

5.2 HESS' LAW

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Introduction

Calculating enthalpy change of reaction from enthalpy change of formations

1. Iron is made when iron(III) oxide is heated with carbon monoxide, as shown by reaction 2.

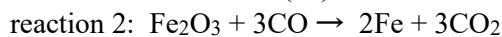


Table 4.1 shows enthalpy change of formation data measured at 298 K and 101 kPa.

substance	equation	value for $\Delta H_f^\ominus / \text{kJ mol}^{-1}$
Fe_2O_3		-824.2
CO		-110.5
CO_2	$\text{C(s)} + \text{O}_2\text{(g)} \rightarrow \text{CO}_2\text{(g)}$	-393.5

(i) Complete Table 4.1 by adding equations with relevant state symbols to represent:

- standard enthalpy change of formation for Fe_2O_3
- standard enthalpy change of formation for CO.

[2]

(ii) Use the data in Table 4.1 to calculate the enthalpy change of reaction, ΔH_r , in kJ mol^{-1} , for reaction 2.

Show your working.

$$\Delta H_r = \dots\dots\dots(\text{ans} = -24.8) \dots\dots\dots \text{kJ mol}^{-1} [2]$$

2. H_3PO_4 is also formed in the process shown in reaction 1.

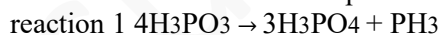


Table 3.1 shows some relevant thermodynamic data.

Table 3.1

compound	enthalpy change of formation, $\Delta H_f / \text{kJ mol}^{-1}$
H_3PO_3	-972
H_3PO_4	-1281
PH_3	+9

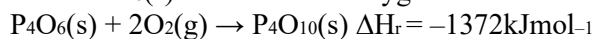
(i) Define enthalpy change of formation.

[2]

(ii) Use the data in Table 3.1 to calculate the enthalpy change, ΔH_r , of reaction 1.

(ans = 54 kJmol⁻¹) [2]

3. When P₄O₆(s) is heated with oxygen it forms P₄O₁₀(s).



The enthalpy change of formation, ΔH_f , of P₄O₁₀(s) is -3012 kJmol⁻¹.

Calculate the enthalpy change of formation, ΔH_f , of P₄O₆(s)

(ans = -1640 kJmol⁻¹) [1]

4. The enthalpy change of combustion of CS₂(l) is represented by the following equation.



The table shows the enthalpy changes of formation of CS₂(l), CO₂(g) and SO₂(g).

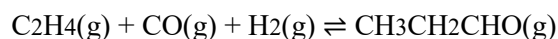
compound	enthalpy change of formation, ΔH_f /kJmol ⁻¹
CS ₂ (l)	+89.7
CO ₂ (g)	-394
SO ₂ (g)	-297

Use the data in the table to calculate the enthalpy change of combustion, ΔH_c , of CS₂(l), in kJmol⁻¹.
Show your working.

ΔH_c of CS₂(l) = ...(ans = -1077)..... kJmol⁻¹ [2]

5. Use the information in Table 3.2 to calculate the enthalpy change, ΔH_r , of the reaction in equation 1.

equation 1



compound	enthalpy change of formation, $\Delta H_f^\circ/\text{kJmol}^{-1}$
$\text{C}_2\text{H}_4(\text{g})$	+52
$\text{CO}(\text{g})$	-111
$\text{CH}_3\text{CH}_2\text{CHO}(\text{g})$	-187

$$\Delta H_r = \dots\dots(\text{ans} = -128)\dots\dots\dots \text{kJmol}^{-1} [2]$$

6. Emissions of SO_2 from coal-fired power stations can be reduced by mixing the coal with powdered limestone. Limestone is heated to form CaO in reaction 1. This then reacts with SO_2 and O_2 to form CaSO_4 in reaction 2.
- reaction 1: $\text{CaCO}_3(\text{s}) \rightarrow \text{CaO}(\text{s}) + \text{CO}_2(\text{g})$
- reaction 2: $\text{CaO}(\text{s}) + \text{SO}_2(\text{g}) + 1/2\text{O}_2(\text{g}) \rightarrow \text{CaSO}_4(\text{s})$ Use the data to calculate the enthalpy change of reaction 2.

