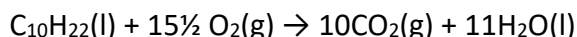


COLLATED QUESTIONS

Hess's Law including application of $\Delta_r H = \sum \Delta_f H(\text{products}) - \sum \Delta_f H(\text{reactants})$ and related calculations.

2017:2

- (c) Carbon dioxide and water are formed when decane burns completely in oxygen. The reaction is shown in the equation below.



Calculate the enthalpy of combustion for decane, given the following data:

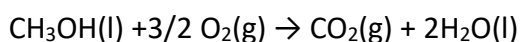
$$\Delta_f H^\circ (\text{C}_{10}\text{H}_{22}(\text{l})) = -301 \text{ kJ mol}^{-1}$$

$$\Delta_c H^\circ (\text{C}) = -393 \text{ kJ mol}^{-1}$$

$$\Delta_c H^\circ (\text{H}_2) = -286 \text{ kJ mol}^{-1}$$

2016: 3

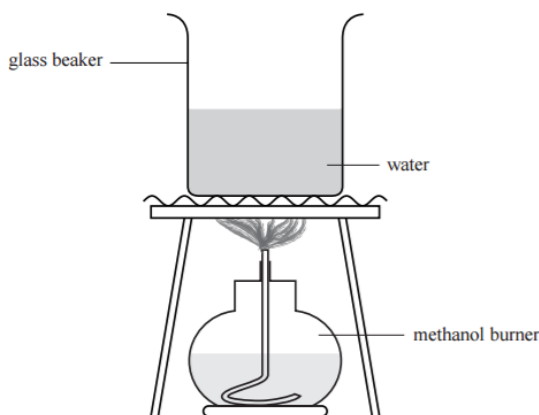
- (a) The equation for the combustion of liquid methanol is:



Calculate the standard enthalpy of combustion of liquid methanol, $\Delta_c H^\circ(\text{CH}_3\text{OH}(\text{l}))$, using the information in the table below.

Compound	kJ mol^{-1}
$\Delta_c H^\circ(\text{C}(\text{s}))$	-394
$\Delta_c H^\circ(\text{H}_2(\text{g}))$	-286
$\Delta_f H^\circ(\text{CH}_3\text{OH}(\text{l}))$	-240

- (b) The enthalpy of combustion of liquid methanol, $\Delta_c H^\circ(\text{CH}_3\text{OH}(\text{l}))$, can also be determined by burning a known mass of methanol and measuring the temperature change in a known mass of water above the burning methanol.



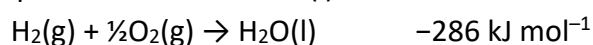
- (i) If 2.56 g of methanol is burned, the temperature of 500 g water increases from 21.2°C to 34.5°C. Using these results, calculate the experimental value of $\Delta_c H^\circ(\text{CH}_3\text{OH}(\text{l}))$.
The specific heat capacity of water is $4.18 \text{ J } ^\circ\text{C}^{-1} \text{ g}^{-1}$. $M(\text{CH}_3\text{OH}) = 32.0 \text{ g mol}^{-1}$

AS91390 Demonstrate understanding of thermochemical principles and the properties of particles and substances

- (ii) Why is the experimental value obtained in part (b)(i) less negative than the theoretical value determined in part (a)?
- (iii) The equation for the evaporation of liquid methanol is: $\text{CH}_3\text{OH}(\text{l}) \rightarrow \text{CH}_3\text{OH}(\text{g})$
Explain the entropy changes of the system and surroundings for the evaporation of methanol.

