

CHEMISTRY



EXAM QUESTION PACK

5 CHEMICAL ENERGETICS

SCORE

/

PERCENTAGE

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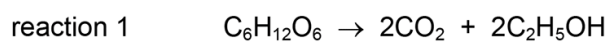
Chapter 5

Chemical energetics

5.1 Enthalpy change, ΔH

228. 9701_m22_qp_12 Q: 8

The equation for reaction 1 is shown.



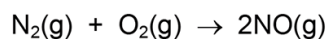
	$\Delta H_c^\ominus / \text{kJ mol}^{-1}$
$\text{C}_6\text{H}_{12}\text{O}_6$	a
$\text{C}_2\text{H}_5\text{OH}$	b

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

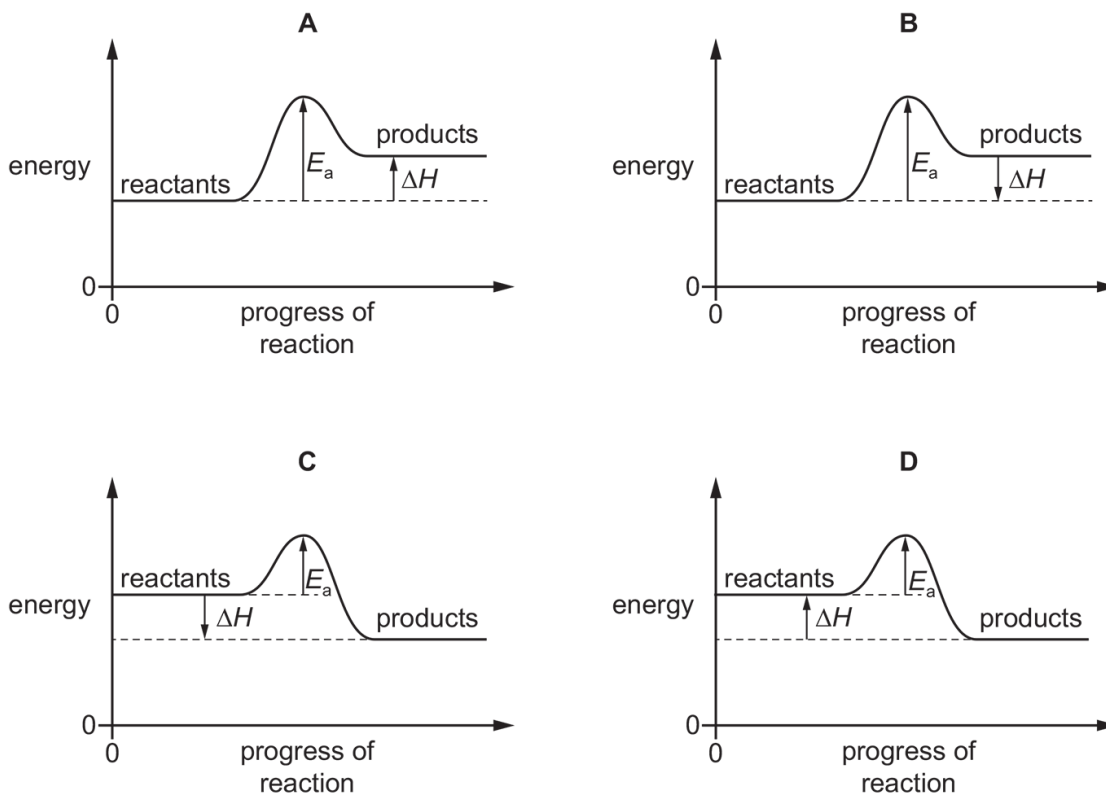
- A** $a + b$ **B** $a - b$ **C** $a + 2b$ **D** $a - 2b$
-

229. 9701_m22_qp_12 Q: 9

Nitrogen monoxide is an atmospheric pollutant that is formed inside car engines by an endothermic reaction between nitrogen and oxygen.

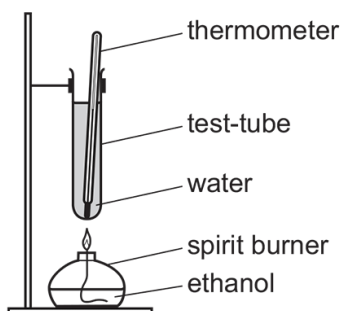


Which diagram correctly represents the energy profile for this reaction?