compound	$\Delta H_f^\circ/\text{kJmol}^{-1}$
$\text{CaO}(\text{s})$	-635
$\text{SO}_2(\text{g})$	-297
$\text{CaSO}_4(\text{s})$	-1434

$$(\text{ans} = -502 \text{ kJ mol}^{-1}) [2]$$

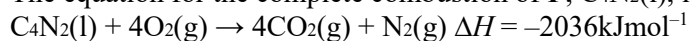
7. Sulfur, S_8 , reacts with chlorine to form several different chlorides. The most common are S_2Cl_2 and SCl_2 . SCl_2 forms when sulfur reacts with an excess of chlorine.

reaction 1	$\text{S}_8(\text{s}) + 4\text{Cl}_2(\text{g}) \rightarrow 4\text{S}_2\text{Cl}_2(\text{l})$	$\Delta H_r = -58.2 \text{ kJmol}^{-1}$
reaction 2	$\text{S}_2\text{Cl}_2(\text{l}) + \text{Cl}_2(\text{g}) \rightarrow 2\text{SCl}_2(\text{l})$	$\Delta H_r = -40.6 \text{ kJmol}^{-1}$

Calculate the enthalpy change of formation, ΔH_f° , of $\text{SCl}_2(\text{l})$. You may find it useful to use Hess's Law to construct an energy cycle.

enthalpy change of formation of $\text{SCl}_2(\text{l})$, $\Delta H_f = \dots$ (ans = -27.6)..... kJ mol^{-1} [2]

8. The equation for the complete combustion of **P**, $\text{C}_4\text{N}_2(\text{l})$, is shown.



The enthalpy change of formation, ΔH_f , of $\text{CO}_2(\text{g})$ is -384 kJ mol^{-1} .

Calculate the enthalpy change of formation, ΔH_f , of **P**, in kJ mol^{-1} .

[2]

9. Water is one of the products in the reaction of B_2O_3 and NH_3 , as shown in reaction 2.



Table 3.1 shows information about the standard enthalpy change of formation, ΔH_f° , of some substances.

substance	$\Delta H_f^\circ / \text{kJ mol}^{-1}$
B_2O_3	-1264
NH_3	-46
BN	-134
H_2O	-286

Calculate the enthalpy change, ΔH , for reaction 2 using the data from Table 3.1.

$$\Delta H = \dots\dots\dots(\text{ans} = +230)\dots\dots\dots \text{kJ mol}^{-1} [2]$$

10. Table 1.1 gives data relevant to the reaction of $\text{Cl}_2(\text{g})$ with $\text{NH}_3(\text{g})$.

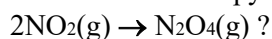
Table 1.1

Compound	enthalpy change of formation, $\Delta H_f^\ominus / \text{kJ mol}^{-1}$
$\text{NH}_3(\text{g})$	– 46
$\text{HCl}(\text{g})$	–92

Use the data in Table 1.1 to calculate the enthalpy change of the reaction of $\text{Cl}_2(\text{g})$ with $\text{NH}_3(\text{g})$.

$$\text{enthalpy change of reaction} = \dots\dots\dots \text{kJ mol}^{-1} [2]$$

1. The standard enthalpy of formation of $\text{NO}_2(\text{g})$ is $+33.2 \text{ kJ mol}^{-1}$.
The standard enthalpy of formation of $\text{N}_2\text{O}_4(\text{g})$ is $+9.2 \text{ kJ mol}^{-1}$.
What is the standard enthalpy change for the reaction



- A $-57.2 \text{ kJ mol}^{-1}$
B $-24.0 \text{ kJ mol}^{-1}$
C $+42.4 \text{ kJ mol}^{-1}$
D $+75.6 \text{ kJ mol}^{-1}$

2. The following data are needed for this question.

$$\Delta H_f^\ominus (\text{N}_2\text{H}_4(\text{l})) = 50.6 \text{ kJ mol}^{-1}$$

$$\Delta H_f^\ominus (\text{N}_2\text{O}_4(\text{g})) = 9.2 \text{ kJ mol}^{-1}$$

$$\Delta H_f^\ominus (\text{H}_2\text{O}(\text{g})) = -241.8 \text{ kJ mol}^{-1}$$

Hydrazine, $\text{N}_2\text{H}_4(\text{l})$, reacts with dinitrogen tetroxide, $\text{N}_2\text{O}_4(\text{g})$, to form nitrogen gas and water vapour.



