

# Warmup:

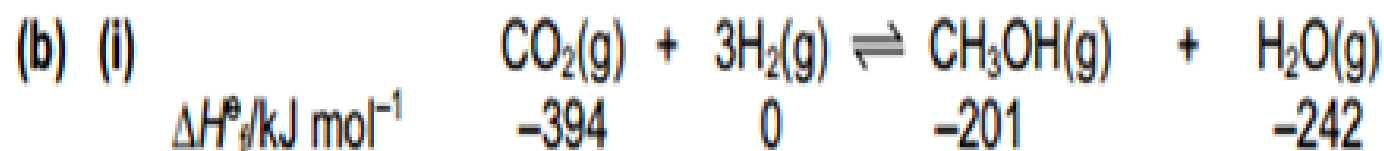
(b) Relevant  $\Delta H_f^\circ$  values for the reaction that synthesises methanol are given in the table.

compound	$\Delta H_f^\circ / \text{kJ mol}^{-1}$
$\text{CO}_2(\text{g})$	-394
$\text{CH}_3\text{OH}(\text{g})$	-201
$\text{H}_2\text{O}(\text{g})$	-242

(i) Use these values to calculate  $\Delta H_{\text{reaction}}^\circ$  for this synthesis of methanol.

Include a sign in your answer.





$$\Delta H_{\text{reaction}}^\ominus = -201 + (-242) - (-394) \quad (1)$$

$$-49 \text{ kJ mol}^{-1} \quad (1)$$

correct sign (1)

(ii) removal of  $\text{CO}_2$  from the atmosphere (1)

$\text{CO}_2$  is a greenhouse gas/causes global warming (1) [5]

(d) The standard enthalpy change of combustion of  $C_2H_2$ ,  $\Delta H_c^\ominus$ , is  $-1300 \text{ kJ mol}^{-1}$  at 298 K.

Values of relevant standard enthalpy changes of formation,  $\Delta H_f^\ominus$ , measured at 298 K, are given in the table.

substance	$\Delta H_f^\ominus / \text{kJ mol}^{-1}$
$CO_2(g)$	-394
$H_2O(l)$	-286

(i) Write balanced equations, with state symbols, that represent the standard enthalpy change of combustion,  $\Delta H_c^\ominus$ , of  $C_2H_2$ , and

.....  
the standard enthalpy change of formation,  $\Delta H_f^\ominus$ , of  $C_2H_2$ .

.....  
(ii) Use the data above and your answer to (i) to calculate the standard enthalpy change of formation,  $\Delta H_f^\ominus$ , of  $C_2H_2$ .  
Show clearly whether the standard enthalpy change of formation of  $C_2H_2$  has a positive or negative value.

For  
Examiner's  
Use

(d) (i) combustion



equation must be for the combustion of one mole of  $\text{C}_2\text{H}_2$

$\text{H}_2\text{O}$  must be shown as liquid

(1)

correct state symbols in this equation

(1)

formation



no mark for state symbols here

(1)

(ii) let  $Z$  be  $\Delta H_f^\ominus$  of  $\text{C}_2\text{H}_2$



$$\Delta H_f^\ominus \quad Z \quad 0 \quad 2(-394) \quad -286$$

$$\Delta H_c^\ominus = -1300 = 2(-394) + (-286) - Z$$

(1)

$$\text{whence } Z = 2(-394) + (-286) - (-1300)$$

$$= +226 \text{ kJ mol}^{-1}$$

value

(1)

sign

(1)

allow ecf on wrong equation

[6]

- (c) (i) Define the term *standard enthalpy change of formation*.

.....

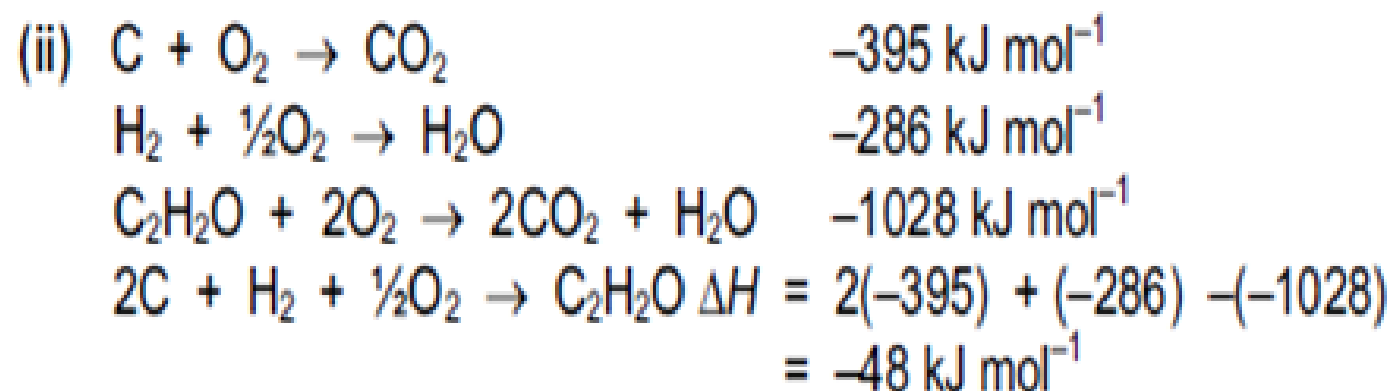
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.....