230. 9701_m21_qp_12 Q: 7

An experiment was performed to determine the enthalpy of combustion of ethanol.



The data collected are shown.

mass of water = W g

mass of ethanol burned = X g

temperature rise = $Y^{\circ}\text{C}$

molar mass of ethanol = Z g mol $^{-1}$

specific heat capacity of water = $4.2 \text{ J K}^{-1} \text{ g}^{-1}$

Which expression can be used to calculate the enthalpy of combustion of ethanol in kJ mol^{-1} ?

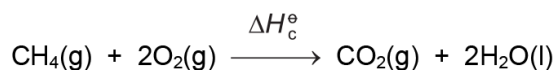
- A** $\frac{-4.2WYZ}{1000X}$ **B** $\frac{-4.2WYX}{1000Z}$ **C** $\frac{-4.2XYZ}{1000W}$ **D** $\frac{-4.2X(Y + 273)Z}{1000W}$

231. 9701_s21_qp_11 Q: 4

ΔH_1° is the standard enthalpy of formation of methane.

ΔH_2° is the standard enthalpy of combustion of carbon.

ΔH_3° is the standard enthalpy of combustion of hydrogen.



Which expression is equivalent to ΔH_c° ?

- A** $\Delta H_1^{\circ} - \Delta H_2^{\circ} + \Delta H_3^{\circ}$
B $\Delta H_1^{\circ} - 2\Delta H_3^{\circ} - \Delta H_2^{\circ}$
C $\Delta H_2^{\circ} - \Delta H_3^{\circ} + \Delta H_1^{\circ}$
D $\Delta H_2^{\circ} + 2\Delta H_3^{\circ} - \Delta H_1^{\circ}$

232. 9701_s21_qp_13 Q: 7

Using the information in the table, what is the enthalpy change, q , for the reaction described?

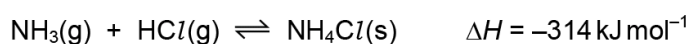


standard enthalpy change	value / kJ mol^{-1}
$\Delta H_{\text{sol}}^\circ \text{ CsBr}(\text{s})$	+25.9
$\Delta H_{\text{hyd}}^\circ \text{ Cs}^+(\text{g})$	-276
$\Delta H_{\text{hyd}}^\circ \text{ Br}^-(\text{g})$	-335

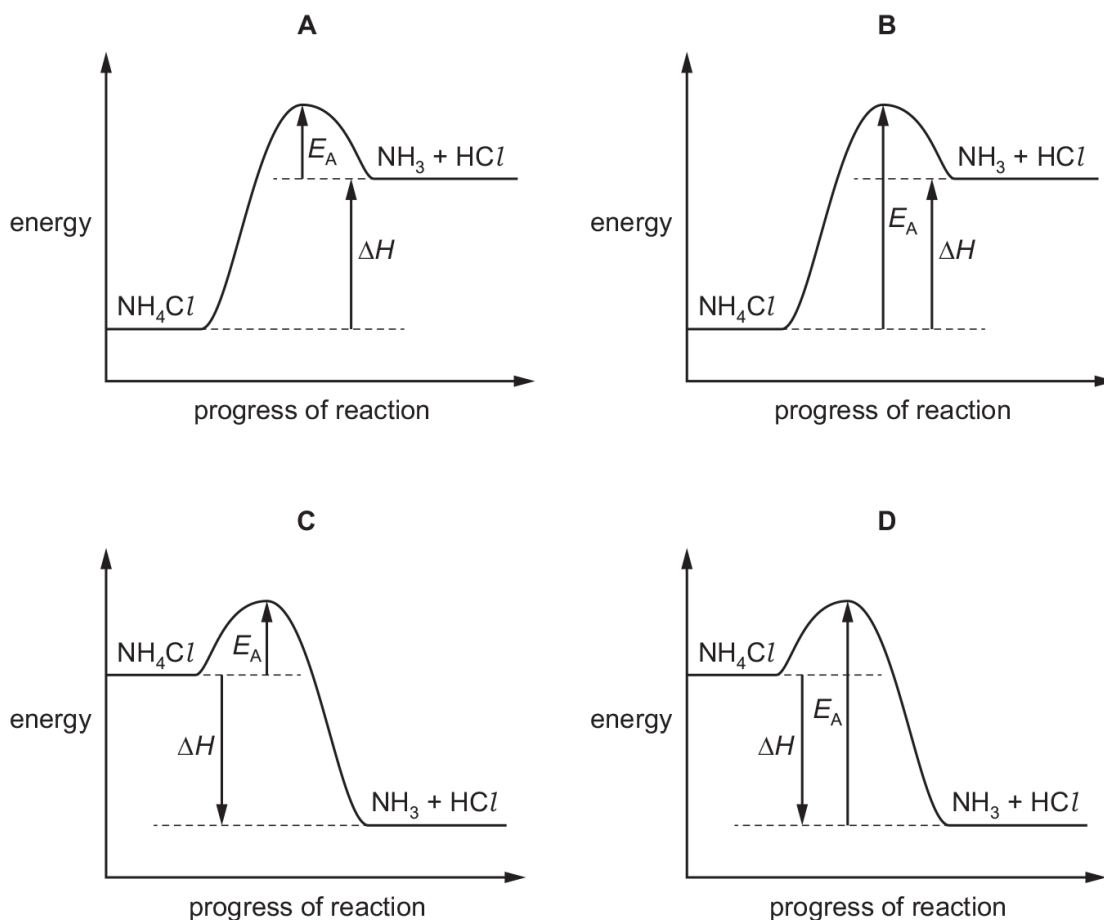
A -636.9**B** -585.1**C** +585.1**D** +636.9