What is the enthalpy change for this reaction?

- A $-1077.6 \text{ kJ mol}^{-1}$
B $-856.8 \text{ kJ mol}^{-1}$
C $-301.6 \text{ kJ mol}^{-1}$
D $-182.0 \text{ kJ mol}^{-1}$

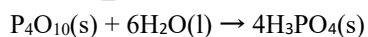
3. The data shown are needed for this question.

$$\Delta H_f^\ominus (\text{P}_4\text{O}_{10}(\text{s})) = -3012 \text{ kJ mol}^{-1}$$

$$\Delta H_f^\ominus (\text{H}_2\text{O}(\text{l})) = -286 \text{ kJ mol}^{-1}$$

$$\Delta H_f^\ominus (\text{H}_3\text{PO}_4(\text{s})) = -1279 \text{ kJ mol}^{-1}$$

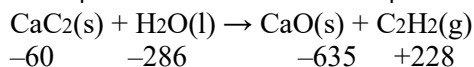
What is $\Delta H^\ominus$ for the reaction shown?



- A $-9844 \text{ kJ mol}^{-1}$
B -388 kJ mol^{-1}

C -97 kJ mol^{-1}
D $+2019 \text{ kJ mol}^{-1}$

4. Calciumcarbide, CaC_2 , reacts with water, as shown. The data below the equations how, in kJ mol^{-1} , the standard enthalpies of formation of the compounds involved.



What is the standard enthalpy change of the reaction shown?

- A -753 kJ mol^{-1}
B -61 kJ mol^{-1}
C $+61 \text{ kJ mol}^{-1}$
D $+753 \text{ kJ mol}^{-1}$

5. Ethanol is increasingly being used as a fuel for cars.

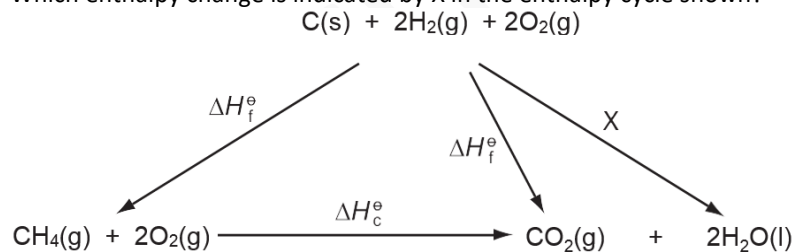
The standard enthalpy change of formation of carbon dioxide is -393 kJ mol^{-1} . The standard enthalpy change of formation of water is -286 kJ mol^{-1} .

The standard enthalpy change of formation of ethanol is -277 kJ mol^{-1} . What is the standard enthalpy change of combustion of ethanol?

- A $-1921 \text{ kJ mol}^{-1}$ B $-1367 \text{ kJ mol}^{-1}$ C -956 kJ mol^{-1} D -402 kJ mol^{-1}

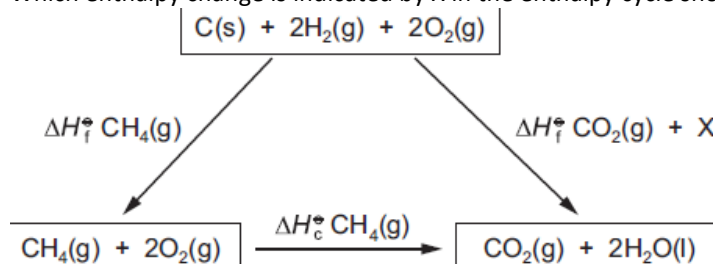
6. Enthalpy changes that are difficult to measure directly can often be determined using Hess' Law to construct an enthalpy cycle.

Which enthalpy change is indicated by X in the enthalpy cycle shown?