2015: 2

The equation for $\Delta_f H^\circ$ of $\text{H}_2\text{O}(\text{l})$ is:

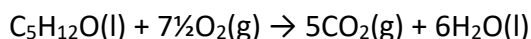


- (a) (i) Write the equation for $\Delta_c H^\circ(\text{H}_2(\text{g}))$.
- (ii) Using the equations above, explain why $\Delta_c H^\circ(\text{H}_2)$ and $\Delta_f H^\circ(\text{H}_2\text{O})$ have the same value of -286 kJ mol^{-1} .
- (b) The enthalpy of formation would change if the water was formed as a gas rather than a liquid.
 - (i) Circle the correct phrase to complete the sentence below. $\Delta_f H^\circ(\text{H}_2\text{O}(\text{g}))$ is:
less negative than / the same as / more negative
than $\Delta_f H^\circ(\text{H}_2\text{O}(\text{l}))$.
 - (ii) Justify your choice
- (c) Calculate the $\Delta_f H^\circ$ for $\text{B}_2\text{H}_6(\text{g})$, given the following data:

$\Delta_f H^\circ(\text{B}_2\text{O}_3(\text{s}))$	$= -1255 \text{ kJ mol}^{-1}$
$\Delta_f H^\circ(\text{H}_2\text{O}(\text{l}))$	$= -286 \text{ kJ mol}^{-1}$
$\text{B}_2\text{H}_6(\text{g}) + 3\text{O}_2(\text{g}) \rightarrow \text{B}_2\text{O}_3(\text{s}) + 3\text{H}_2\text{O}(\text{l})$	$\Delta_r H^\circ = -2148 \text{ kJ mol}^{-1}$

2015: 3

- (d) The equation for the combustion of pentan-1-ol is:



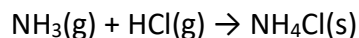
Calculate $\Delta_c H^\circ$ for pentan-1-ol, given the following data:

$\Delta_f H^\circ(\text{C}_5\text{H}_{12}\text{O}(\text{l}))$	$= -295 \text{ kJ mol}^{-1}$
$\Delta_f H^\circ(\text{CO}_2(\text{g}))$	$= -394 \text{ kJ mol}^{-1}$
$\Delta_f H^\circ(\text{H}_2\text{O}(\text{l}))$	$= -286 \text{ kJ mol}^{-1}$

AS91390 Demonstrate understanding of thermochemical principles and the properties of particles and substances

2014: 2

- (c) An equation for the reaction of ammonia gas with hydrogen chloride gas is:



Calculate the standard enthalpy change, $\Delta_r H^\circ$, for this reaction, using the following data.

$$\Delta_f H^\circ (\text{NH}_3(\text{g})) = -46 \text{ kJ mol}^{-1}$$

$$\Delta_f H^\circ (\text{HCl}(\text{g})) = -92 \text{ kJ mol}^{-1}$$

$$\Delta_f H^\circ (\text{NH}_4\text{Cl}(\text{s})) = -314 \text{ kJ mol}^{-1}$$

2014: 3

- (d) (i)

Compound	kJ mol^{-1}
$\Delta_c H^\circ (\text{C}(\text{s}))$	-394
$\Delta_f H^\circ (\text{H}_2\text{O}(\text{l}))$	-286
$\Delta_c H^\circ \text{C}_2\text{H}_5\text{OH}(\text{l})$	-1367

Calculate the standard enthalpy of formation of liquid ethanol using the information given above.

- (ii) Discuss how the value of the enthalpy change would differ if the ethanol product formed was a gas rather than a liquid. No calculation is necessary.

2013: 2

- (a) (ii) When gaseous hydrogen and oxygen are heated in a test tube, droplets of liquid water form on the sides of the test tube. Calculate $\Delta_f H^\circ (\text{H}_2\text{O}(\text{l}))$, given the following data:

$$\Delta_f H^\circ (\text{H}_2\text{O}(\text{g})) = -242 \text{ kJ mol}^{-1}$$

$$\Delta_{\text{vap}} H^\circ (\text{H}_2\text{O}(\text{l})) = +44 \text{ kJ mol}^{-1}$$

- (b) (i) When 25.0 mL of a 1.00 mol L^{-1} hydrochloric acid solution, HCl, is added to 25.0 mL of a 1.00 mol L^{-1} ammonia solution, NH_3 , a temperature rise of 6.50°C is recorded, as a neutralisation reaction occurs to produce aqueous ammonium chloride and water.

Calculate $\Delta_r H^\circ$ for this neutralisation reaction.

The mass of the mixture is 50.0 g.