- (ii) Use the data below to calculate the standard enthalpy change of formation of ketene.

	$\Delta H^\circ/\text{kJ mol}^{-1}$
standard enthalpy change of formation of $\text{CO}_2$	-395
standard enthalpy change of combustion of $\text{H}_2$	-286
standard enthalpy change of combustion of $\text{CH}_2=\text{C}=\text{O}$	-1028

(c) (i) enthalpy change when  
1 mol of a compound is formed (1)  
from its elements (1)  
in their standard states under standard conditions (1)



correct cycle (1) use of 2 for C/CO<sub>2</sub> (1) answer (1)

[6]

(d) H<sub>2</sub>O/water/steam (1)

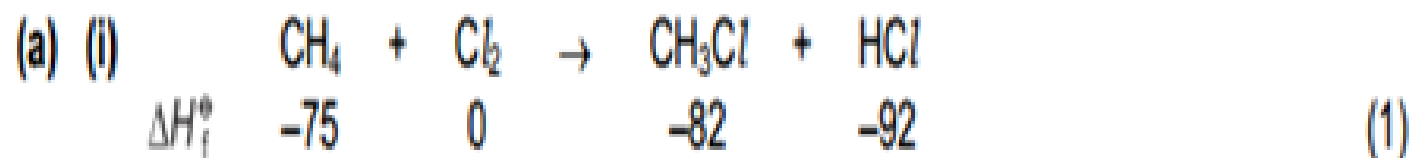
[1]

- 3 Alkanes such as methane,  $\text{CH}_4$ , undergo few chemical reactions. Methane will, however, react with chlorine but not with iodine.

Relevant standard enthalpy changes of formation for the reaction of methane with chlorine to form chloromethane,  $\text{CH}_3\text{Cl}$ , are given below.

	$\Delta H_f^\ominus/\text{kJ mol}^{-1}$
$\text{CH}_4$	-75
$\text{CH}_3\text{Cl}$	-82
$\text{HCl}$	-92

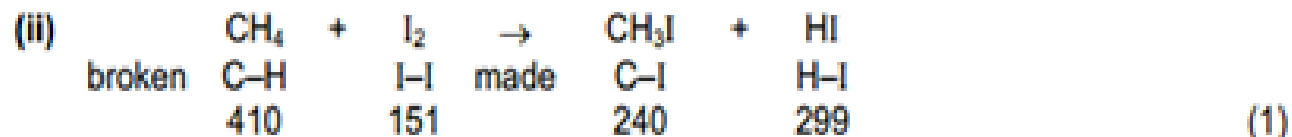
- (a) (i) Use the data to calculate  $\Delta H_{\text{reaction}}^\ominus$  for the formation of  $\text{CH}_3\text{Cl}$ .



$$\begin{aligned} \Delta H_{\text{reaction}}^\ominus &= -82 + (-92) - (-75) \\ &= -99 \text{ kJ mol}^{-1} \end{aligned} \quad \text{(1)}$$

(ii) The corresponding reaction with iodine does **not** take place.

Use bond energy data from the *Data Booklet* to calculate a 'theoretical value' for  $\Delta H_{\text{reaction}}$  for the following equation.



$$\begin{aligned}\Delta H_{\text{reaction}}^{\circ} &= -240 + (-299) + 410 + 151 \\ &= +22 \text{ kJ mol}^{-1}\end{aligned}\quad (1)$$

(iii) Suggest why this reaction does **not** in fact occur.

(iii) activation energy is too great

.....

.....

