of the solution is 4.2 J g^{-1} K^{-1}. Calculate the enthalpy of neutralisation for NaOH in the reaction. **(-59.94 kJ mol^{-1})**

7. (i) Define the standard enthalpy of neutralisation of an acid (ΔH_n°)
   (ii) 100 mL of 0.5 mol dm^{-3} HCl and 100 mL of 0.5 mol dm^{-3} NaOH were mixed in a constant pressure calorimeter with a negligible heat capacity. Initial temperature of the system is 22.5 ℃ and the final temperature rose to 25.86 ℃. If the density of the resulting solution is 1.00 g cm^{-3} and the specific heat capacity is 4.184 J g^{-1} ℃$^{-1}$ calculate the standard enthalpy of neutralisation. **(-56.23 kJ mol^{-1})**

8. Zn powder was added to a polystyrene container having 100 mL of 5 mol dm^{-3} CuSO$_4$ for the complete reduction of Cu^{2+} to Cu.

$$Zn(aq) + Cu^{2+}(aq) \rightarrow Zn^{2+}(aq) + Cu(s)$$
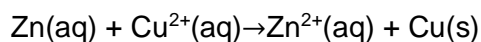
Overall temperature rise is from 18 °C to 42 °C. Calculate the molar enthalpy change for the above reaction. Specific heat capacity of the solution is 4.18 kJ kg^{-1} K^{-1}. **(+20.64 kJ mol^{-1})**

9. Pentaborane (B_5H_9) is a colourless liquid with a high reactivity. It reacts explosively upon mixed with O_2.
$$2B_5H_9(l) + 12\ O_2(g) \rightarrow 5\ B_2O_3(s) + 9H_2O(l)$$
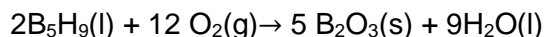
Standard enthalpy of formation of $H_2O(l)$ is -286 kJ mol^{-1}, $B_5H_9(l)$ is +100 kJ mol^{-1} and that of $B_2O_3(s)$ is -1264 kJ mol^{-1}. Calculate the standard enthalpy of combustion of $B_5H_9(l)$ using the equation method. **(-9094 kJ mol^{-1})**
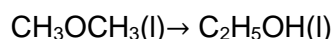
10. (i) Define the standard enthalpy of a reaction.
(ii) Give the definitions and the relevant reactions for the standard enthalpy of combustion and the standard enthalpy of formation.

11. Calculate the standard enthalpy of combustion for hexane (C_6H_{14}) and propane (C_3H_6) using the following data
(a) 84.06 kJ of heat was released when 1.72 g of hexane (C_6H_{14}) is combusted.
(b) 1.1 g of propane (C_3H_6) was combusted, and the temperature of the system was increased by 6.4 K. Heat capacity of the calorimeter and the contents is 8.575 kJ K^{-1}. **(-4203 kJ mol^{-1}, -2195.2 kJ mol^{-1})**

12. Standard enthalpy of formation of $CCl_4(g)$, $H_2O(g)$, $CO_2(g)$ and $HCl(g)$ at 298 K are (-107, -242, -394 and -92) kJ mol^{-1} respectively. Calculate the enthalpy change for the following reaction.

$$CCl_4(g) + 2\ H_2O(g) \rightarrow CO_2(g) + 4\ HCl(g)$$
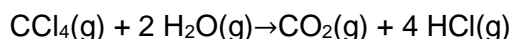
(-171 kJ mol^{-1})

13. (i) Standard enthalpy changes of $C_2H_5OH(l)$ and $CH_3OCH_3(l)$ are -277 kJ mol^{-1} and (-184) kJ mol^{-1} respectively. Calculate the enthalpy change of the reaction given below.

$$CH_3OCH_3(l) \rightarrow C_2H_5OH(l)$$

(-93 kJ mol^{-1})

(ii) Use the data given in the table to calculate the standard enthalpy of the following reaction.

Compound	ΔH_f°/kJ mol^{-1}
$NH_3(g)$	-46
$HBr(g)$	-36
$NH_4Br(s)$	-271

$$NH_3(g) + HBr(g) \rightarrow NH_4Br(s)$$
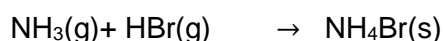
(-189 kJ mol^{-1})

14. (i) Standard enthalpy changes for the formation of ethene $C_2H_2(g)$, $HCl(g)$ and $C_2H_5Cl(g)$ are +52.3, -92.3 and -105 kJ mol^{-1} respectively. Calculate the enthalpy change for the following reaction.

$$H_2C=CH_2(g) + HCl(g) \rightarrow C_2H_5Cl(g)$$

(-65 kJ mol^{-1})

(ii) Standard enthalpy changes for combustion of $HC \equiv CH(g)$, C(s,gr) and $H_2(g)$ are (-1300), -394 and -286 kJ mol^{-1} respectively. Calculate the standard enthalpy of formation of $HC \equiv CH(g)$. **(+226 kJ mol^{-1})**
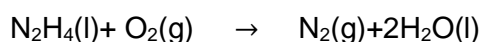
15. Standard enthalpy change for the combustion of benzene ($C_6H_6(l)$) is -3267.6 kJ mol^{-1}. Standard enthalpy changes for the formation of $CO_2(g)$ and $H_2O(l)$ are -393.5 and -285.9 kJ mol^{-1} respectively. Calculate the standard enthalpy of formation of $C_6H_6(l)$. **(48.9 kJ mol^{-1})**

16.

Compound	ΔH_f°/kJ mol^{-1}
C(s,gr)	-394
H_2(g)	-286
C_2H_5OH(l)	-1400

Calculate the standard enthalpy of formation of $C_2H_5OH(l)$. **(-246 kJ mol^{-1})**

17. Standard enthalpy of combustion for $H_2(g)$, $C_6H_{10}(l)$ and $C_6H_{12}(l)$ are -241, -3800 and -3920 kJ mol^{-1} respectively. Calculate the standard enthalpy of hydrogenation (reacting with H_2) of $C_6H_{10}(l)$. **(-121 kJ mol^{-1})**

18. Standard enthalpy of formation of $N_2H_4(l)$ and $H_2O(l)$ are +51 and -286 kJ mol^{-1} respectively. Calculate the standard enthalpy change for the following reaction.

$$N_2H_4(l) + O_2(g) \rightarrow N_2(g) + 2H_2O(l)$$

(-623 kJ mol^{-1})

19. Calculate the standard enthalpy of formation for the 1-propanol (C_3H_7OH) using the data given below.

| Compound	ΔH_c°/kJ mol^{-1}
C_3H_7OH(l)	-2010
H_2(g)	-286
C(s, gr)	-394

(-316 kJ mol^{-1})

20. The standard enthalpy of combustion of S(s, Rhombic) is -287 kJ mol^{-1} for 1 mol of atoms of sulphur. Standard enthalpy of formation of $H_2S(g)$ and $H_2O(l)$ are -20.2 and -286 kJ mol^{-1} respectively. Calculate the standard enthalpy change of the following reaction.

$$SO_2(g) + 2H_2S(g) \rightarrow 3S(s, Rh) + H_2O(l)$$

(+329.4 kJ mol^{-1})

21. NH_4NO_3 is frequently used as a fertilizer and can also be used as an explosive. ΔH_f° values of $NH_4NO_3(s)$ and $H_2O(l)$ are -365 and -286 kJ mol^{-1} respectively. Calculate the heat released by dissociation of 1.0 mol of NH_4NO_3 according to the following reaction.

$$2NH_4NO_3(s) \rightarrow 2N_2(g) + 4H_2O(l) + O_2(g)$$
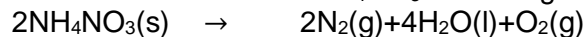
(For 1 mol = 207 kJ are released)

22. Standard enthalpy of dissolution of $Na_2SO_4(s)$ is -2.4 kJ mol^{-1} and that of $Na_2SO_4.10 H_2O$ is +70.2 kJ mol^{-1}. Calculate the ΔH_r° of the following reaction.

$$Na_2SO_4(s) + 10 H_2O(l) \rightarrow Na_2SO_4.10H_2O(s)$$
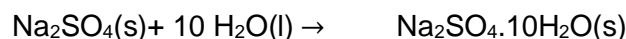
(-72.6 kJ mol^{-1})

23. Standard enthalpy of formation for the compounds of interest are given below. $CuSO_4(s)$ = -66.5 kJ mol^{-1}, $CuSO_4.5H_2O(s)$ = +11.7 kJ mol^{-1}, $H_2O(l)$ = -286 kJ mol^{-1}. Calculate the ΔH_r° for the reaction:

$$CuSO_4(s) + 5 H_2O(l) \rightarrow CuSO_4.5H_2O(s)$$

(+1508.2 kJ mol^{-1})

24. Standard enthalpy of formation for ethene ($H_2C=CH_2(g)$) and ethane ($H_3C-CH_3(g)$) are +52 kJ mol^{-1} and -83 kJ mol^{-1} respectively. Calculate enthalpy change of hydrogenation of ethene.
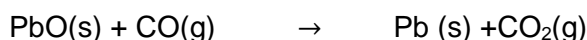
(-135 kJ mol^{-1})

25.