233. 9701_w21_qp_12 Q: 9

The equation for the formation of ammonium chloride is shown.



Which diagram shows the correctly labelled reaction pathway diagram for the decomposition of ammonium chloride?



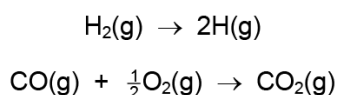
234. 9701_w21_qp_13 Q: 8

Which equation represents the enthalpy change of atomisation of iodine?

- A** $\frac{1}{2} \text{I}_2(\text{g}) \rightarrow \text{I}(\text{g})$
B $\text{I}_2(\text{g}) \rightarrow 2\text{I}(\text{g})$
C $\frac{1}{2} \text{I}_2(\text{s}) \rightarrow \text{I}(\text{g})$
D $\text{I}_2(\text{s}) \rightarrow 2\text{I}(\text{g})$
-

235. 9701_s20_qp_11 Q: 5

Two reactions are shown.

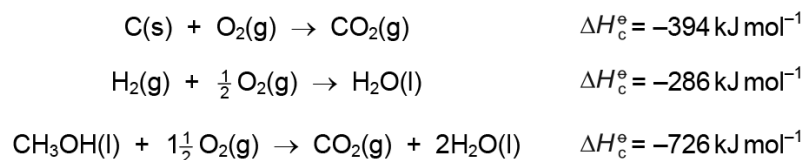


If molar amounts are used, how can the two energy changes associated with these reactions be described?

- A** enthalpy of atomisation and enthalpy of combustion
B enthalpy of atomisation and enthalpy of formation
C bond energy and enthalpy of combustion
D bond energy and enthalpy of formation
-

236. 9701_m19_qp_12 Q: 8

The standard enthalpy changes of combustion of carbon, hydrogen and methanol are shown.

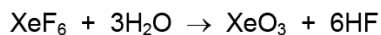


Which expression gives the standard enthalpy change of formation of methanol in kJ mol^{-1} ?

- A** $-394 + (-286) - (-726)$
B $-394 + (-286 \times 2) - 726$
C $-394 + (-286 \times 2) - (-726)$
D $-726 - (-394) - (-286 \times 2)$
-

237. 9701_m19_qp_12 Q: 9

The equation for a chemical reaction is shown. All substances are in their standard states.

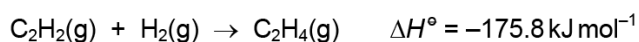
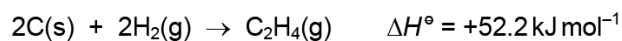


Which statement describes the standard enthalpy change of reaction for this reaction?