[5]



## Bond energies

### (a) Diatomic molecules

Bond	Energy / kJ mol <sup>-1</sup>
H-H	436
D-D	442
N≡N	994
O=O	496
F-F	158
Cl-Cl	244
Br-Br	193
I-I	151
H-F	562
H-Cl	431
H-Br	366
H-I	299

Bond	Energy / kJ mol <sup>-1</sup>
C-C	350
C=C	610
C≡C	840
C-C (benzene)	520
C-H	410
C-Cl	340
C-Br	280
C-I	240
C-O	360
C=O	740
C-N	305
C=N	610
C≡N	890
N-H	390
N-N	160
N=N	410
O-H	460
O-O	150
Si-Cl	359
Si-H	320
Si-O	444
Si-Si	222
S-Cl	250
S-H	347
S-S	264

The unsaturated hydrocarbon, **E**, is obtained by cracking hexane and is important in the chemical industry.

The standard enthalpy change of combustion of **E** is  $-2059 \text{ kJ mol}^{-1}$ .

**(d)** Define the term *standard enthalpy change of combustion*.

..... **(d)** enthalpy change when 1 mol of a substance (1) .....

..... is burnt in an excess of oxygen/air under standard conditions  
or is completely combusted under standard conditions (1) ..... **[2]**

When 0.47 g of **E** was completely burnt in air, the heat produced raised the temperature of 200 g of water by  $27.5^\circ\text{C}$ . Assume no heat losses occurred during this experiment.

**(e)** **(i)** Use relevant data from the *Data Booklet* to calculate the amount of heat released in this experiment.

$$\begin{aligned} \text{(e) (i) heat released} &= m c \delta T = 200 \times 4.18 \times 27.5 \text{ (1)} \\ &= 22990 \text{ J} = 23.0 \text{ kJ (1)} \end{aligned}$$

## Important values, constants and standards

<b>Molar gas constant</b>	$R = 8.31 \text{ J K}^{-1} \text{ mol}^{-1}$
<b>Faraday constant</b>	$F = 9.65 \times 10^4 \text{ C mol}^{-1}$
<b>Avogadro constant</b>	$L = 6.02 \times 10^{23} \text{ mol}^{-1}$
<b>Planck constant</b>	$h = 6.63 \times 10^{-34} \text{ J s}$
<b>Speed of light in a vacuum</b>	$c = 3.00 \times 10^8 \text{ m s}^{-1}$
<b>Rest mass of proton, <math>{}^1_1\text{H}</math></b>	$m_p = 1.67 \times 10^{-27} \text{ kg}$
<b>Rest mass of neutron, <math>{}^1_0\text{n}</math></b>	$m_n = 1.67 \times 10^{-27} \text{ kg}$
<b>Rest mass of electron, <math>{}^0_{-1}\text{e}</math></b>	$m_e = 9.11 \times 10^{-31} \text{ kg}$
<b>Electronic charge</b>	$e = -1.60 \times 10^{-19} \text{ C}$
<b>Molar volume of gas</b>	$V_m = 22.4 \text{ dm}^3 \text{ mol}^{-1}$ at s.t.p. $V_m = 24.0 \text{ dm}^3 \text{ mol}^{-1}$ under room conditions (where s.t.p. is expressed as 101 kPa, approximately, and 273 K (0 °C))
<b>Ionic product of water</b>	$K_w = 1.00 \times 10^{-14} \text{ mol}^2 \text{ dm}^{-6}$ (at 298 K (25 °C))
<b>Specific heat capacity of water</b>	$= 4.18 \text{ kJ kg}^{-1} \text{ K}^{-1}$ ( $= 4.18 \text{ J g}^{-1} \text{ K}^{-1}$ )

3 For some chemical reactions, such as the thermal decomposition of potassium hydrogencarbonate,  $\text{KHCO}_3$ , the enthalpy change of reaction cannot be measured directly.

In such cases, the use of Hess' Law enables the enthalpy change of reaction to be calculated from the enthalpy changes of other reactions.

(a) State Hess' Law.

.....

.....

..... [2]

3 (a) the overall enthalpy change/energy change/ $\Delta H$  for a reaction (1)

is independent of the route taken **or**  
is independent of the number of steps involved  
provided the initial and final conditions are the same (1) [2]

In order to determine the enthalpy change for the thermal decomposition of potassium hydrogencarbonate, two separate experiments were carried out.

### experiment 1

30.0 cm<sup>3</sup> of 2.00 mol dm<sup>-3</sup> hydrochloric acid (an excess) was placed in a conical flask and the temperature recorded as 21.0 °C.

When 0.0200 mol of potassium carbonate, K<sub>2</sub>CO<sub>3</sub>, was added to the acid and the mixture stirred with a thermometer, the maximum temperature recorded was 26.2 °C.

(b) (i) Construct a balanced equation for this reaction.

.....