Compound	Energy/ kJ mol^{-1}
$\Delta H_c^{\circ}(H_2(g))$	-286
$\Delta H_c^{\circ}(CH_4(g))$	-890
$\Delta H_c^{\circ}(C_2H_6(g))$	-1560
$\Delta H_c^{\circ}(C(s, gr))$	-344
$\Delta H_f^{\circ}(C_3H_8(g))$	-104

Calculate the enthalpy change for the following reaction.

$$C_3H_8(g) + H_2(g) \rightarrow C_2H_6(g) + CH_4(g)$$
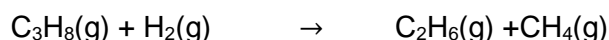
(+92 kJ mol^{-1})

26. ΔH_f° values for PbO(s), CO(g) and CO_2(g) are -219, -111 and -394 kJ mol^{-1} respectively. Calculate the enthalpy change for the following reaction.

$$PbO(s) + CO(g) \rightarrow Pb (s) + CO_2(g)$$

(-64 kJ mol^{-1})

27. ΔH_c° of C_2H_2(g), H_2(g) and C_2H_6(g) are -1301, -286 and -1560 kJ mol^{-1} respectively. Calculate the enthalpy change for the following reaction.

$$HC \equiv CH (g) + 2 H_2(g) \rightarrow C_2H_6(g)$$
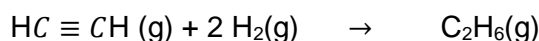
(-313 kJ mol^{-1})

28.

Compound	ΔH_f°/kJ mol^{-1}
Pb(NO$_3$)$_2$ (s)	-452
PbO (s)	-217
NO$_2$(g)	+33

Calculate the ΔH_r° for the thermal decomposition of 1 mol of Pb(NO$_3$)$_2$.

(+301 kJ mol^{-1})

29. Write down the reaction for the thermal decomposition of $\{(NH_4)_2Cr_2O_7 (s)\}$ stating the proper physical states. Then, calculate the enthalpy of thermal dissociation of $\{(NH_4)_2Cr_2O_7 (s)\}$ using the following data.

Compound	ΔH_f°/kJ mol^{-1}
(NH$_4$)$_2$Cr$_2$O$_7$ (s)	-1810
H$_2$O (g)	-240
Cr$_2$O$_3$(g)	-1140

(-290 kJ mol^{-1})

30. ΔH_f° for CO_2(g) and H_2O(l) are -394 and -242 kJ mol^{-1} respectively. ΔH_c° for ethane is (-1560 kJ mol^{-1}). Hydrogenation enthalpy of ethene with gaseous H_2 is -138 kJ mol^{-1}. Calculate the ΔH_f° of C_2H_4(g).

(+184 kJ mol^{-1})

31.

Reaction	ΔH_r°/ kJ mol^{-1}
$H_2(g) \rightarrow 2H(g)$	+436
$Br_2(l) \rightarrow 2\,Br(g)$	+194
$H_2(g)+Br_2(l) \rightarrow\ 2\,HBr(g)$	-104

Calculate the enthalpy change of the following reaction.

$$H(g)\quad +\quad Br(g)\quad\quad \rightarrow\quad\quad HBr(g)$$

(-367 kJ mol^{-1})
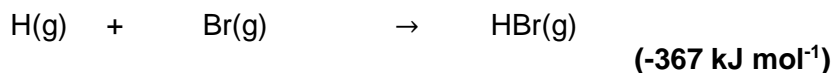
32. (i) Define the term "Standard bond dissociation enthalpy".
 (ii) First, second, third and fourth bond dissociation enthalpies of $CH_4(g)$ are +433, +480, + 425 and +336 kJ mol^{-1} respectively. Calculate the average bond dissociation enthalpy of C-H bond.

(+418.5 kJ mol^{-1})

33. Average bond dissociation enthalpy values for bonds are given below.

Bond	ΔH_{BDE}°/ kJ mol^{-1}
C-H	+416
C-C	+348
C=C	+612
H-H	+436

Calculate the ΔH_r° for the following reaction:

$$H_2C=CH_2\ (g) +\quad H_2(g)\quad\quad \rightarrow\quad\quad CH_3\text{-}CH_3(g)$$

(-132 kJ mol^{-1})

34.

| Compound	Energy/ kJ mol^{-1}
$\Delta H_f^\circ(CH_4(g))$	-75
$\Delta H_f^\circ(C_2H_4(g))$	+52
$\Delta H_f^\circ(C_2H_6(g))$	-85
$\Delta H_D^\circ(H_2(g))$	+436
$\Delta H_{sub}^\circ(C\ (s,\ gr))$	+718

Calculate the standard bond dissociation energy for C-H, C-C and C=C.

**(416.25 kJ mol^{-1}, 331.5 kJ mol^{-1}, 591 kJ mol^{-1})**

35. Standard bond dissociation energies of several bonds are given below

Bond	Energy/ kJ mol^{-1}
$C-C$	348
$C-H$	412
$C-Br$	276
$C=C$	612
$Br-Br$	193

Calculate the standard enthalpy change for the given reaction using this data.

$$H_2C=CH\text{-}CH_3(g)+ Br_2(g)\quad\quad \rightarrow\quad\quad CH_3BrCHBrCH_3(g)$$
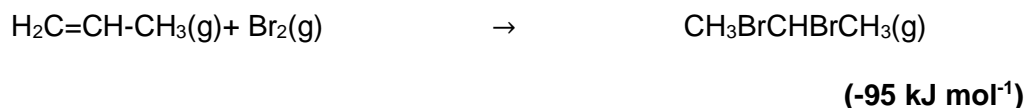
(-95 kJ mol^{-1})

36. Consider that benzene(C_6H_6) has a structure with an alternative single and double bond in a hexagon, calculate the standard enthalpy change for the reaction.

$$3C_2H_2(g) \longrightarrow C_6H_6(g)$$
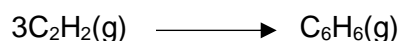
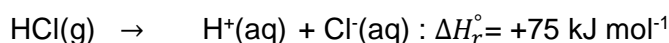| Bond	Bond Dissociation Energy/ kJ mol^{-1}
$C - C$	348
$C - H$	412
$C \equiv C$	837
$C = C$	612

(-369 kJ mol^{-1})

37. (I) Explain what is meant by the average bond dissociation enthalpy in terms of N-H bond of NH_3.

(II)

Hydrocarbon	ΔH_f°/kJ mol^{-1}
$C_2H_6(g)$	-84.7
$C_2H_2(g)$	+227
$C_2H_4(g)$	+52.3

Bond dissociation enthalpies of H-H and C-H are +436 and +412 kJ mol^{-1} respectively. Standard atomisation enthalpy of graphite is +715 kJ mol^{-1}. Calculate the bond dissociation enthalpies of C-C bonds in each of these hydrocarbons.

(C-C = +350. 7 kJ mol^{-1}; C=C = +601.7 kJ mol^{-1}; $C \equiv C$ = +815 kJ mol^{-1})

38. (i) Ionisation energy of H(g) is +1310 kJ mol^{-1} and the electron gain of Cl(g) is -347 kJ mol^{-1}.

$$H(g) \quad + \quad Cl(g) \quad \rightarrow \quad HCl(g); \quad \Delta H_r^\circ = \text{-432 kJ mol}^{-1}$$

$$HCl(g) \quad \rightarrow \quad H^+(aq) + Cl^-(aq) : \Delta H_r^\circ = \text{+75 kJ mol}^{-1}$$

Hydration enthalpies of some ions are as follows:

Ion	Cl$^-$	I$^-$	Br$^-$
Enthalpy of Hydration/ kJ mol^{-1}	-380	-310	-350

Using data given above, Calculate the standard hydration enthalpy of a proton.

(-940 kJ mol^{-1})

39. Experimental value of ΔH_f° ($C_6H_6(g)$) is +83 kJ mol^{-1}.

Bond	C-C	C=C	C-H
Average bond dissociation energy/ kJ mol^{-1}	348	615	412

If the atomisation energy of C(s, gr) and H(g) are +715 and +218 kJ mol^{-1} respectively then calculate the theoretical value of ΔH_f° benzene(g). Why do you think there is a difference in the theoretical value and the experimental value?
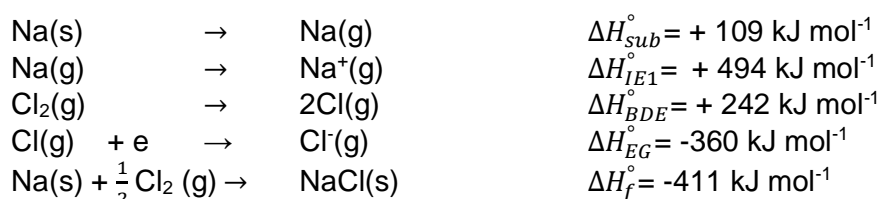
(+237 kJ mol^{-1})

40. (i) Draw the Born Haber cycle for KCl(s).
(ii) Calculate the enthalpy change for the first electron gain of Cl(g) using the following data drawing an energy cycle.