Assume specific heat capacity of the aqueous ammonium chloride = 4.18 J $\text{g}^{-1} \text{ } ^\circ\text{C}^{-1}$

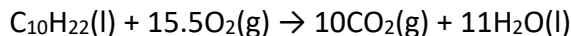
- (ii) When the $\Delta_r H^\circ$ for the neutralisation above was found experimentally in a school laboratory, the value obtained was lower than the theoretical value.

Account for the difference in values, and suggest how this difference could be minimised.

AS91390 Demonstrate understanding of thermochemical principles and the properties of particles and substances

2013: 3

- (b) Decane is a component of petrol. Carbon dioxide and water are formed when decane burns completely in oxygen.

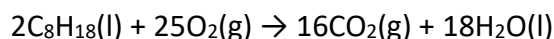


Calculate $\Delta_c H^\circ(\text{C}_{10}\text{H}_{22}(\text{l}))$, given the following data:

$$\begin{aligned}\Delta_f H^\circ(\text{C}_{10}\text{H}_{22}(\text{l})) &= -250 \text{ kJ mol}^{-1} \\ \Delta_f H^\circ(\text{CO}_2(\text{g})) &= -393 \text{ kJ mol}^{-1} \\ \Delta_f H^\circ(\text{H}_2\text{O}(\text{l})) &= -286 \text{ kJ mol}^{-1}\end{aligned}$$

2012:3

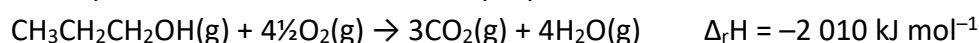
- (a) (i) Explain what is meant by the symbol $\Delta_c H^\circ$
(ii) An equation for the combustion of octane is:



Calculate $\Delta_c H^\circ(\text{C}_8\text{H}_{18}(\text{l}))$, given the following data:

$$\begin{aligned}\Delta_f H^\circ(\text{C}_8\text{H}_{18}(\text{l})) &= -250 \text{ kJ mol}^{-1} \\ \Delta_f H^\circ(\text{CO}_2(\text{g})) &= -394 \text{ kJ mol}^{-1} \\ \Delta_f H^\circ(\text{H}_2\text{O}(\text{l})) &= -286 \text{ kJ mol}^{-1}\end{aligned}$$

- (b) The equation for the combustion of propan-1-ol is:



Calculate the bond enthalpy for the C=O bond, using the enthalpy of the reaction above and the bond enthalpy data in the table.

Bond	Bond enthalpy / kJ mol^{-1}
C–H	+414
C–O	+358
O=O	+498
C–C	+346
O–H	+463

- (c) Define bond enthalpy and explain why the bond enthalpy value calculated for C=O is higher than the C–O bond enthalpy.

2011:3

- (c) The equation for the combustion of ethanol is: $\text{C}_2\text{H}_5\text{OH}(\text{l}) + 3\text{O}_2(\text{g}) \rightarrow 2\text{CO}_2(\text{g}) + 3\text{H}_2\text{O}(\text{l})$

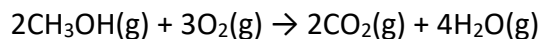
Calculate $\Delta_c H^\circ(\text{C}_2\text{H}_5\text{OH}(\text{l}))$, given the following data:

$$\begin{aligned}\Delta_f H^\circ(\text{C}_2\text{H}_5\text{OH}(\text{l})) &= -277 \text{ kJ mol}^{-1} \\ \Delta_f H^\circ(\text{CO}_2(\text{g})) &= -394 \text{ kJ mol}^{-1} \\ \Delta_f H^\circ(\text{H}_2\text{O}(\text{l})) &= -286 \text{ kJ mol}^{-1}\end{aligned}$$

AS91390 Demonstrate understanding of thermochemical principles and the properties of particles and substances

2011:4

- (a) Explain why $\Delta_f H^\circ(\text{CO}_2(\text{g}))$ and $\Delta_c H^\circ(\text{C}(\text{s}))$ have the same value of -394 kJ mol^{-1} .
 (b) Complete combustion of methanol can be represented by the following chemical equation:



Use the following bond enthalpies to calculate $\Delta_r H$ for this reaction.