- A $-4 \times$ the enthalpy of combustion of hydrogen
B $+4 \times$ the enthalpy of combustion of hydrogen
C $-2 \times$ the enthalpy of formation of water
D $+2 \times$ the enthalpy of formation of water

7. Which enthalpy change is indicated by X in the enthalpy cycle shown?

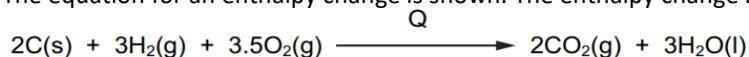


- A – 4 x the enthalpy of combustion of hydrogen
 B + 4 x the enthalpy of combustion of hydrogen
 C – 2 x the enthalpy of formation of water
 D + 2 x the enthalpy of formation of water

8. Which expression gives the standard enthalpy change of combustion of methane?

- A** $\Delta H_f^\ominus(\text{CH}_4) + \Delta H_f^\ominus(\text{CO}_2) - 2\Delta H_f^\ominus(\text{H}_2\text{O})$
B $\Delta H_f^\ominus(\text{CO}_2) + 2\Delta H_f^\ominus(\text{H}_2\text{O}) + \Delta H_f^\ominus(\text{CH}_4)$
C $\Delta H_f^\ominus(\text{CH}_4) + 2\Delta H_f^\ominus(\text{H}_2\text{O}) - \Delta H_f^\ominus(\text{CO}_2)$
D $\Delta H_f^\ominus(\text{CO}_2) + 2\Delta H_f^\ominus(\text{H}_2\text{O}) - \Delta H_f^\ominus(\text{CH}_4)$

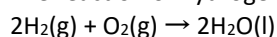
9. The equation for an enthalpy change is shown. The enthalpy change is Q.



What is the correct expression to calculate Q?

- A** $2 \times \Delta H_c^\ominus[\text{CO}_2\text{(g)}] - 3 \times \Delta H_f^\ominus[\text{H}_2\text{(g)}]$
B $3 \times \Delta H_f^\ominus[\text{H}_2\text{O(g)}] + 2 \times \Delta H_c^\ominus[\text{CO}_2\text{(g)}]$
C $2 \times \Delta H_f^\ominus[\text{CO}_2\text{(g)}] - 3 \times \Delta H_f^\ominus[\text{H}_2\text{(g)}]$
D $3 \times \Delta H_f^\ominus[\text{H}_2\text{O(l)}] + 2 \times \Delta H_f^\ominus[\text{CO}_2\text{(g)}]$

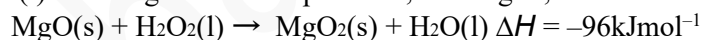
10. The reaction of hydrogen with oxygen is shown.



Which expression corresponds to the standard enthalpy change of this reaction?

- A** $2 \times \Delta H_f^\ominus(\text{H}_2\text{O})$
B $\Delta H_c^\ominus(\text{H}_2\text{O}) - \Delta H_c^\ominus(\text{H}_2)$
C $\Delta H_c^\ominus(\text{H}_2)$
D $2 \times \Delta H_f^\ominus(\text{H}_2\text{O}) + 2 \times \Delta H_c^\ominus(\text{H}_2)$

1. (i) Magnesium peroxide, MgO_2 , is made in the following reaction.

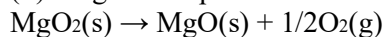


compound	enthalpy change of formation, $\Delta H_f^\ominus$, /kJmol ⁻¹
MgO(s)	-602
H ₂ O ₂ (l)	-188
H ₂ O(l)	-286

Use the data given to calculate the enthalpy change of formation of $\text{MgO}_2\text{(s)}$.

$$\Delta H_f \text{MgO}_2(\text{s}) = \dots\dots\dots \text{kJmol}^{-1} [2]$$

(ii) Magnesium peroxide decomposes slowly to form magnesium oxide and oxygen.



Use your answer to (i) and the data in the table to calculate the enthalpy change of this reaction.

If you were unable to obtain an answer to (i), use the value $\Delta H_f = -550 \text{kJmol}^{-1}$. This is not the correct answer.

$$\text{enthalpy change of reaction} = \dots\dots\dots \text{kJmol}^{-1} [1]$$

11. $\text{POCl}_3(\text{g})$ forms when $\text{PCl}_3(\text{g})$ reacts with $\text{O}_2(\text{g})$.

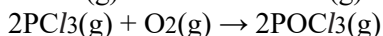


Table 1.3 gives some relevant data.