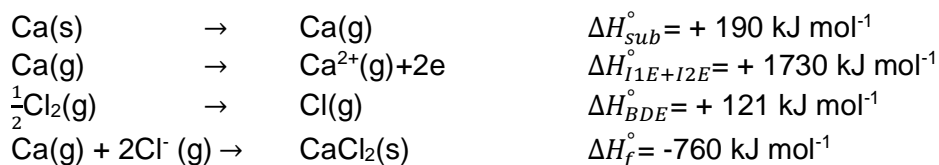| Enthalpy	Energy/ kJ mol^{-1}
$\Delta H^{\circ}_{sub}(K(s))$	+90
$\Delta H^{\circ}_{IE1}(K(g))$	+420
$\Delta H^{\circ}_{BDE}(Cl_2(g))$	+244
$\Delta H^{\circ}_{LE}KCl(s)$	-706
$\Delta H^{\circ}_{f}(KCl(s))$	-436

(-362 kJ mol^{-1})

41. Calculate the standard lattice energy for NaCl(s) using the following data using an energy level diagram.

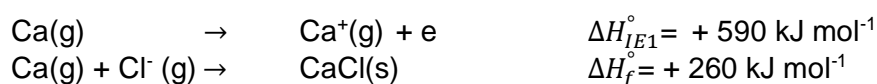|			
Na(s)	$\rightarrow$	Na(g)	ΔH°_{sub}= + 109 kJ mol^{-1}
Na(g)	$\rightarrow$	Na$^+$(g)	ΔH°_{IE1}= + 494 kJ mol^{-1}
Cl$_2$(g)	$\rightarrow$	2Cl(g)	ΔH°_{BDE}= + 242 kJ mol^{-1}
Cl(g) + e	$\rightarrow$	Cl$^-$(g)	ΔH°_{EG}= -360 kJ mol^{-1}
Na(s) + $\frac{1}{2}$Cl$_2$ (g) $\rightarrow$		NaCl(s)	ΔH°_{f}= -411 kJ mol^{-1}

(-775 kJ mol^{-1})

42. Calculate the electron gain enthalpy of chlorine using the given data below if the lattice energy of CaCl2(s) is -2195 kJ mol^{-1}.

Ca(s)	$\rightarrow$	Ca(g)	ΔH°_{sub}= + 190 kJ mol^{-1}
Ca(g)	$\rightarrow$	Ca^{2+}(g)+2e	$\Delta H^{\circ}_{I1E+I2E}$= + 1730 kJ mol^{-1}
$\frac{1}{2}$Cl$_2$(g)	$\rightarrow$	Cl(g)	ΔH°_{BDE}= + 121 kJ mol^{-1}
Ca(g) + 2Cl$^-$ (g) $\rightarrow$		CaCl$_2$(s)	ΔH°_{f}= -760 kJ mol^{-1}

(-363.5 kJ mol^{-1})

Also, calculate the ΔH°_{f} (CaCl(s)) using other information given below. How would you account for the stability of CaCl(s) and CaCl$_2$(s)?

Ca(g)	$\rightarrow$	Ca$^+$(g) + e	ΔH°_{IE1}= + 590 kJ mol^{-1}
Ca(g) + Cl$^-$ (g) $\rightarrow$		CaCl(s)	ΔH°_{f}= + 260 kJ mol^{-1}

(+797.5 kJ mol^{-1})

43. (i) Define the term "Standard heat of combustion" of a substance.
(ii) Define the term "Standard enthalpy of formation of a compound"
(iv)   Calculate the heat of formation of C$_2$H$_2$(g) at 25 °C using the given values of enthalpy of combustion.

Compound	ΔH°_{C}/ kJ mol^{-1}
H$_2$(g)	-286
C$_2$H$_2$(g)	-1300
C(s, gr)	-394

(+226 kJ mol^{-1})

44. Bond dissociation energies of few bonds are given below.

Bond	Std. BDE/ kJ mol^{-1}
C-I	218
H-I	297
C-C	346

C=C	611
C-H	413

Calculate the standard enthalpy change for the following reaction.

$$C_2H_4(g) \quad + HI(g) \quad \rightarrow \quad C_2H_5I(g)$$

(-69 kJ mol^{-1})
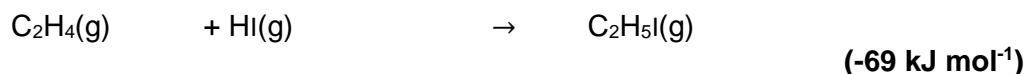
45. Standard enthalpy values of certain reactions are given below

$$2Al(s) + O_2(g) \quad \rightarrow \quad Al_2O_3(s) \quad \Delta H_r^\circ = \text{-1600 kJ mol}^{-1}$$
$$2Fe(s) + \frac{3}{2}O_2(g) \quad \rightarrow \quad Fe_2O_3(s) \quad \Delta H_r^\circ = \text{-836 kJ mol}^{-1}$$

(i) Calculate the ΔH_r° value for the formation of Fe(s) from $Fe_2O_3(s)$ and Al(s) using a suitable enthalpy diagram.

(ii) Calculate the enthalpy change when 7 kg of Fe is produced using the reaction given in (i) above. (Fe = 56)

(-764 kJ mol^{-1}, 47,750 kJ)

46. 1.538 kJ of heat was released during a complete combustion of 0.03 g of ethane ($C_2H_6(g)$). 2.199 kJ of heat was released when 0.044 g of propane ($C_3H_8(g)$) was allowed to undergo complete combustion. Calculate the average bond energies of C-C and C-H using the given enthalpies below.

$$O_2(g) \quad \rightarrow \quad 2O(g) \quad \Delta H_r^\circ = \text{+498 kJ mol}^{-1}$$
$$CO_2(g) \quad \rightarrow \quad C(g) \quad + \quad 2O(g) \quad \Delta H_r^\circ = \text{+1607 kJ mol}^{-1}$$
$$H_2O(g) \quad \rightarrow \quad 2H(g) \quad + \quad O(g) \quad \Delta H_r^\circ = \text{+971 kJ mol}^{-1}$$
$$H_2O(l) \quad \rightarrow \quad H_2O(g) \quad \Delta H_r^\circ = \text{+15 kJ mol}^{-1}$$
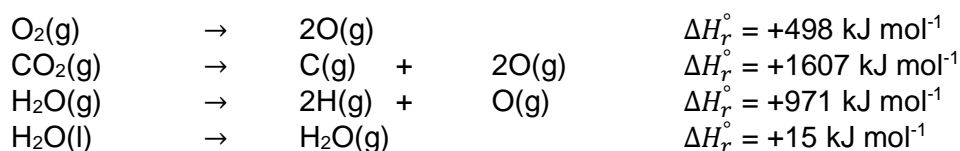
(C-C = 332 kJ mol^{-1}, C-H = 426.5 kJ mol^{-1})

47. Calculate the enthalpy of formation of 1 mol of sucrose ($C_{12}H_{22}O_{11}(s)$) using a suitable enthalpy diagram using the data given below.

Compound	Heat of combustion /kJ mol^{-1}
$H_2(g)$	-285.6
$C_{12}H_{22}O_{11}(s)$	-5670
$C(s, gr)$	-383

(-2067.6 kJ mol^{-1})

48. (i) Explain the term enthalpy of neutralisation.

(ii) Explain why the enthalpy of neutralisation of a mono basic strong acid by a strong base shows the same constant value.

(iii) Briefly explain an experimental procedure to determine the enthalpy of neutralisation of an acid in the laboratory.

(iv) 1.425 kJ of heat is released when 0.025 mol of HCl is neutralised by a strong acid. 1.357 kJ of heat is released when 0.025 mol of a weak acid is neutralised by a strong base. Calculate the standard enthalpy of dissociation of the weak acid.

(+2.72 kJ mol^{-1})

49. (i) Explain what is meant by the standard enthalpy of bond dissociation using $Cl_2(g)$ as an example.

(ii) Calculate the standard enthalpy of bond dissociation for N-H using the data provided

Standard bond dissociation of $H_2(g)$ = 432 kJ mol^{-1}
Standard bond dissociation of $N_2(g)$ = 946 kJ mol^{-1}
Standard enthalpy of formation $NH_3(g)$ = -46 kJ mol^{-1}
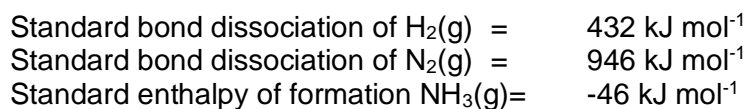
(+381.33 kJ mol^{-1})

50.

Bond	H-H	C-C	C-H	C=C
ΔH_{BDE}°/ kJ mol^{-1}	+433	+346	+413	+612

Calculate the standard enthalpy change for the hydrogenation of buta-1,3-diene ($H_2C=CH-CH=CH_2$) to butane ($H_3C-CH_2-CH_2-CH_3$).
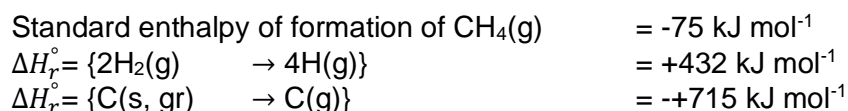
51. The enthalpy of the reaction between aqueous KOH and aqueous HCl is the same compared to that of the reaction between aqueous KOH and HBr. However, the standard enthalpy of the reaction between aqueous NH_3 and HBr is lower. Explain why it is so.

52. Consider the following reaction.

AgCl(s)   +   KBr(aq)   →   AgBr(s)   +   KCl(aq)

This reaction takes place slowly, only when the reaction mixture is stirred vigorously. Therefore, the enthalpy change of the reaction cannot be directly found out. Suggest a method to determine this ΔH_r° more accurately.

53. Calculate the average bond dissociation energy of C-H bond of CH_4 using the data given below.

Standard enthalpy of formation of CH_4(g)   = -75 kJ mol^{-1}
ΔH_r°= {2H$_2$(g)   → 4H(g)}   = +432 kJ mol^{-1}
ΔH_r°= {C(s, gr)   → C(g)}   = -+715 kJ mol^{-1}

54. Calculate the standard enthalpy of formation of HF(g) using the data given below.

Bond	H-H	H-F	F-F
ΔH_{BDE}°/ kJ mol^{-1}	+432	+569	+158

55. It is observed that the temperature of a reaction mixture has increased by 8 °C when 25.00 mL of 3.00 mol dm^{-3} HCl is mixed with 0.025 mols of Na_2CO_3 at the room temperature. The specific heat capacity of the resulting solution is 5000 J kg^{-1} °C^{-1}. Density of the solution is 1000 kg m^{-3}.