(ii) Calculate the quantity of heat produced in **experiment 1**, stating your units. Use relevant data from the *Data Booklet* and assume that all solutions have the same specific heat capacity as water.



$$(ii) \text{ heat produced} = m \times c \times \delta T = 30.0 \times 4.18 \times 5.2 \\ = 652.08 \text{ J per } 0.0200 \text{ mol of K}_2\text{CO}_3 \quad (1)$$

- (iii) Use your answer to (ii) to calculate the enthalpy change per mole of  $\text{K}_2\text{CO}_3$ . Give your answer in  $\text{kJ mol}^{-1}$  and include a sign in your answer.

$$\text{(iii) } 0.020 \text{ mol } \text{K}_2\text{CO}_3 = 652.08 \text{ J}$$

$$1 \text{ mol } \text{K}_2\text{CO}_3 = \frac{652.08 \times 1}{0.0200} = 32604 \text{ J}$$

$$\text{enthalpy change} = -32.60 \text{ kJmol}^{-1}$$

- (iv) Explain why the hydrochloric acid must be in an excess.

.....

..... [4]

- (iv) to prevent the formation of  $\text{KHCO}_3$  or  
to ensure complete neutralisation

## experiment 2

The experiment was repeated with 0.0200 mol of potassium hydrogencarbonate,  $\text{KHCO}_3$ . All other conditions were the same.

In the second experiment, the temperature fell from  $21.0^\circ\text{C}$  to  $17.3^\circ\text{C}$ .

(c) (i) Construct a balanced equation for this reaction.

.....

(ii) Calculate the quantity of heat absorbed in **experiment 2**.

(iii) Use your answer to (ii) to calculate the enthalpy change per mole of  $\text{KHCO}_3$ . Give your answer in  $\text{kJ mol}^{-1}$  and include a sign in your answer.



(ii) heat absorbed =  $m \times c \times \delta T = 30.0 \times 4.18 \times 3.7$   
 $= 463.98 \text{ J per } 0.0200 \text{ mol of KHCO}_3$  (1)

(iii)  $0.020 \text{ mol KHCO}_3 \equiv 463.98 \text{ J}$

$$1 \text{ mol KHCO}_3 \equiv \frac{463.98 \times 1}{0.0200} = 23199 \text{ J}$$

enthalpy change =  $+23.20 \text{ kJmol}^{-1}$  (1) [3]



(d) When  $\text{KHCO}_3$  is heated, it decomposes into  $\text{K}_2\text{CO}_3$ ,  $\text{CO}_2$  and  $\text{H}_2\text{O}$ .



Use Hess' Law and your answers to (b)(iii) and (c)(iii) to calculate the enthalpy change for this reaction.

Give your answer in  $\text{kJ mol}^{-1}$  and include a sign in your answer.

$$(d) \Delta H = 2 \times (+23.20) - (-32.60) = +79.00 \text{ kJ mol}^{-1}$$

[2]

[Total: 11]

(c) The standard enthalpy changes of formation of  $\text{NH}_3(\text{g})$  and  $\text{H}_2\text{O}(\text{g})$  are as follows.

$$\text{NH}_3(\text{g}), \Delta H_f^\ominus = -46.0 \text{ kJ mol}^{-1}$$

$$\text{H}_2\text{O}(\text{g}), \Delta H_f^\ominus = -242 \text{ kJ mol}^{-1}$$

Use these data and the value of  $\Delta H_{\text{reaction}}^\ominus$  given below to calculate the standard enthalpy change of formation of  $\text{NO}(\text{g})$ .

Include a sign in your answer.



Enthalpy change of reaction from changes of formation:

Products - Reactants

$$4(-46) \rightarrow 4Y + 6(-242) \quad \text{solve for Y because NO is the unknown}$$

$$H_r = 4Y - 1452 + 184 \text{ where } H_r = -906$$

$$\text{so } 4Y = -906 + 1452 - 184 = 362$$

$$\text{and } 362/4 = 90.5 \text{ kJ mol}^{-1}$$

7 Propanone has the molecular formula  $C_3H_6O$ .

The enthalpy change of combustion of hydrogen is  $-286 \text{ kJ mol}^{-1}$ .

The enthalpy change of combustion of carbon is  $-394 \text{ kJ mol}^{-1}$ .

The enthalpy change of combustion of propanone is  $-1786 \text{ kJ mol}^{-1}$ .

Using this information, what is the enthalpy change of formation of propanone?