Bond	Bond enthalpy / kJ mol^{-1}
C–H	+414
C–O	+358
O–H	+463
C=O	+745
O=O	+498

- (c) (i) Use the information below to show that the $\Delta_c H^\circ$ of propene, $\text{CH}_2=\text{CHCH}_3(\text{g})$, is $-2058 \text{ kJ mol}^{-1}$.
 $\text{C} \quad \text{CH}_2=\text{CHCH}_3(\text{g}) + \text{H}_2(\text{g}) \rightarrow \text{CH}_3\text{CH}_2\text{CH}_3(\text{g}) \quad \Delta_r H^\circ = -124 \text{ kJ mol}^{-1}$
 $\text{CH}_3\text{CH}_2\text{CH}_3(\text{g}) \quad \Delta_c H^\circ = -2220 \text{ kJ mol}^{-1}$
 $\text{H}_2\text{O}(\text{l}) \quad \Delta_f H^\circ = -286 \text{ kJ mol}^{-1}$
- (ii) The $\Delta_c H^\circ$ of propene was found experimentally in a school laboratory to be $-1368 \text{ kJ mol}^{-1}$. The theoretical value is $-2058 \text{ kJ mol}^{-1}$. Account for the difference in values, and suggest how this difference could be minimised.

Answers

2016: 3

(a) $\Delta_c H^\circ = -394 + (2 \times -286) - (-240)$

$\Delta_c H^\circ = -966 + 240$

$\Delta_c H^\circ = -726 \text{ kJ mol}^{-1}$

(b) (i) $q = mc\Delta T$

$q = 500 \text{ g} \times 4.18 \text{ J } ^\circ\text{C}^{-1} \text{ g}^{-1} \times (34.5^\circ\text{C} - 21.2^\circ\text{C})$

$q = 27\,797 \text{ J} = 27.797 \text{ kJ}$

$n(\text{CH}_3\text{OH}) = m/M = 2.56/32 = 0.08 \text{ mol}$

$\Delta_c H = -q / n = -27.797 / 0.08 = -347 \text{ kJ mol}^{-1}$

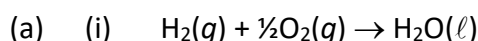
(ii) Heat loss to surroundings / incomplete combustion which means the temperature of the water doesn't increase as much leading to a less negative enthalpy / the experiment wasn't insulated.

(iii) Entropy

There is an increase in entropy since gaseous particles are formed; gaseous particles have a more random / disordered arrangement (greater dispersal of matter) than liquid particles.

The enthalpy of the surroundings decreases as the alcohol evaporates as energy is absorbed from the surroundings to break the intermolecular forces between methanol molecules; thus the entropy of the surroundings decreases.

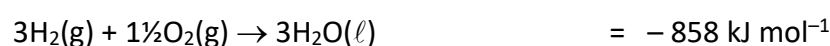
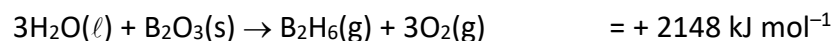
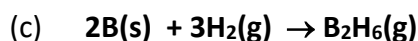
2015: 2



(ii) The equation for the combustion of hydrogen is the same as the equation for the heat of formation of water.

(b) (i) The $\Delta_f H^\circ (\text{H}_2\text{O}(\text{g}))$ will be **less negative** than $\Delta_f H^\circ (\text{H}_2\text{O}(\ell))$.

(ii) Making bonds releases energy. As less bonding is present in water as a gas than a liquid then less energy will be released when gaseous water is formed thus the $\Delta_f H^\circ (\text{H}_2\text{O}(\text{g}))$ will be less negative.



$= + 35 \text{ kJ mol}^{-1}$

AS91390 Demonstrate understanding of thermochemical principles and the properties of particles and substances

2015: 3

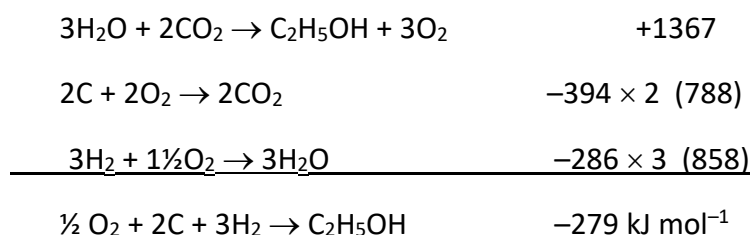
$$\begin{aligned}
 \text{(d)} \quad \Delta_c H^\circ &= \Sigma \Delta_f H^\circ (\text{products}) - \Sigma \Delta_f H^\circ (\text{reactants}) \\
 &= [(5 \times -394) + (6 \times -286)] - [-295] \\
 &= -3686 + 295 \\
 &= -3391 \text{ kJ mol}^{-1}
 \end{aligned}$$