(i)   Calculate the amount of the heat released during the above reaction if the heat released by the reaction is used only to raise the temperature of the mixture.

(ii)   Calculate the enthalpy of neutralisation of HCl. Write any assumptions you used in the calculation.

(iii)   Following reactions were carried out under the same conditions as of (i)
         (a) $NaHCO_3$(s) + HCl(aq) → $NaCl$(aq) + CO_2(g) + H_2O(l)
         (b) 2$NaHCO_3$(s) → Na_2CO_3(aq) + CO_2(g) + H_2O(l)

If the ΔH_r° for the reaction (iii) a is -25.5 kJ mol^{-1} then calculate the enthalpy change for the reaction (iii)b.

56. following standard enthalpy of neutralisation values were obtained at 25 °C using aqueous solutions of given compounds

Acid	HCl(aq)	HNO$_3$(aq)	C$_2$H$_5$COOH(aq)

ΔH_n°/ kJ mol^{-1}	-57	-57	-51

(i)   Give reasons for the observations above.
(ii)   Deduce the molar dissociation energies of the following
         a. H_2O(l)   b. C_2H_5COOH (aq)

57. You are provided with the following data

Heat source	Molecular Weight/ g mol^{-1}	Standard boiling point/ °C	Standard enthalpy of combustion / kJ mol^{-1}
C_3H_8(g)	44	-42	-2200
C_8H_{18}(l)	114	+126	-5130

(i) 1 kg of each of propane and octane were combusted separately at the standard conditions. Calculate the following for each.
                (a) The amount of heat released.
                (b) The mass of the gaseous CO_2 formed.

(i)   Using these values, you obtained for (i), state which compound is the most appropriate as a heat source. Give your reason.

58. Estimate the standard enthalpy change for the following reaction.

C_2H_5OH(l)+CH_3COOH(l) $\rightleftharpoons$ $CH_3CO_2C_2H_5$(l) + H_2O(l)
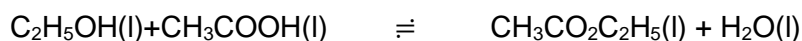
Bond	Standard bond enthalpy / kJ mol^{-1}
C-H	114
C=O	724
C-C	347
O-H	464
C-O	360

The experimental value for the ΔH_r° of the above reaction is +6 kJ mol^{-1}. Explain why the practical value deviates from the calculated value.

59. The temperature in a calorimeter containing 100 g of water is 22.7°C. Fifty grams of water are heated to boiling (99.1°C at this location) and quickly poured into the calorimeter. The final temperature is 44.8°C. From these data, calculate the heat capacity of the calorimeter.

60. State the Hess' law.
         $PCl_{5(g)} + H_2O(g) \rightarrow POCl_{3(g)} + 2HCl_{(g)}$
Calculate the enthalpy change for the above reaction using the information given below.
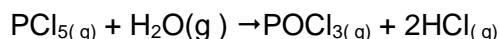
$P_{(white)}+ \frac{3}{2} Cl_{2(g)} + \frac{1}{2} O_{2(g)} \rightarrow POCl_{3(g)}$ $\triangle H° = -558.5$ kJ mol^{-1}
$H_{2(g)} + Cl_{2(g)} \rightarrow 2HCl$ $\triangle H° = -184.6$ kJ mol^{-1}
$PCl_{5(g)} \rightarrow P_{(white)} + \frac{5}{2} Cl_{2(g)}$ $\triangle H° = +374.9$ kJ mol^{-1}
$H_2O_{(g)} \rightarrow H_{2(g)} + \frac{1}{2} O_{2(g)}$ $\triangle H° = +241.8$ kJ mol^{-1}
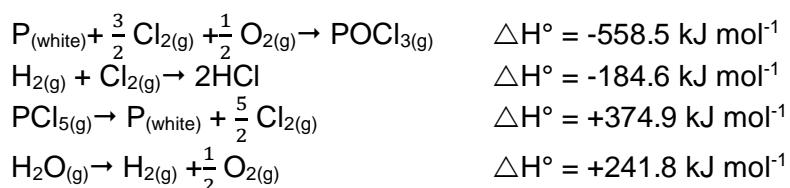
61. i) The standard enthalpy of neutralization for NaOH and KOH is equal. Explain.

   ii) The heat liberated on the neutralization of HCN by NaOH is 12.1 kJ/mol. How many kilo joules are absorbed in ionizing 1 mol of HCN in water?

62. The heats of combustion, forming $CO_{2(g)}$ and $H_2O_{(l)}$, of ethane, $C_2H_{6(g)}$), and ethylene, $C_2H_{4(g)}$, are -1559.8 and -1410.9 kJ mol^{-1}, respectively. Compute ΔH for the reaction
$C_2H_{4(g)} + H_{2(g)} \rightarrow C_2H_{6(g)}$

63. The heats of combustion of $C_2H_{6(g)}$, $C_{(s)}$ and $H_2O_{(l)}$ are -1560 kJ mol^{-1}, -393 kJ mol^{-1} and -286 kJ mol^{-1}, respectively. Compute ΔH for the formation of $C_2H_{6(g)}$.

64. The heats of combustion of $CS_2(l)$, $C(s,gr)$ and $S(s,Rh)$ are -1200 kJ mol^{-1}, -393 kJ mol^{-1} and -287 kJ mol^{-1}, respectively. Calculate ΔH for the formation of $CS_2(l)$ using an enthalpy diagram.

65. Calculate ΔH of pent-3-en-1-yne if $\triangle H°_s$ for $C(s, gr)$ is 715 kJ mol^{-1} and the bond-dissociation energies, in kJ mol^{-1}, are 413 for C-H, 346 for C-C, (837 for C≡C), 432 for H-H and 611 for C=C.
Structure of pent-3-en-1-yne
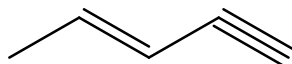
66. Calculate $\triangle H°_f$ of $MgCl_3$ if,

$\triangle H°_{LE}$ ($MgCl_3$)	= -5800 kJ/mol	$\triangle H°_{I1}$(Mg) = 738 kJ/mol
$\triangle H°_{I2}$ (Mg)	= 1447 kJ/mol	$\triangle H°_s$ (Mg) = 146 kJ/mol
$\triangle H°_{EA}$(Cl)	= -364 kJ/mol	$\triangle H°_D$ (Cl-Cl) = 242 kJ/mol

67. Consider following enthalpy data.

Bond	$\triangle H°_D$ / kJ mol $^{-1}$
C-H	416
C-C	331
C=C	591
H-H	436

   Also,
   $\triangle H°_s$ (C) = 715 kJ/mol : $\triangle H°_c$(C) = -393 kJ/mol : $\triangle H°_c$ (C_6H_6) = -3170 kJ/mol
   $\triangle H°_c$ (H_2) = -286 kJ/mol

   Calculate $\triangle H°_f$ (C_6H_6) using two different methods.

68. The reaction for the hydrogenation of acetylene, C_2H_2 (g) proceeds according to:
   C_2H_2 (g) + 2 H_2 (g) $\rightarrow$ C_2H_6 (g)
   Calculate $\Delta H°$ for this reaction by combining the equations (and $\Delta H°$'s) for the following reactions.
   i) 2 C_2H_2 (g) + 5 O_2 (g) $\rightarrow$ 4 CO_2 (g) + 2 H_2O (l) $\Delta H° = - 2599$ kJ mol^{-1}
   ii) 2 C_2H_6 (g) + 7 O_2 (g) $\rightarrow$ 4 CO_2 (g) + 6 H_2O (l) $\Delta H° = - 3119$ kJ mol^{-1}
   iii) 2 H_2 (g) + O_2 (g) $\rightarrow$ 2 H_2O (l) $\Delta H° = - 572$ kJ mol^{-1}

69. When heated cautiously, ammonium nitrate, NH_4NO_3, decomposes according to
           NH_4NO_3 (s) $\rightarrow$ N_2O (g) + 2 H_2O (g)

a) Calculate $\Delta H°$ for the decomposition reaction.
b) Calculate total heat evolved when the reaction takes place for 1.00 kg of NH_4NO_3.

70. One might think that we could react SO_2 (g) with oxygen to produce SO_3 (g), but this reaction does not occur readily. Instead, the following two step sequence may be used to produce SO_3 (g).

NO (g) + $\frac{1}{2}O_2$ (g) $\rightarrow$ NO_2 (g) $\qquad \Delta H° = - 57.2$ kJ
NO_2 (g) + SO_2 (g) $\rightarrow$ NO (g) + SO_3 (g) $\qquad \Delta H° = - 41.7$ kJ
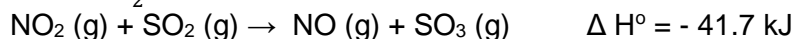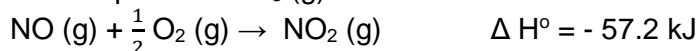
Use these two reactions to determine $\Delta H°_f$ for the reaction of SO_2 (g) with oxygen to form SO_3 (g). Then....

      (c) Using the $\Delta H°_f$ for SO_2 (g) found on later part of this tutorial, calculate the $\Delta H°_f$ for SO_3 (g).

b) Is this reaction endothermic or exothermic?

71. A 2.56 g sample of solid sulphur is burned in excess oxygen in a calorimeter to form SO_2 (g). The calorimeter has a heat capacity of 923 JK^{-1} and contains 815 g of water. Calculate the temperature change that would occur from this reaction.

(HINTS: Write the equation for the combustion. How does the equation for the combustion reaction compare with the equation for the formation of SO_2?)