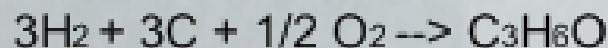
A  $-1106 \text{ kJ mol}^{-1}$

Enthalpy change of formation from enthalpy changes of combustion:

B  $-540 \text{ kJ mol}^{-1}$

Reactants - Products

C  $-254 \text{ kJ mol}^{-1}$



$$3(-286) + 3(-394) \rightarrow -1786$$

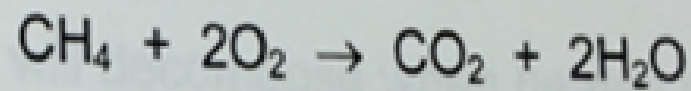
$$-858 + -1182 \rightarrow -1786$$

D  $+1106 \text{ kJ mol}^{-1}$

$$\text{Reactants} - \text{Products} = -254$$

12 Use of the Data Booklet is relevant to this question.

This question should be answered using bond enthalpy data. The equation for the combustion of methane is given below.

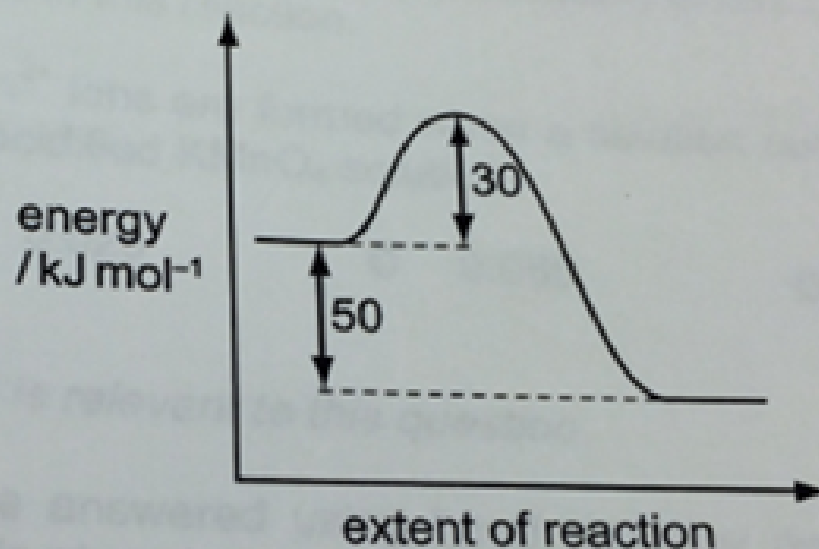


What is the enthalpy change of combustion of methane?

- A  $-1530 \text{ kJ mol}^{-1}$
- B  $-1184 \text{ kJ mol}^{-1}$
- C  $-770 \text{ kJ mol}^{-1}$
- D**  $-688 \text{ kJ mol}^{-1}$

7 The reaction pathway for a reversible reaction is shown below.

4



Which statement is correct?

- A** The activation energy of the reverse reaction is +80 kJ mol<sup>-1</sup>.
- B** The enthalpy change for the forward reaction is +30 kJ mol<sup>-1</sup>.
- C** The enthalpy change for the forward reaction is +50 kJ mol<sup>-1</sup>.
- D** The enthalpy change for the reverse reaction is +30 kJ mol<sup>-1</sup>.

A	B	C	D
1, 2 and 3 are correct	1 and 2 only are correct	2 and 3 only are correct	1 only is correct

32 An ideal gas obeys the gas laws under all conditions of temperature and pressure.

Which of the following are true for an ideal gas?

- ① The molecules have negligible volume.
- ② There are no forces of attraction between molecules.
- ③ The molecules have an average kinetic energy which is proportional to its absolute temperature.

33 For which reactions does the value of  $\Delta H^\circ$  represent both a standard enthalpy change of combustion and a standard enthalpy change of formation?

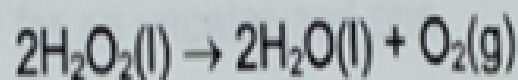
- ①  $\text{C(s)} + \text{O}_2\text{(g)} \rightarrow \text{CO}_2\text{(g)}$
- 2  $2\text{C(s)} + \text{O}_2\text{(g)} \rightarrow 2\text{CO(g)}$
- 3  $\text{CO(g)} + \frac{1}{2}\text{O}_2\text{(g)} \rightarrow \text{CO}_2\text{(g)}$

- 8 Hydrogen peroxide slowly decomposes into water and oxygen. The enthalpy change of reaction can be calculated using standard enthalpies of formation.

$$\Delta H_f^\ominus(\text{hydrogen peroxide(l)}) = -187.8 \text{ kJ mol}^{-1}$$

$$\Delta H_f^\ominus(\text{water(l)}) = -285.8 \text{ kJ mol}^{-1}$$

Using a Hess cycle, what is the enthalpy change of reaction for this decomposition?