2014:2

$$\begin{aligned}
 \text{(c)} \quad \Delta_r H^\circ &= \Sigma \Delta_f H^\circ \text{ products} - \Sigma \Delta_f H^\circ \text{ reactants} \\
 &= (-314) - (-46 + -92) \\
 &= -176 \text{ kJ mol}^{-1}
 \end{aligned}$$

2014:3

(d) (i)



- (ii) The enthalpy change would be more positive. Heat energy is absorbed when converting a liquid to a gas. Therefore, if the ethanol formed were in the gaseous state, less energy would be released in its formation / products would have a higher enthalpy.

2013:2

$$\begin{aligned}
 \text{(a)} \quad \text{(ii)} \quad &\text{Find} \quad \text{H}_2(\text{g}) + \frac{1}{2} \text{O}_2(\text{g}) \rightarrow \text{H}_2\text{O}(\ell) \\
 &\text{Given} \quad \text{H}_2\text{O}(\ell) \rightarrow \text{H}_2\text{O}(\text{g}) \quad \Delta H = 44 \text{ kJ mol}^{-1} \text{ (reverse)} \\
 &\text{H}_2(\text{g}) + \frac{1}{2} \text{O}_2(\text{g}) \rightarrow \text{H}_2\text{O}(\text{g}) \quad \Delta H = -242 \text{ kJ mol}^{-1} \\
 &\Delta_f H^\circ(\text{H}_2\text{O}(\ell)) = -44 + (-242) = -286 \text{ kJ mol}^{-1}
 \end{aligned}$$

2013:2

$$\begin{aligned}
 \text{(b)} \quad \text{(i)} \quad q &= mc\Delta T = 50 \times 4.18 \times 6.5 = 1358.5 \text{ J} = 1.3585 \text{ kJ} \\
 n &= c \times V = 1 \times 0.025 = 0.025 \text{ mol}
 \end{aligned}$$

$$\begin{aligned}
 \Delta_r H^\circ &= \frac{-q}{n} = \frac{-1.3585 \text{ kJ}}{0.025 \text{ mol}} \\
 &= -54.3 \text{ kJ mol}^{-1}
 \end{aligned}$$

AS91390 Demonstrate understanding of thermochemical principles and the properties of particles and substances

- (ii) Conditions were not standard.

Needed to carry out under standard conditions.

OR Heat lost to atmosphere / beaker / surroundings.

Insulate equipment; ensure all / as much of the energy produced as possible is collected and measured.

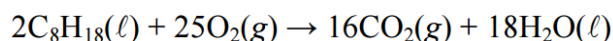
2012:3

- (a) (i) The heat evolved / energy change when one mole of a substance is combusted / burnt in oxygen / reacted completely in oxygen under standard conditions

- (ii)

$$\begin{array}{rcl}
 8\text{C} + 9\text{H}_2 \rightarrow \text{C}_8\text{H}_{18} & 2 \text{ (250)} & = 500 \\
 \text{C} + \text{O}_2 \rightarrow \text{CO}_2 & 16 \text{ (-394)} & = -6304 \\
 \text{H}_2 + 1/2\text{O}_2 \rightarrow \text{H}_2\text{O} & 18 \text{ (-286)} & = -5148 \\
 & \hline
 & -10\,952 / 2 & = -5476 \text{ kJ mol}^{-1}
 \end{array}$$

OR



$$\begin{aligned}
 \Delta_r H^\circ &= \Sigma \Delta_f H^\circ_{\text{products}} - \Sigma \Delta_f H^\circ_{\text{reactants}} \\
 &= 16(-394) + 18(-286) - 2(-250) = -10952 \text{ kJ mol}^{-1} \\
 \Delta_c H^\circ &= -10952 / 2 = -5476 \text{ kJ mol}^{-1}
 \end{aligned}$$