72. a) Consider the molecules CF_4 (g), CCl_4 (g) and CBr_4 (g).
Calculate
      (d) the C – F bond energy in CF_4 (g) ΔH_f for CF_4 (g) = -933 kJ mol^{-1}
ii) the C – Cl bond energy in CCl_4 (g) $\Delta H°_f$ for CCl_4 (g) = - 96 kJmol^{-1}
iii) the C – Br bond energy in CBr_4 (g) $\Delta H°_f$ for CBr_4 (g) = + 79 kJmol^{-1}
b) For hexafluoroethane, $F_3C – CF_3$, $\Delta H°_f$ = - 1343 kJ mol^{-1}.
Using the C – F bond energy calculated in a) calculate the energy of the C – C bond in $F_3C – CF_3$.
b) Consider the following reaction: CCl_4 (g) + F_2 (g) $\rightarrow$ CF_2Cl_2 (g) + Cl_2 (g)
i) Use the bond energy data from a) (and other information from your table estimate $\Delta H°r$ for this reaction.
ii) Use the ΔH from i) to calculate the $\Delta H°_f$ for CF_2Cl_2 (g).

73. Carbon disulphide has the structure: S = C = S. The energy of the C = S bond is 579 kJ mol^{-1}. Use this bond energy and other information on your tables to estimate the $\Delta H°_f$ for CS_2 (g).

74. a) Use $\Delta H°_f$ values to calculate the total bond energy of ethylene, C_2H_4 (g).

b) The structure of ethylene is $H_2C = CH_2$. If the energy of the C – H bond in ethylene is 409 kJ mol^{-1}, calculate the energy of the C = C bond in ethylene.

75. a) Use $\Delta H°_f$ values to calculate the average N – H bond energy in NH_3.
b) $\Delta H°_f$ for N_2H_4 (g) = + 95.4 kJ mol^{-1} Use the value of the N – H bond found in a) to calculate the energy of the N – N bond in hydrazine. Why do you think that this value is so different from the bond energy of gaseous N_2?

c) The energy of the N – F bond is 278 kJ mol^{-1}; of the N – Cl bond is 192 kJ mol^{-1}.

Use these values to calculate the ΔH°_f values for NF_3 (g) and NCl_3 (g). One of these compounds is explosive and one is stable. Which is explosive?

76. In SO_2 (g) and SO_3 (g), the sulphur to oxygen bonds are double bonds (ie, S = O). Use the ΔH°_f values from question 70 to calculate the energy of the S = O bond in each of these compounds.

77. a) Calculate the amount of heat energy required to change 50 g of ice at $-10\ ^\circ C$ to

water at 25 $^\circ C$. (DATA: Specific heat of ice = 2.1 $JK^{-1}g^{-1}$, Heat of Fusion = 6.0 kJ mol -1)
b) A mixture of ice and water contains 500 g of ice and 300 g of liquid water at 0 $^\circ C$. Calculate the amount of heat energy required to convert this mixture to 800 g of liquid water at 100 $^\circ C$. (HINT: You must first melt the ice, and then heat all the water.)

c) 100 g of ice at 0 $^\circ C$ are added to 200 g of water at 25 $^\circ C$. What mass of ice will remain when the mixture reaches thermal equilibrium? (HINT: If both ice and water are present, the temperature of the mixture must be 0 $^\circ C$.)

78. a) Calculate ΔH° for the conversion of methane into chloroform....
   CH_4 (g) + 3 Cl_2 (g) $\rightarrow$ $CHCl_3$ (g) + 3 HCl (g)
        by using the following equations:
            (e) $\frac{1}{2}$ H_2 (g) + $\frac{1}{2}$ Cl_2 (g) $\rightarrow$ HCl (g) ΔH° = - 92.3 kJ mol^{-1}
   ii) C (graphite) + 2 H_2 (g) $\rightarrow$ CH_4 (g) ΔH° = - 74.5 kJ mol^{-1}
   iii) C (graphite) + $\frac{1}{2}$ H_2 (g) + $\frac{3}{2}Cl_2$ (g) $\rightarrow$ $CHCl_3$ (l) ΔH° = - 135.1 kJ mol^{-1}
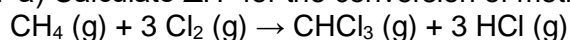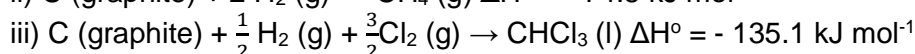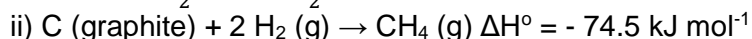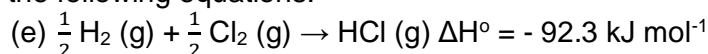
79. A 1.50 g sample of benzoic acid, C_5H_5COOH, was burned in excess oxygen in a calorimeter. The calorimeter had a heat capacity of 893 JK^{-1} and contained 775 g of water. The initial temperature of the calorimeter and contents was 22.50 $^\circ C$, which rose to 31.69 $^\circ C$ at the completion of the combustion.
a) Calculate the heat evolved in this combustion reaction.
b) Now calculate the molar heat of combustion, in kJ mol^{-1}, for benzoic acid.

80. Given the following equation: $Na_2O_{(s)}$ + 2$HI_{(g)}$ $\rightarrow$ 2 $NaI_{(s)}$ + $H_2O_{(l)}$ 501.6 kJ
   a) If 9.00 g of NaI are formed by the process, how much heat (q) will be involved? **(15.0 kJ)**
   b) State whether the reaction is endothermic or exothermic.

81. When concentrated nitric acid HNO_3 is added to water, heat is liberated. This "heat of solution" is 30.09 kJ/mol of HNO_3 diluted. How many grams of nitric acid must be diluted to release 3611.52 kJ of heat? **(7.564 kg)**

82. Given a) $C_{(diamond)}$ + $O_{2(g)}$ $\rightarrow$ $CO_{2(g)}$ ΔH = -395.01 kJ/mol

            b) $C_{(graphite)}$ + $O_{2(g)}$ $\rightarrow$ $CO_{2(g)}$ ΔH = -393.13 kJ/mol
   Calculate the ΔH for the manufacturing of diamond from graphite. **(1.88 kJ)**

83. Calculate the ΔH for the reaction: $C_{(s)}$ + $H_2O_{(g)}$ $\rightarrow$ $CO_{(g)}$ + $H_{2(g)}$
   using the following information:
         $C_{(s)}$ + $O_{2(g)}$ $\rightarrow$ $CO_{2(g)}$ ΔH = -392.92 kJ/mol
         $CO_{(g)}$ + $\frac{1}{2}$ $O_{2(g)}$ $\rightarrow$ $CO_{2(g)}$ ΔH = -282.57 kJ/mol

$$H_{2(g)} + \frac{1}{2} O_{2(g)} \rightarrow H_2O_{(g)} \qquad\qquad \Delta H = \text{-241.60 kJ/mol}$$
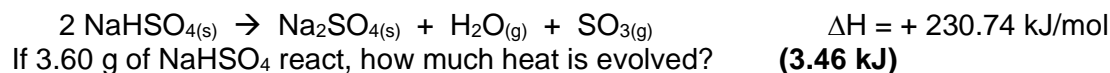
(131.25 kJ)

84. Using the heats of formation, calculate the enthalpy change for the combustion reaction of C_2H_4 forming carbon dioxide and water (all gases). **(1323 kJ)**

85. Given the following equation:

$$2\ NaHSO_{4(s)} \rightarrow Na_2SO_{4(s)} + H_2O_{(g)} + SO_{3(g)} \qquad\qquad \Delta H = \text{+ 230.74 kJ/mol}$$
If 3.60 g of $NaHSO_4$ react, how much heat is evolved? **(3.46 kJ)**

86. Given the following equation $C_{(s)} + O_{2(g)} \rightarrow CO_{2(g)} \qquad \Delta H = \text{-392.92 kJ/mol}$

a) How many grams of carbon must be burned to produce 2553.98 kJ of energy?
(78.06 g)
b) How many grams of oxygen will be consumed in the production of this energy? **(208.0 g)**

87. Given the equations $\quad 89.45\ kJ + SO_{2(g)} + \frac{1}{2} O_{2(g)} \rightarrow SO_{3(g)}$

$$S_{(s)} + \frac{3}{2} O_{2(g)} \rightarrow SO_{3(g)} + 203.98\ kJ$$
Calculate the heat of formation of sulphur dioxide from sulphur and oxygen.
(-293.44kJ/mol)