A  $+98 \text{ kJ mol}^{-1}$

B  $-98 \text{ kJ mol}^{-1}$

**C**  $-196 \text{ kJ mol}^{-1}$

D  $-947.2 \text{ kJ mol}^{-1}$

The responses **A** to **D** should be selected on the basis of

<b>A</b>	<b>B</b>	<b>C</b>	<b>D</b>
1, 2 and 3 are correct	1 and 2 only are correct	2 and 3 only are correct	1 only is correct

**33** Under given conditions, what governs the rate of a forward reaction?

**1** the activation energy of the reaction **D**

**2** the enthalpy change of the reaction

**3** the equilibrium constant of the reaction



14 Slaked lime,  $\text{Ca(OH)}_2$ , may be made from limestone,  $\text{CaCO}_3$ .

On heating in a lime kiln at  $1000\text{ }^\circ\text{C}$ , limestone decomposes as follows.



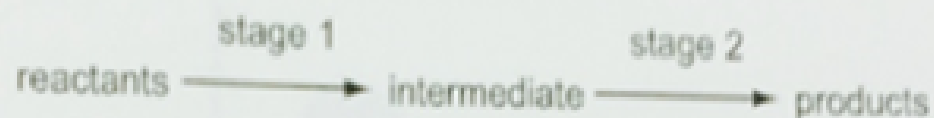
Water is then reacted with calcium oxide,  $\text{CaO}$ , as follows.



What are the enthalpy changes of these reactions?

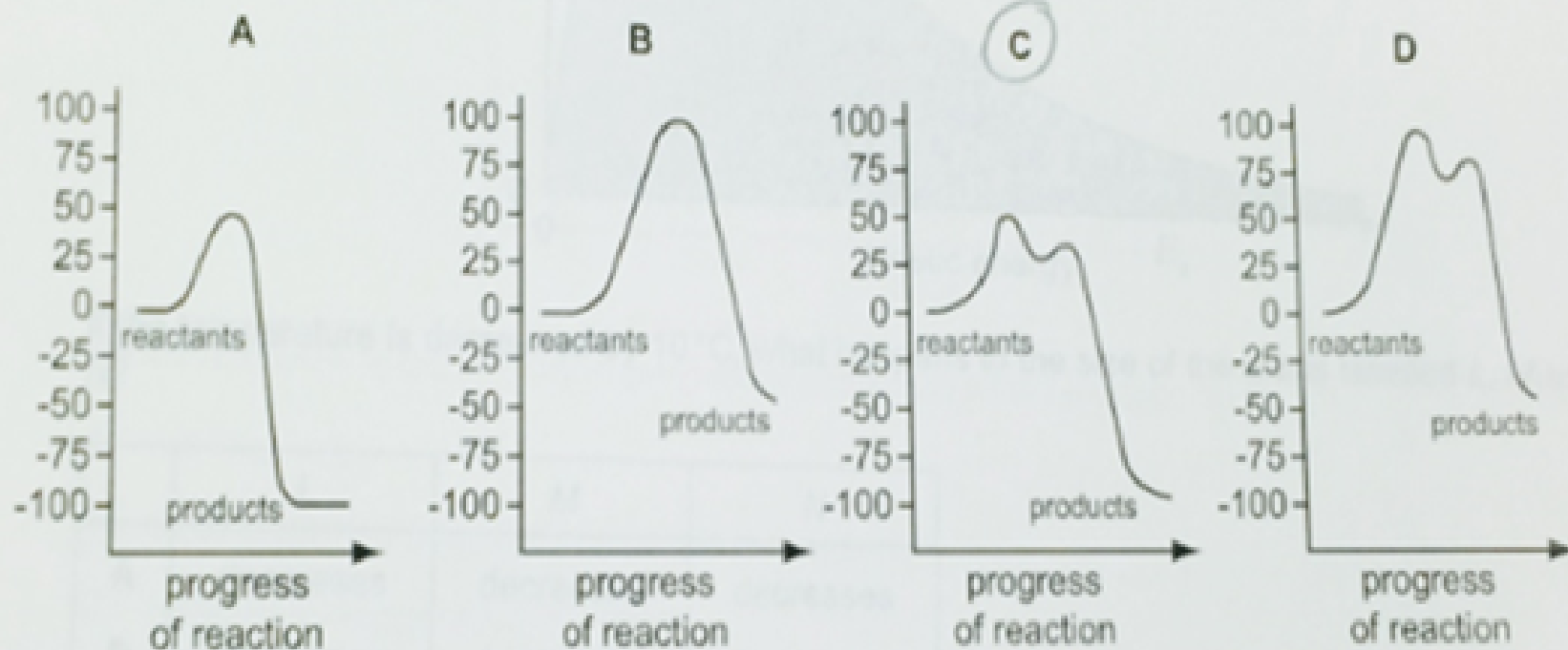
	reaction 1	reaction 2
A	endothermic	endothermic
<input checked="" type="radio"/> B	endothermic	exothermic
C	exothermic	endothermic
D	exothermic	exothermic

- 7 An exothermic chemical reaction proceeds by two stages.