Table 1.3

process	value/ kJmol^{-1}
enthalpy change of formation of $\text{PCl}_3(\text{g})$	-289
enthalpy change of formation of $\text{POCl}_3(\text{g})$	-592
$\text{O}_2(\text{g}) \rightarrow 2\text{O}(\text{g})$	+496

(i) Define enthalpy change of formation, ΔH_f .

[2]

(ii) Calculate the bond energy of P=O in POCl_3 using the data in Table 1.3.

Show your working.

$$\text{bond energy of P=O} = \dots\dots\dots (\text{ans} = +551) \dots\dots\dots \text{kJmol}^{-1} [2]$$

6. The enthalpy changes of formation, ΔH_f° , of both PCl_3 and PCl_5 are exothermic.

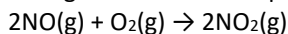
PCl_3 reacts with chlorine.



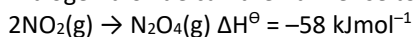
Which pair of statements is correct?

	statement 1	statement 2
A	$\Delta H_{\text{reaction}}^{\circ}$ is less negative than $\Delta H_f^{\circ}(\text{PCl}_5)$.	The Cl_2 bond energy is needed in calculating $\Delta H_{\text{reaction}}^{\circ}$ from enthalpies of formation.
B	$\Delta H_{\text{reaction}}^{\circ}$ is more negative than $\Delta H_f^{\circ}(\text{PCl}_5)$.	The Cl_2 bond energy is needed in calculating $\Delta H_{\text{reaction}}^{\circ}$ from enthalpies of formation.
C	$\Delta H_{\text{reaction}}^{\circ}$ is less negative than $\Delta H_f^{\circ}(\text{PCl}_5)$.	The Cl_2 bond energy is not needed in calculating $\Delta H_{\text{reaction}}^{\circ}$ from enthalpies of formation.
D	$\Delta H_{\text{reaction}}^{\circ}$ is more negative than $\Delta H_f^{\circ}(\text{PCl}_5)$.	The Cl_2 bond energy is not needed in calculating $\Delta H_{\text{reaction}}^{\circ}$ from enthalpies of formation.

11. Nitrogen monoxide is rapidly oxidised to nitrogen dioxide.

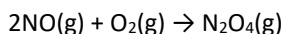


Nitrogen dioxide can then dimerise to form dinitrogen tetroxide.



$$\Delta H_f^{\circ} \text{ NO} = +91 \text{ kJ mol}^{-1} \text{ and } \Delta H_f^{\circ} \text{ NO}_2 = +34 \text{ kJ mol}^{-1}$$

What is the value of the standard enthalpy change for the reaction shown?



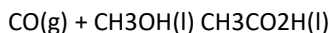
A $+56 \text{ kJ mol}^{-1}$

B -1 kJ mol^{-1}

C -115 kJ mol^{-1}

D -172 kJ mol^{-1}

12. Carbon monoxide and methanol can react together to form ethanoic acid.



Standard enthalpy changes of combustion are given in the table.

Compound	standard enthalpy change of combustion,
CO	$-283.0 \text{ kJ mol}^{-1}$
CH ₃ OH	$-726.0 \text{ kJ mol}^{-1}$
CH ₃ CO ₂ H	$-874.1 \text{ kJ mol}^{-1}$

What is the value for the reaction between carbon monoxide and methanol?

A $-1883.1 \text{ kJ mol}^{-1}$

B $-134.9 \text{ kJ mol}^{-1}$

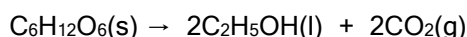
C $+134.9 \text{ kJ mol}^{-1}$

D $+1883.1 \text{ kJ mol}^{-1}$

Enthalpy change of reaction from enthalpy change of combustions

13. The standard enthalpy changes of combustion of glucose and ethanol are given as -2820 and $-1368 \text{ kJ mol}^{-1}$ respectively.

Glucose, $\text{C}_6\text{H}_{12}\text{O}_6$, can be converted into ethanol.



What is the standard enthalpy change for this reaction?