88. Calculate the ΔH for the reaction $\qquad H_{2(g)} + \frac{1}{2} O_{2(g)} \rightarrow H_2O_{(l)}$
Given the following equtions:
$C_{(s)} + 2\ H_2O_{(g)} \rightarrow CO_{2(g)} + 2\ H_{2(g)} \quad \Delta H = \text{+163.02 kJ/mol}$
$C_{(s)} + \frac{1}{2} O_{2(g)} \rightarrow CO_{(g)} \qquad\qquad\qquad \Delta H = \text{-121.22 kJ/mol}$
$H_2O_{(g)} \rightarrow H_2O_{(l)} \qquad\qquad\qquad\qquad \Delta H = \text{-40.55 kJ/mol}$
$CO_{(g)} + \frac{1}{2} O_{2(g)} \rightarrow CO_{2(g)} \qquad\qquad \Delta H = \text{-282.99 kJ/mol}$
(-324.16 kJ mol^{-1} H$_2$O$_{(l)}$)
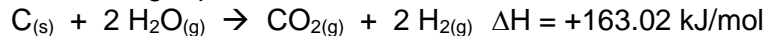
89. The following reactions are carried out at 25°C and 101.3 kPa.
$Br_{2(l)} + Cl_{2(g)} + 14.63\ kJ \rightarrow 2\ BrCl_{(g)}$
$Pb(NO_3)_{2(s)} + 290.93\ kJ \rightarrow PbO_{(s)} + \frac{1}{2} O_{2(g)}\ 2\ NO_{2(g)}$
$4\ C_{(s)} + 4\ H_{2(g)} + O_{2(g)} \rightarrow C_3H_7COOH_{(l)} + 522.08\ kJ$
$NH_{3(g)} + \frac{7}{4} O_{2(g)} \rightarrow NO_{2(g)} + \frac{3}{2} H_2O_{(g)} + 282.57\ kJ$
a) What criteria (two) do you use to decide whether a standard enthalpy is really a standard enthalpy of formation?
b) In which of the reactions above can the heat of reaction be written as a standard heat of formation? Write the numerical values in ΔH_f notation for each of your choices.
c) Which of the heats of reaction remaining can be used to obtain the standard heat of formation? Explain.
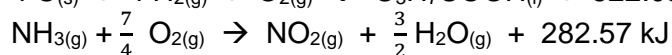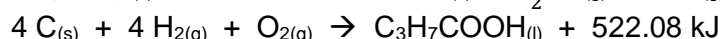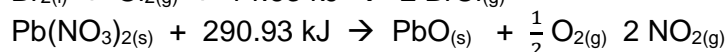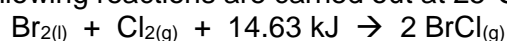
90. Use the $\Delta H_f°$ in the Table of heats of formation to determine the $\Delta H°$ for the reaction:
$$2H_2S_{(g)} + 3O_{2(g)} \rightarrow 2H_2O_{(l)} + 2SO_{2(g)}$$
(-1124 kJ mol^{-1})
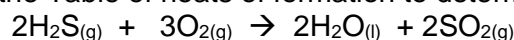
91. A sample of sucrose (table sugar) with a mass of 1.32 g is burned in a 1 L bomb calorimeter. The temperature changed from 25.00 °C to 27.31 °C. Calculate the heat

of combustion of sucrose in units of kilojoules per mole. The formula of sucrose is $C_{12}H_{22}O_{11}$. **(2.51× 10^3 kJ/mol)**

92. Gram for gram, fats in food have much more chemical energy than sugar. One component of fat is stearic acid, $C_{18}H_{36}O_2$. When a sample of 1.02 g of stearic acid was burned completely in a 1 L bomb calorimeter, the temperature of the calorimeter rose by 4.26 °C. Calculate the molar heat of combustion of stearic acid in kilojoules per mole. **(4.97×10^3 kJ/mol)**

93. The reaction of 2.000 mol of gaseous hydrogen with 1.000 mol of gaseous oxygen to form 2.000 mol of liquid water releases 517.8 kJ, provided that all reactants and products are brought to 25 °C and 1 atm. Write a thermochemical equation for the formation of 1.000 mol of liquid water. **(-258.9 kJ/mol)**

94. A reaction in a 1 L bomb calorimeter liberated 1.05 x 10^4 J and caused the temperature of the water to rise to 26.13 °C. What was the initial temperature in the calorimeter? **(23.6°C)**

95. In a calorimetry experiment the burning of 5.08 g of benzene (C_6H_6) released enough heat to raise the temperature of 5.00 kg of water from 10.1°C to 19.6 °C. Calculate the molar heat of combustion of benzene. **(-3.05 x10^3 kJ/mol)**

96. If 8.00 g of ammonium nitrate (NH_4NO_3) is dissolved in one liter of water for use as a plant fertilizer, the water decreases in temperature from 21.00 °C to 20.39 °C. Determine the molar heat of solution of ammonium nitrate.

(25.7 kJ mol^{-1})

97. An aqueous solution of calcium hydroxide neutralizes aqueous hydrochloric acid as follows
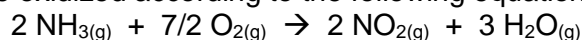
$$Ca(OH)_{2(aq)} + 2\,HCl_{(aq)} \rightarrow CaCl_{2(aq)} + 2\,H_2O_{(l)}$$
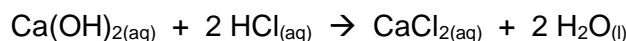
Calculate ΔH for the above reaction using the following equations as needed:

$CaO_{(s)} + 2\,HCl_{(aq)} \rightarrow CaCl_{2(aq)} + H_2O_{(l)}$ $\Delta H = -186$ kJ

$CaO_{(s)} + H_2O_{(l)} \rightarrow Ca(OH)_{2(s)}$ $\Delta H = -62.3$ kJ

$Ca(OH)_{2(s)} \rightarrow Ca(OH)_{2(aq)}$ $\Delta H = -12.6$ kJ
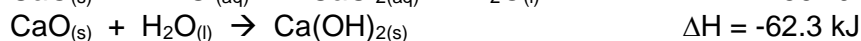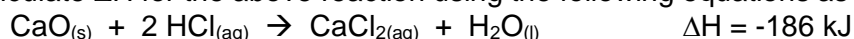
(-111 kJ mol^{-1})

98. Ammonia can be oxidized according to the following equation

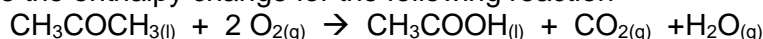$$2\,NH_{3(g)} + 7/2\,O_{2(g)} \rightarrow 2\,NO_{2(g)} + 3\,H_2O_{(g)}$$

Show how the following three equations can be rearranged and added to find ΔH for the oxidation of ammonia.

½ $N_{2(g)}$ + 3/2 $H_{2(g)} \rightarrow NH_{3(g)}$ $\Delta H = -46.2$ kJ

½ $N_{2(g)}$ + $O_{2(g)} \rightarrow NO_{2(g)}$ $\Delta H = 33.8$ kJ

$H_{2(g)}$ + ½ $O_{2(g)} \rightarrow H_2O_{(g)}$ $\Delta H = -241.8$ kJ
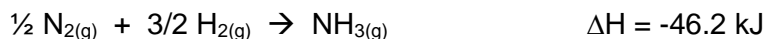
(-565.4 kJ mol^{-1})

99. Determine the enthalpy change for the following reaction

$$CH_3COCH_{3(l)} + 2\,O_{2(g)} \rightarrow CH_3COOH_{(l)} + CO_{2(g)} + H_2O_{(g)}$$

Using Hess's Law and the following equations:

$CH_3COCH_{3(l)} + 4\,O_{2(g)} \rightarrow 3\,CO_{2(g)} + 3\,H_2O_{(l)}$ $\Delta H = -1787$ kJ

$H_2O_{(g)} \rightarrow H_2O_{(l)}$ $\Delta H = -44.1$ kJ

$CH_3COOH_{(l)} + 2\,O_{2(g)} \rightarrow 2\,CO_{2(g)} + 2\,H_2O_{(l)}$ $\Delta H = -835$ kJ
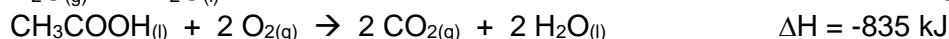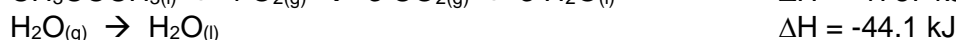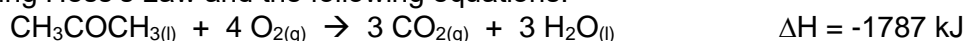
(-908 kJ mol^{-1})

100. ΔH for the complete combustion of ethene is -1390 kJ mol^{-1} according to the reaction $C_2H_{4(g)} + 3\,O_{2(g)} \rightarrow 2\,CO_{2(g)} + 2\,H_2O_{(l)}$
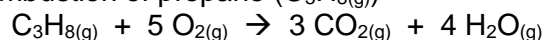
ΔH_f of $CO_{2(g)}$ = -394 kJ mol^{-1} $\quad\quad\quad\quad\quad$ ΔH_f of $H_2O_{(l)}$ = -266 kJ mol^{-1}

Use the above information to find the standard heat of formation of ethene.

(70 kJ mol^{-1})

101.   Using the tables of standard enthalpy of formation determine the enthalpy change for the combustion of propane ($C_3H_{8(g)}$)

$$C_3H_{8(g)} + 5\,O_{2(g)} \rightarrow 3\,CO_{2(g)} + 4\,H_2O_{(g)}$$

(-2044 kJ mol^{-1})

102.   Consider the following thermochemical equations:

$C_{(s)} + \frac{1}{2}\,O_{2(g)} \rightarrow CO_{(g)}$ $\quad\quad\quad\quad\quad\quad$ ΔH = -110.5 kJ mol^{-1}

$CO_{(g)} + \frac{1}{2}\,O_{2(g)} \rightarrow CO_{2(g)}$ $\quad\quad\quad\quad\quad$ ΔH = -283.0 kJ mol^{-1}

Use them to find ΔH° in kilojoules for the reaction: $C_{(s)} + O_{2(g)} \rightarrow CO_{2(g)}$

(-393.5 kJ mol^{-1})

103.

Calculate the standard enthalpy change of the reaction

Anhydrous copper(II) sulphate + Water $\longrightarrow$ Copper(II) sulphate-5-water
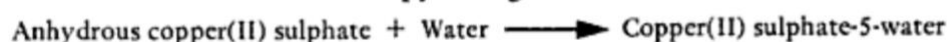
Use the values for the standard enthalpy of solution:

a) anhydrous copper(II) sulphate, -66.5 kJ mol^{-1}

b) copper(II) sulphate-5-water, 11.7 kJ mol^{-1}.