- (b)

Enthalpy change = $\Sigma(\text{bonds broken}) - \Sigma(\text{bonds formed})$

$$x = E_{(\text{C}=\text{O})}$$

$$\begin{aligned}
 \text{Bonds broken} &= 7(\text{C-H}) + 2(\text{C-C}) + 1(\text{C-O}) + 1(\text{O-H}) + 4.5(\text{O=O}) \\
 &= 7(414) + 2(346) + 358 + 463 + 4.5(498) \\
 &= 2898 + 692 + 358 + 463 + 2241
 \end{aligned}$$

$$\text{Bonds broken} = 6\,652 \text{ kJ mol}^{-1}$$

$$\begin{aligned}
 \text{Bonds formed} &= 6(\text{C=O}) + 8(\text{O-H}) \\
 &= 6(x) + 8(463) \\
 &= 6(x) + 3704
 \end{aligned}$$

$$-2010 = (6652) - (6(x) + 3704)$$

$$-2010 = 2948 - 6(x)$$

$$-4958 = -6(x)$$

$$E_{(\text{C}=\text{O})} = 826 \text{ kJ mol}^{-1} \text{ OR } 826.3 \text{ kJ mol}^{-1}$$

- (c) The bond enthalpy is the energy required to break one mole of bonds between (pairs of) atoms (in the gaseous state). C=O bond enthalpy is larger than C-O bond enthalpy as more energy is required to break the double bond than a single bond.

2011:3

- (c)

AS91390 Demonstrate understanding of thermochemical principles and the properties of particles and substances

$$\begin{aligned}\Delta_r H &= \sum \Delta_f H^\circ (\text{products}) - \sum \Delta_f H^\circ (\text{reactants}) \\ &= [(2 \times -394) + (3 \times -286)] - [-277] \\ &= -1646 + 277 \\ &= -1\,369 \text{ kJ mol}^{-1}\end{aligned}$$

2011:4

- (a) $\Delta_f H^\circ (\text{CO}_2(\text{g}))$ is equal to the enthalpy change for the reaction in which one mole of $\text{CO}_2(\text{g})$ is formed from its elements in their standard state. $\text{C}(\text{s}) + \text{O}_2(\text{g}) \rightarrow \text{CO}_2(\text{g})$.
This is also the equation for $\Delta_c H^\circ (\text{C}(\text{s}))$, the combustion of one mole of carbon under standard conditions.

(b)

$$\text{Enthalpy change} = \sum \text{bonds broken} - \sum \text{bonds formed}$$

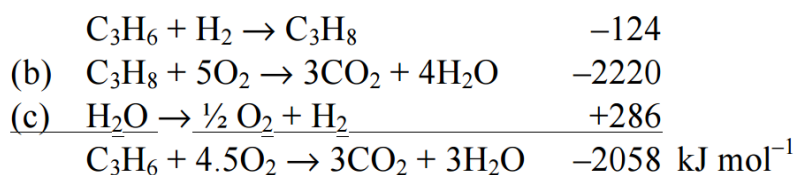
Bonds broken	Bonds formed
C – H $413 \times 6 = 2478$	C=O $745 \times 4 = 2980$
C – O $358 \times 2 = 716$	O–H $463 \times 8 = 3704$
O – H $463 \times 2 = 926$	
O = O $498 \times 3 = 1494$	
+5614	<hr/> – 6684

$$\Delta_r H = -1070 \text{ kJ mol}^{-1}$$

OR

$$\text{Bonds broken} = 4688 \quad \text{Bonds formed} = 5758$$

- (c) (i) (a) $\text{C}_3\text{H}_6 + 4\frac{1}{2} \text{O}_2 \rightarrow 3\text{CO}_2 + 3\text{H}_2\text{O}$



- (ii) Conditions were not standard. Carry out under standard conditions.
Heat lost to atmosphere / beaker / by evaporation. Insulate equipment, ensure all / as much as possible, of the energy produced is collected and measured.
Not complete combustion – make sure O_2 supply sufficient for complete combustion.