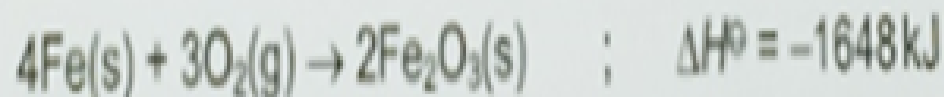


The activation energy of stage 1 is  $50 \text{ kJ mol}^{-1}$ . The overall enthalpy change of reaction is  $-100 \text{ kJ mol}^{-1}$ .

Which diagram represents the reaction pathway for this reaction?



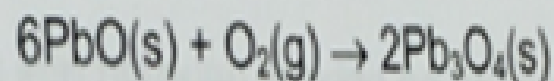
- 8 Skiers trapped by snowstorms use heat packs to keep warm. The heat may be generated by the reaction below.



What is the standard enthalpy change of formation of iron(III) oxide?

- A  $0 \text{ kJ mol}^{-1}$
- B  $-824 \text{ kJ mol}^{-1}$
- C  $-1648 \text{ kJ mol}^{-1}$
- D  $-3296 \text{ kJ mol}^{-1}$

- 8 Red lead oxide,  $\text{Pb}_3\text{O}_4$ , is used in metal priming paints. It can be made by heating  $\text{PbO}$  in air.



Which two values are needed to calculate the enthalpy change for this reaction?

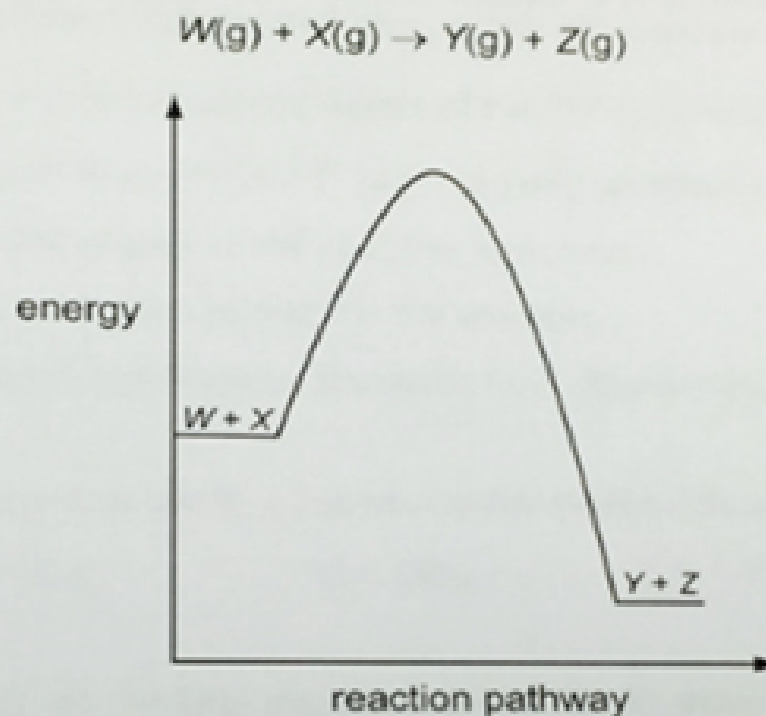
A enthalpy change of combustion of lead and enthalpy change of formation of  $\text{Pb}_3\text{O}_4$

B enthalpy change of combustion of  $\text{PbO}$  and enthalpy change of formation of  $\text{Pb}_3\text{O}_4$

C enthalpy change of formation of  $\text{PbO}$  and enthalpy change of atomisation of  $\text{O}_2$

D enthalpy change of formation of  $\text{PbO}$  and enthalpy change of formation of  $\text{Pb}_3\text{O}_4$

- 9 The diagram represents the reaction pathway for the following reaction.



What statement can be made about the reverse reaction,  $Y(g) + Z(g) \rightarrow W(g) + X(g)$ ?

- A** It will have a larger activation energy and a positive  $\Delta H$ .
- B** It will have a larger activation energy and a negative  $\Delta H$ .
- C** It will have a smaller activation energy and a positive  $\Delta H$ .
- D** It will have a smaller activation energy and a negative  $\Delta H$ .

5 Which quantity would best indicate the relative strengths of the hydrogen bonds between the molecules in liquid hydrogen halides?