A $-1452 \text{ kJ mol}^{-1}$

B -84 kJ mol^{-1}

C $+84 \text{ kJ mol}^{-1}$

D $+1452 \text{ kJ mol}^{-1}$

14. Hess' Law and bond energy data can be used to calculate the enthalpy change of a reaction. Bromoethane, $\text{CH}_3\text{CH}_2\text{Br}$, can be made by reacting ethene with hydrogen bromide.
 $\text{CH}_2=\text{CH}_2 + \text{HBr} \rightarrow \text{CH}_3\text{CH}_2\text{Br}$
 What is the enthalpy change for this reaction?

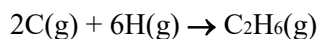
A – 674 kJ mol⁻¹
 B – 64 kJ mol⁻¹
 C +186 kJ mol⁻¹
 D +346 kJ mol⁻¹

15. Use relevant enthalpy changes from the tables to answer this question.

reaction	ΔH / kJ mol ⁻¹
$\text{C(s)} + 2\text{H}_2(\text{g}) \rightarrow \text{CH}_4(\text{g})$	–76
$\text{CH}_4(\text{g}) + 2\text{O}_2(\text{g}) \rightarrow \text{CO}_2(\text{g}) + 2\text{H}_2\text{O}(\text{g})$	–890
$\text{CH}_4(\text{g}) \rightarrow \text{C(g)} + 4\text{H(g)}$	1648
$3\text{C(s)} + 4\text{H}_2(\text{g}) \rightarrow \text{C}_3\text{H}_8(\text{g})$	–105

bond	bond enthalpy / kJ mol ⁻¹
H–H	436
C–C	350
C=C	610
C=O	805

Which value can be calculated for the enthalpy change for the following reaction?



A –2822 kJ mol⁻¹
 B –2122 kJ mol⁻¹
 C –1998 kJ mol⁻¹
 D –1772 kJ mol⁻¹

16. Solid sulfur consists of molecules made up of eight atoms covalently bonded together.

The bonding in sulfur dioxide is $\text{O}=\text{S}=\text{O}$.

enthalpy change of combustion of S_8 , $\text{S}_8(\text{s}) = -2376 \text{ kJ mol}^{-1}$

energy required to break 1.0 mol $\text{S}_8(\text{s})$ into gaseous atoms = 2232 kJ mol⁻¹

$\text{O}=\text{O}$ bond enthalpy = 496 kJ mol⁻¹

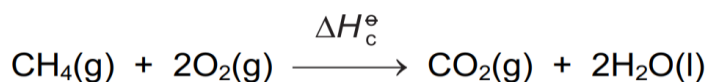
Using these data, what is the value of the $\text{S}=\text{O}$ bond enthalpy?

A 239 kJ mol⁻¹ B 257 kJ mol⁻¹ C 319 kJ mol⁻¹ D 536 kJ mol⁻¹

17. The standard enthalpy change of combustion of carbon is –394 kJ mol⁻¹.
 The standard enthalpy change of combustion of hydrogen is –286 kJ mol⁻¹.
 The standard enthalpy change of formation of butane is –129 kJ mol⁻¹.
 What is the standard enthalpy change of combustion of butane?

- A** -551 kJ mol^{-1}
B $-2877 \text{ kJ mol}^{-1}$
C $-3135 \text{ kJ mol}^{-1}$
D $-4307 \text{ kJ mol}^{-1}$

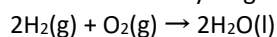
18. $\Delta H_1^\ominus$ is the standard enthalpy of formation of methane.
 $\Delta H_2^\ominus$ is the standard enthalpy of combustion of carbon.
 $\Delta H_3^\ominus$ is the standard enthalpy of combustion of hydrogen.



Which expression is equivalent to $\Delta H_c^\ominus$?

- A** $\Delta H_1^\ominus - \Delta H_2^\ominus + \Delta H_3^\ominus$
B $\Delta H_1^\ominus - 2\Delta H_3^\ominus - \Delta H_2^\ominus$
C $\Delta H_2^\ominus - \Delta H_3^\ominus + \Delta H_1^\ominus$
D $\Delta H_2^\ominus + 2\Delta H_3^\ominus - \Delta H_1^\ominus$

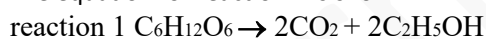
19. The reaction of hydrogen with oxygen is shown.



Which expression corresponds to the standard enthalpy change of this reaction?