104.

Calculate the standard enthalpy change in the reaction

$$PbO(s) + CO(g) \longrightarrow Pb(s) + CO_2(g)$$

The standard enthalpies of formation of lead(II) oxide, carbon monoxide and carbon dioxide are -219, -111, and -394 kJ mol^{-1}, respectively.

105.

Calculate the standard enthalpy change in the reaction

$$PbO(s) + CO(g) \longrightarrow Pb(s) + CO_2(g)$$

The standard enthalpies of formation of lead(II) oxide, carbon monoxide and carbon dioxide are -219, -111, and -394 kJ mol^{-1}, respectively.

106.

The standard enthalpies of formation of $CO_2(g)$ and $H_2O(g)$ are -394 and -242 kJ mol^{-1}. The standard enthalpy of combustion of ethane is -1560 kJ mol^{-1}. The standard enthalpy of reduction of ethene to ethane by gaseous hydrogen is -138 kJ mol^{-1}. Calculate the standard enthalpy of formation of ethene.

107.

The following are standard enthalpies of formation, $\Delta H_f^\ominus$, in kJ mol^{-1} at 298 K:

$CH_4(g)$; -76; $CO_2(g)$, -394; $H_2O(l)$, -286; $H_2O(g)$, -242; $NH_3(g)$, -46.2; $HNO_3(l)$, -176; $C_2H_5OH(l)$, -278; $C_8H_{18}(l)$, -210.

a) Calculate the standard enthalpy change at 298 K for the reaction
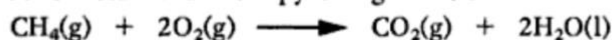
$$CH_4(g) + 2O_2(g) \longrightarrow CO_2(g) + 2H_2O(l)$$

b) Calculate the standard enthalpy change for the reaction

$$\tfrac{1}{2}N_2(g) + \tfrac{3}{2}H_2O(g) \longrightarrow NH_3(g) + \tfrac{3}{4}O_2(g)$$

c) Calculate the standard enthalpy change for the reaction

$$\tfrac{1}{2}N_2(g) + \tfrac{1}{2}H_2O(g) + \tfrac{5}{4}O_2(g) \longrightarrow HNO_3(l)$$
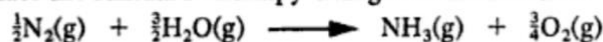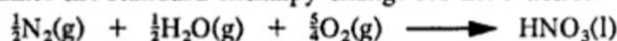
d) Calculate the enthalpy change which occurs when each of the following is burned completely under standard conditions:
i) 1.00 kg hydrogen, ii) 1.00 kg ethanol(l), iii) 1.00 kg octane(l).

108.

Consult the average standard bond enthalpies and standard enthalpies of atomisation (in kJ mol^{-1}) listed below:

C—C	348	C=O	743	C(graphite)	718
C=C	612	H—Cl	432	$\tfrac{1}{2}H_2(g)$	218
C≡C	837	C—Cl	338	$\tfrac{1}{2}O_2(g)$	248
C—H	412	C—Br	276	$\tfrac{1}{2}Br_2(g)$	96.5
C—O	360	H—Br	366	$\tfrac{1}{2}Cl_2(g)$	121
H—O	463				

a) Calculate the standard enthalpy of formation of ethane and of ethene.

b) Find the standard enthalpy change for the reaction,

$$CH_2{=}CH{-}CH_3(g) + Br_2(g) \longrightarrow CH_2BrCHBrCH_3(g)$$
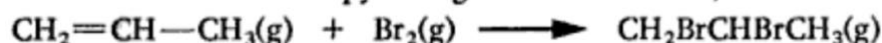
c) Find the standard enthalpy of formation of methoxymethane, $CH_3OCH_3(g)$.

d) Calculate the standard enthalpy of formation of gaseous ethyl ethanoate, $CH_3CO_2C_2H_5(g)$.

109.

Use the data below to draw an energy diagram for the formation of potassium chloride. Calculate the electron affinity of chlorine.

Standard enthalpy of sublimation of potassium = 90 kJ mol^{-1}
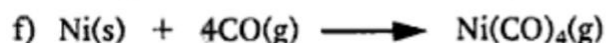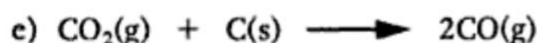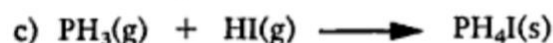Standard enthalpy of ionisation of potassium = 420 kJ mol^{-1}
Standard enthalpy of dissociation of chlorine = 244 kJ mol^{-1}
Standard lattice enthalpy of potassium chloride = -706 kJ mol^{-1}
Standard enthalpy of formation of potassium chloride = -436 kJ mol^{-1}

110.

Predict whether the following reactions will have a positive or negative value of $\Delta S^{\ominus}$:

a) $NH_4NO_3(s) \longrightarrow N_2O(g) + 2H_2O(g)$

b) $2H_2O_2(aq) \longrightarrow 2H_2O(l) + O_2(g)$

c) $PH_3(g) + HI(g) \longrightarrow PH_4I(s)$

d) $3O_2(g) \longrightarrow 2O_3(g)$

e) $CO_2(g) + C(s) \longrightarrow 2CO(g)$

f) $Ni(s) + 4CO(g) \longrightarrow Ni(CO)_4(g)$

111.

Use the following values of standard entropy content and standard enthalpy of formation to calculate standard free energy changes:

Substance	$\Delta H_F^{\ominus}/kJ\, mol^{-1}$	$S^{\ominus}/J\, K^{-1}\, mol^{-1}$
HgO(s) (red)	−90.7	72.0
HgO(s) (yellow)	−90.2	73.0
HgS(s) (red)	−58.2	77.8
HgS(s) (black)	−54.0	83.3

a) Calculate the value of $\Delta G^{\ominus}$ for the change

$$HgO(s)\ (red) \longrightarrow HgO(s)\ (yellow)$$
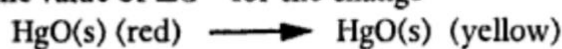
at 25 °C and at 100 °C. At what temperature will the change take place?

b) Calculate the value of $\Delta G^{\ominus}$ for the change

$$HgS(s)\ (red) \longrightarrow HgS(s)\ (black)$$
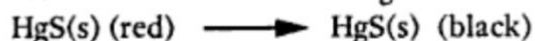
at 25 °C. At what temperature will the change occur?

112.

Cis-but-2-ene has $\Delta H_F^{\ominus} = -5.7\, kJ\, mol^{-1}$ and $S^{\ominus} = 301\, J\, K^{-1}\, mol^{-1}$; *trans*-but-2-ene has $\Delta H_F^{\ominus} = -10.1\, kJ\, mol^{-1}$ and $S^{\ominus} = 296\, J\, K^{-1}\, mol^{-1}$. Calculate

a) $\Delta G^{\ominus}$ for the transition *cis*-but-2-ene $\longrightarrow$ *trans*-but-2-ene and

b) for the transition *trans*-but-2-ene $\longrightarrow$ *cis*-but-2-ene

Which is the more stable isomer?

113.

Some energy data are tabulated below.

Process	$\Delta H^{\ominus}$ (298 K)/kJ mol^{-1}
$Na(s) \longrightarrow Na(g)$	$+108$
$\frac{1}{2}Cl_2(g) \longrightarrow Cl(g)$	$+121$
$Na(g) \longrightarrow Na^+(g) + e^-$	$+496$
$Cl(g) + e^- \longrightarrow Cl^-(g)$	-349
$Ca(g) \longrightarrow Ca^{2+}(g) + 2e^-$	$+1736$
$Ca^{2+}(g) \longrightarrow Ca^{3+}(g) + e^-$	$+4941$
$Ca^{2+}(g) + 2Cl^-(g) \longrightarrow CaCl_2(s)$	-2220
$Ca^{3+}(g) + 3Cl^-(g) \longrightarrow CaCl_3(s)$	-4800 (est)
$NaCl(s) \longrightarrow Na^+(g) + Cl^-(g)$	$+787$
$NaCl(s) + water \longrightarrow Na^+(aq) + Cl^-(aq)$	$+4$

Using this information,
i) calculate the standard molar enthalpy change for the process

$$Na(s) + \tfrac{1}{2}Cl_2(g) \longrightarrow Na^+(g) + Cl^-(g)$$
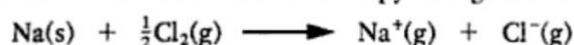
ii) explain why $CaCl_3(s)$ does not exist but $CaCl_2(s)$ does
iii) comment on the difference between the values of the enthalpy change of lattice breaking of $NaCl(s)$ and the enthalpy of solution of $NaCl(s)$ in water and define a term which is useful in this context
iv) discuss the processes occurring at the molecular level when solid sodium chloride dissolves in water.

114.

The industrial preparation of the polymer, poly(tetrafluoroethene) or PTFE, is based on the synthesis of the monomer tetrafluoroethene, $CF_2{=}CF_2$, which is produced by thermal cracking of chlorodifluoromethane, $CHClF_2$, according to reaction (1) below.

$$2CHClF_2(g) \rightleftharpoons CF_2{=}CF_2(g) + 2HCl(g) \qquad (1)$$
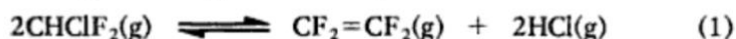
Here the $CHClF_2$ is diluted by superheated steam, which also acts as the heat source.