A bond dissociation energies

B enthalpy changes of solution

C enthalpy changes of formation

D enthalpy changes of vaporisation

19 The gaseous oxides of nitrogen have positive enthalpy changes of formation.

Which factor is likely to make the most significant contribution to these enthalpy changes?

- A** the high bond energy of the nitrogen molecule,  $N_2$
- B** the high electron affinity of nitrogen atoms
- C** the high electron affinity of oxygen atoms
- D** the similarity of the electronegativities of oxygen and nitrogen

The responses **A** to **D** should be selected on the basis of

<b>A</b>	<b>B</b>	<b>C</b>	<b>D</b>
1, 2 and 3 are correct	1 and 2 only are correct	2 and 3 only are correct	1 only is correct

33 Which of the enthalpy changes of the following reactions can **only** be obtained by application of Hess' Law?

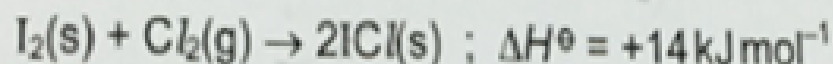
- 1 The hydration of anhydrous copper sulphate to form crystals of  $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$ .
- 2 The formation of methane from its elements.
- 3 The combustion of glucose,  $\text{C}_6\text{H}_{12}\text{O}_6$ .

B



7 Iodine trichloride,  $\text{ICl}_3$ , is made by reacting iodine with chlorine.

$$\Delta H_f = \Delta H_1 - \Delta H_2$$



By using the data above, what is the enthalpy change of the formation for solid iodine trichloride?

A  $-60 \text{ kJ mol}^{-1}$

B  $-74 \text{ kJ mol}^{-1}$

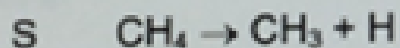
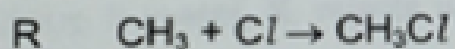
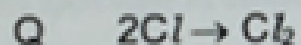
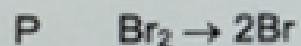
C  $-81 \text{ kJ mol}^{-1}$

D  $-162 \text{ kJ mol}^{-1}$

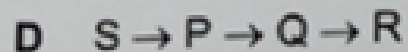
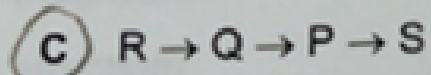
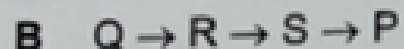
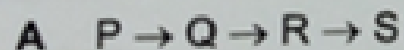
4 Some bond energy values are listed below.

bond	bond energy / $\text{kJ mol}^{-1}$
C-H	410
C-Cl	340
Cl-Cl	244
Br-Br	193

These bond energy values relate to the following four reactions.



What is the order of enthalpy changes of these reactions from most negative to most positive?

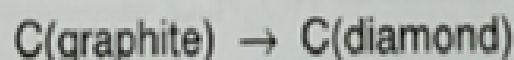


The responses **A** to **D** should be selected on the basis of

<b>A</b>	<b>B</b>	<b>C</b>	<b>D</b>
1, 2 and 3 are correct	1 and 2 only are correct	2 and 3 only are correct	1 only is correct

No other combination of statements is used as a correct response.

33 The conversion of graphite into diamond is an endothermic reaction ( $\Delta H = +3 \text{ kJ mol}^{-1}$ ).

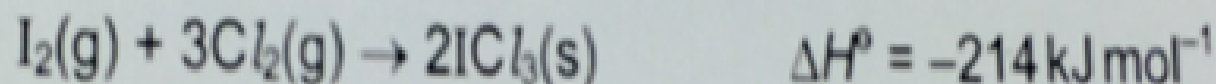


Which statements are correct?

- ① The enthalpy change of atomisation of diamond is smaller than that of graphite.
- ② The bond energy of the C–C bonds in graphite is greater than that in diamond.
- ③ The enthalpy change of combustion of diamond is greater than that of graphite.

A

5 Given the following enthalpy changes,



What is the standard enthalpy change of formation of iodine trichloride,  $\text{ICl}_3(\text{s})$ ?

A  $+176 \text{ kJ mol}^{-1}$

**B**  $-88 \text{ kJ mol}^{-1}$

C  $-176 \text{ kJ mol}^{-1}$

D  $-214 \text{ kJ mol}^{-1}$

- 8 The standard enthalpy changes of formation of iron(II) oxide,  $\text{FeO}(\text{s})$ , and aluminium oxide,  $\text{Al}_2\text{O}_3(\text{s})$ , are  $-266\text{kJ mol}^{-1}$  and  $-1676\text{kJ mol}^{-1}$  respectively.

What is the enthalpy change under standard conditions for the following reaction?



- A +878 kJ    **B -878 kJ**    C -1942 kJ    D -2474 kJ