- A** $2 \times \Delta H_f^\ominus(\text{H}_2\text{O})$
B $\Delta H_c^\ominus(\text{H}_2\text{O}) - \Delta H_c^\ominus(\text{H}_2)$
C $\Delta H_c^\ominus(\text{H}_2)$
D $2 \times \Delta H_f^\ominus(\text{H}_2\text{O}) + 2 \text{ (H}_2\text{)}$

20. The equation for reaction 1 is shown.

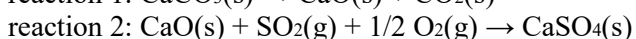
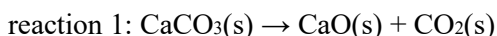


	$\Delta H_c^\ominus / \text{kJ mol}^{-1}$
$\text{C}_6\text{H}_{12}\text{O}_6$	<i>a</i>
$\text{C}_2\text{H}_5\text{OH}$	<i>b</i>

What is the correct expression for the enthalpy change of reaction 1?

- A** $a + b$ **B** $a - b$ **C** $a + 2b$ **D** $a - 2b$

12. Emissions of SO_2 from coal-fired power stations can be reduced by mixing the coal with powdered limestone. Limestone is heated to form CaO in reaction 1. This then reacts with SO_2 and O_2 to form CaSO_4 in reaction 2.

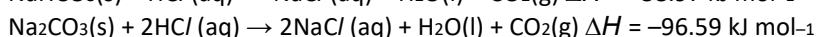
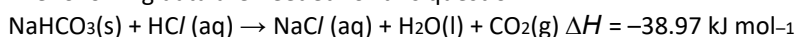


Use the data to calculate the enthalpy change of reaction 2.

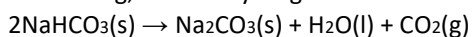
compound	$\Delta H_f / \text{kJ mol}^{-1}$
$\text{CaO}(\text{s})$	-635
$\text{SO}_2(\text{g})$	-297
$\text{CaSO}_4(\text{s})$	-1434

enthalpy change of reaction 2 = ... kJmol⁻¹ [2]

21. The following data are needed for this question.



On heating, sodium hydrogencarbonate decomposes as shown.



What is the enthalpy change for this decomposition?

A -57.62 kJ mol⁻¹

B -18.65 kJ mol⁻¹

C 18.65 kJ mol⁻¹

D 57.62 kJ mol⁻¹

13. Compounds **P**, **Q** and **R** have all been found in the atmosphere of one of Saturn's moons.

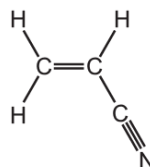
P



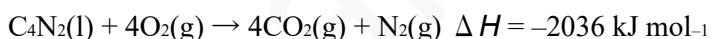
Q



R



The equation for the complete combustion of **P**, C₄N₂(l), is shown.



(i) The enthalpy change of formation, ΔH_f , of CO₂(g) is -384 kJ mol⁻¹.

Calculate the enthalpy change of formation, ΔH_f , of **P**, in kJ mol⁻¹.

[2]

22. Nitric acid is made industrially by the oxidation of ammonia. The overall equation for the process is shown.



The process happens in three stages. The equations and enthalpy changes for these stages are given.

stage 1	$4\text{NH}_3 + 5\text{O}_2 \rightarrow 4\text{NO} + 6\text{H}_2\text{O}$	$H = -904 \text{ kJ mol}^{-1}$
stage 2	$2\text{NO} + \text{O}_2 \rightarrow 2\text{NO}_2$	$H = -114 \text{ kJ mol}^{-1}$
stage 3	$4\text{NO}_2 + \text{O}_2 + 2\text{H}_2\text{O} \rightarrow 4\text{HNO}_3$	$H = -348 \text{ kJ mol}^{-1}$

What is the enthalpy change of the process shown in equation 1?

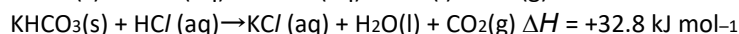
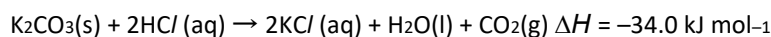
A $-1480 \text{ kJ mol}^{-1}$

B -370 kJ mol^{-1}

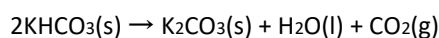
C $-341.5 \text{ kJ mol}^{-1}$

D $+82 \text{ kJ mol}^{-1}$

23. The enthalpy changes of two reactions are shown.



What is the enthalpy change for the reaction shown?