The monomer $CF_2{=}CF_2$ is also obtained via reaction (2).

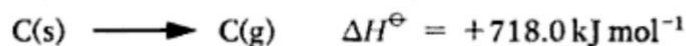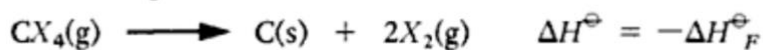$$2CHF_3(g) \rightleftharpoons CF_2{=}CF_2(g) + 2HF(g)$$
$$\Delta H^{\ominus} = +198.1 \text{ kJ mol}^{-1} \qquad (2)$$
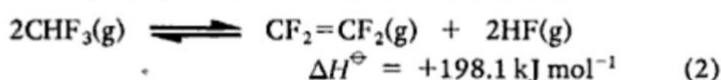
Consider this information, together with the data in the table below, and answer the following questions.

Compound	$\Delta H_F^{\ominus}$ /kJ mol^{-1}	Compound	$\Delta H_F^{\ominus}$ /kJ mol^{-1}	Molecule $X{-}X$	$D(X-X)$ /kJ mol^{-1}
$HCl(g)$	-92.3	$CF_4(g)$	-679.6	$F{-}F(g)$	154.7
$CHClF_2(g)$	-485.2	$CCl_4(g)$	-106.6	$Cl{-}Cl(g)$	246.7
$CF_2{=}CF_2(g)$	-658.3				

115.

a) i) Calculate the value of the enthalpy change, $\Delta H^{\ominus}$, for reaction (1). State, giving your reasons, how you would expect the yield of the tetrafluoroethene monomer to be affected by: 1. increase of temperature and 2. increase of pressure. In the latter case explain how your conclusion is compatible with the experimental conditions described.

   ii) Indicate and explain whether there are any drawbacks to the use of reaction (2) which would make reaction (1) preferable.

b) i) Use the expressions

$$CX_4(g) \longrightarrow C(s) + 2X_2(g) \qquad \Delta H^{\ominus} = -\Delta H^{\ominus}_F$$

$$C(s) \longrightarrow C(g) \qquad \Delta H^{\ominus} = +718.0\,\text{kJ mol}^{-1}$$

and

$$2X_2(g) \longrightarrow 4X(g) \qquad \Delta H^{\ominus} = 2D(X-X)$$
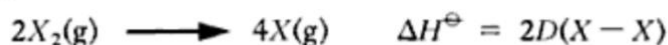
where $X = $ F, Cl, to calculate $\Delta H^{\ominus}$ for the *two* processes

$$CX_4(g) \longrightarrow C(g) + 4X(g).$$

Hence find the average C–X bond energies for the species $CX_4(g)$ (where $X = $ F and $X = $ Cl). Given that the average C–H bond energy is 416.1 kJ mol^{-1}, explain the implications of your results for the relative chemical reactivities of C–H, C–F and C–Cl bonds.

116.

Methanol can be produced from methane by a two-step process.

Step 1 $CH_4(g) + H_2O(g) \rightleftharpoons CO(g) + 3H_2(g)$

Step 2 $CO(g) + 2H_2(g) \rightleftharpoons CH_3OH(g)$
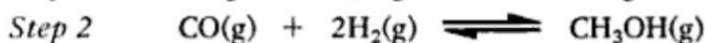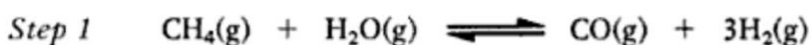
i) Use the following enthalpies of combustion to calculate the enthalpy change, ΔH, for each of the two steps.

	$CH_4(g)$	$CO(g)$	$H_2(g)$	$CH_3OH(g)$
$\Delta H_c/\text{kJ mol}^{-1}$	-808	-283	-245	-671

(*Note*   Where water is a product of combustion the figures refer to the formation of $H_2O(g)$.)

117.   Write down the chemical equations for the reactions appropriate to each of the following statements relevant to 298 K.

(i)   The standard electron gain enthalpy of chlorine is +350 kJ mol^{-1}.

(ii)   The standard lattice enthalpy of sodium fluoride is -620 kJ mol^{-1}.

(iii)   The standard enthalpy of formation of water is -300 kJ mol^{-1}.

(iv)   The standard enthalpy of formation of trinitrotoluene ($C_7H_5N_3O_6$) is -250 kJ mol^{-1}.

(v)   The standard enthalpy of combustion of methane is -800 kJ mol^{-1}.

Trinitrotoluene can react with O_2(g) according to the following equation.
$$2C_7H_5N_3O_6(s) + 8O_2(g) \rightarrow 3N_2(g) + 5H_2(g) + 14CO_2(g)$$

The standard enthalpy at 298 K for this rection is 2550 kJ per mole of TNT. Obtaining only the necessary data from above, calculate the standard enthalpy of formation of CO_2(g) at 298 K.

118.

An important reaction in the Ostwald Processs, the industrial production of sulphuric acid, is shown by the equation below in which sulphur dioxide is oxidised to sulphur trioxide.

$$SO_2(g) + \tfrac{1}{2}O_2(g) \rightarrow SO_3(g)$$
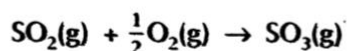
Substance	ΔH°_f/kJ mol^{-1}	S°/J K^{-1} mol^{-1}
SO_2(g)	–297	248
O_2(g)	0	205
SO_3(g)	–396	257

(a) Calculate ΔH° and ΔS° (per mole of SO_2(g) reacted) for this reaction.

(b) Calculate ΔG° for the reaction at 298 K.

(c) Over what temperature range is the reaction spontaneous?

119.

When 1 mole of rubidium chloride is dissolved in water at 298 K to form a solution of concentration 1 mol dm^{-3}, the enthalpy change is $+19$ kJ mol^{-1}:
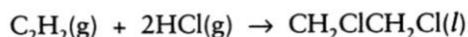
$$RbCl(s) + aq \longrightarrow Rb^+(aq) + Cl^-(aq)$$
$$\Delta H^\ominus_{298} = +19 \text{ kJ mol}^{-1}$$
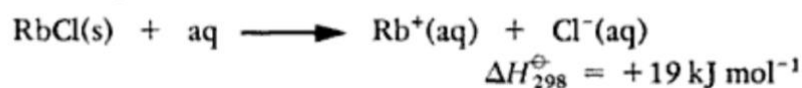
i) Calculate the entropy change in the system for this process from the data:

$$S^\ominus[RbCl(s)] = +95.9 \text{ J mol}^{-1} K^{-1}$$
$$S^\ominus[Rb^+(aq)] = +121.5 \text{ J mol}^{-1} K^{-1}$$
$$S^\ominus[Cl^-(aq)] = +56.5 \text{ J mol}^{-1} K^{-1}$$

120.

Hydrogen chloride can undergo an addition reaction with ethyne as shown below.

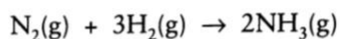$$C_2H_2(g) + 2HCl(g) \rightarrow CH_2ClCH_2Cl(l)$$

Substance	$\Delta H°_f$/kJ mol^{-1}	$S°$/J K^{-1} mol^{-1}
$C_2H_2(g)$	227	201
$HCl(g)$	–92	187
$CH_2ClCH_2Cl(l)$	–166	208

(a) Calculate $\Delta H°$ and $\Delta S°$ (per mole of $C_2H_2(g)$) for the reaction given.

(b) Over what temperature range is this reaction thermodynamically feasible?

121.

The industrial production of ammonia by the Haber Process is represented by the following equation.

$$N_2(g) + 3H_2(g) \rightarrow 2NH_3(g)$$

The relevant data are given below.

Substance	$\Delta H°_f$/kJ mol^{-1}	$S°$/J K^{-1} mol^{-1}
$N_2(g)$	0	192
$H_2(g)$	0	131
$NH_3(g)$	–46	193

(a) Calculate $\Delta H°$ and $\Delta S°$ (per mole of $N_2(g)$) for this reaction.

(b) Calculate $\Delta G°$ (per mole of $N_2(g)$) for the reaction at 500 K.

(c) Over what temperature range is the reaction spontaneous?

122. (a) When 0.025 mol $Na_2CO_3(s)$ was added to 25 mL of 3.00 mol dm^{-3} HCl solution at room temperature, the temperature of the solution was observed to increase by 8.0 °C. The specific thermal capacity of the resulting solution is 5000 J kg^{-1} K^{-1} and its density is 1000 kg m^{-3}.

(i) Calculate the heat liberated during the above-mentioned reaction.

(ii) Calculate the enthalpy of neutralisation, per mole of HCl reacted. State any other assumptions you make in this calculation.

(iii) The enthalpy change ΔH, for the reaction,

$$NaHCO_3(s) + HCl(aq) \rightarrow NaCl(aq) + CO_2(g) + H_2O(l)$$

Carried under the same conditions as the above-mentioned reaction is -25.5 kJ mol^{-1}. Calculate the enthalpy change ΔH, for the reaction,

$$2NaHCO_3(s) \rightarrow Na_2CO_3(aq) + CO_2(g) + H_2O(l)$$

Carried out under the same condition.

(f) You are provided with following thermos-chemical data

Standard enthalpy of formation of KCl(s)	= -437 kJ mol^{-1}
Standard enthalpy of sublimation of K(s)	= +89 kJ mol^{-1}
Standard enthalpy of dissociation of $Cl_2(g)$	= +244 kJ mol^{-1}

Standard enthalpy of first ionisation K(g) = +418 kJ mol^{-1}
Standard enthalpy of electron gain of Cl(g) = -349 kJ mol^{-1}

Calculate the standard lattice enthalpy of KCl(s)

123.