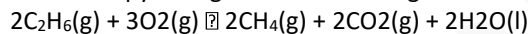


A $-31.6 \text{ kJ mol}^{-1}$ B 1.2 kJ mol^{-1} C 66.8 kJ mol^{-1} D 99.6 kJ mol^{-1}

24. The enthalpy change for a reaction can be calculated from values of:

- enthalpies of formation, ΔH_f°
- enthalpies of combustion, ΔH_c°
- bond energies, E .

The enthalpy change of the reaction given = ΔH_r° .



Which expression could be used to calculate ΔH_r° ?

A $\Delta H_c^\circ(\text{C}_2\text{H}_6(\text{g}))$

B $2\Delta H_c^\circ(\text{C}_2\text{H}_6(\text{g})) - 2\Delta H_c^\circ(\text{CH}_4(\text{g}))$

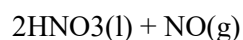
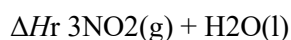
C $E(\text{C}-\text{C}) + 2E(\text{C}-\text{H}) - 4E(\text{C}=\text{O}) - 4E(\text{H}-\text{O})$

D $\Delta H_f^\circ(\Delta H_f^\circ(\text{CH}_4(\text{g}))) + \Delta H_f^\circ(\text{CO}_2(\text{g})) + \Delta H_f^\circ(\text{H}_2\text{O}(\text{l})) - \Delta H_f^\circ(\text{C}_2\text{H}_6(\text{g}))$

14. Complete the Hess' cycle using the values given in the table and hence calculate the enthalpy change, ΔH_r , for this reaction.

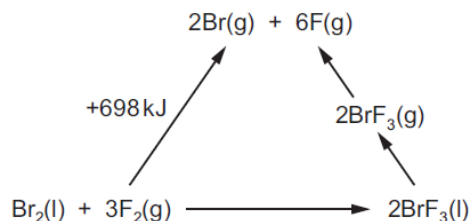
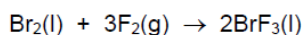
Show your working.

substance	$\Delta H_f / \text{kJ mol}^{-1}$
$\text{NO}_2(\text{g})$	34.0
$\text{H}_2\text{O}(\text{l})$	-286
$\text{HNO}_3(\text{l})$	-173
$\text{NO}(\text{g})$	91.1



ΔH_r

25. An energy cycle is drawn for the following reaction.



The standard enthalpy of formation of $\text{BrF}_3(\text{l}) = -301 \text{ kJ mol}^{-1}$.

The enthalpy change of $\text{BrF}_3(\text{l})$ to $\text{BrF}_3(\text{g})$ is $+44 \text{ kJ mol}^{-1}$.

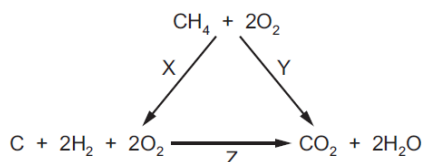
What is the average bond energy of the $\text{Br}-\text{F}$ bond in BrF_3 ?

- A** 152 kJ mol^{-1} **B** 202 kJ mol^{-1} **C** 304 kJ mol^{-1} **D** 404 kJ mol^{-1}

26. Which pair of standard enthalpy changes are numerically equal?

- A** atomisation of $\text{CH}_4(\text{g})$ and formation of $\text{CH}_4(\text{g})$
B combustion of $\text{CH}_3\text{OH}(\text{l})$ and combustion of graphite + 2(combustion of $\text{H}_2(\text{g})$)
C combustion of graphite and formation of $\text{CO}_2(\text{g})$
D neutralisation of $\text{HCl}(\text{aq})$ with $\text{NaOH}(\text{aq})$ and formation of $\text{H}_2\text{O}(\text{l})$

27. An energy cycle is shown.



The energy changes involved are X , Y and Z .

The numerical value of energy change Y is either -890 or $+890$.

The numerical value of energy change Z is either -964 or $+964$.

Which of the three values are negative?

- A** X and Z **B** X only **C** Y and Z **D** Y only

*** ... ***

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