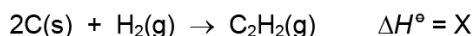
- A** the enthalpy change when a total of one mole of products is produced
 - B** the enthalpy change when a total of one mole of reactants is reacted
 - C** the enthalpy change when one mole of water reacts
 - D** the enthalpy change when six moles of hydrogen fluoride are produced
-

238. 9701_s19_qp_11 Q: 8

Two reactions and their enthalpy changes are shown.



These data can be used to calculate the enthalpy change for the reaction shown.

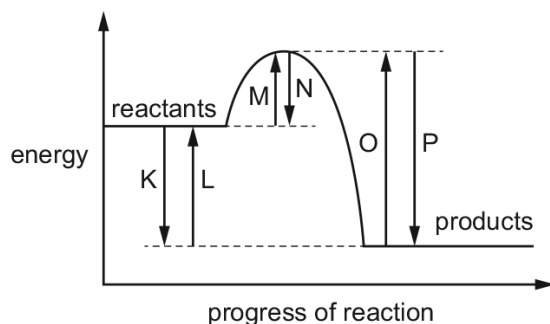


What is the value of X?

- A** $-228.0 \text{ kJ mol}^{-1}$
 - B** $-123.6 \text{ kJ mol}^{-1}$
 - C** $+123.6 \text{ kJ mol}^{-1}$
 - D** $+228.0 \text{ kJ mol}^{-1}$
-

239. 9701_s19_qp_12 Q: 8

A reaction pathway diagram is shown.

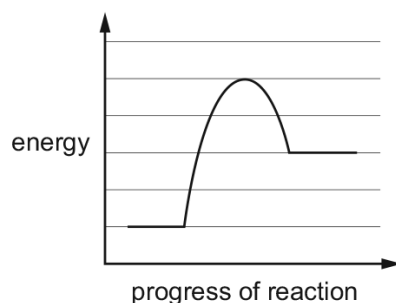


Which row is correct?

	enthalpy change of the forward reaction	activation energy of the reverse reaction
A	K	M
B	K	O
C	L	O
D	P	M

240. 9701_s19_qp_13 Q: 6

The reaction pathway diagram for a chemical reaction is shown.



Which statement is correct?

- A** The activation energy of the forward reaction and the enthalpy change of the backward reaction have the same sign.
- B** The activation energy of the forward reaction is more than twice the enthalpy change of the backward reaction and opposite in sign.
- C** The enthalpy change of the forward reaction and the activation energy of the backward reaction have the same sign.
- D** The enthalpy change of the forward reaction is more than twice the activation energy of the backward reaction.

241. 9701_w19_qp_11 Q: 7

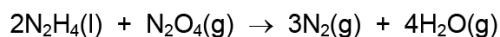
The following data are needed for this question.

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

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

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

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.

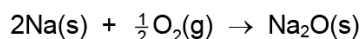


What is the enthalpy change for this reaction?

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

242. 9701_w19_qp_11 Q: 8

Sodium burns in oxygen giving out heat energy and forming the compound Na_2O . The equation for this reaction is shown.



Which statement about the reaction is correct?

- A ΔH° for the reaction is equal to twice the bond energy of the Na–O bond.
 - B ΔH° for the reaction is positive.
 - C The equation represents the standard enthalpy change of combustion of sodium.
 - D The equation represents the standard enthalpy change of formation of sodium oxide.
-

243. 9701_w19_qp_12 Q: 6

Which reaction is endothermic?

- A $\text{Ca}(\text{OH})_2(\text{aq}) + 2\text{HCl}(\text{aq}) \rightarrow \text{CaCl}_2(\text{aq}) + 2\text{H}_2\text{O}(\text{l})$
 - B $2\text{Cl}(\text{g}) \rightarrow \text{Cl}_2(\text{g})$
 - C $2\text{Ca}(\text{s}) + \text{O}_2(\text{g}) \rightarrow 2\text{CaO}(\text{s})$
 - D $\text{CaCO}_3(\text{s}) \rightarrow \text{CaO}(\text{s}) + \text{CO}_2(\text{g})$
-

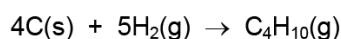
244. 9701_m18_qp_12 Q: 8

Which equation represents the standard enthalpy change of formation of water?

- A** $\text{H}_2(\text{g}) + \frac{1}{2} \text{O}_2(\text{g}) \rightarrow \text{H}_2\text{O}(\text{g})$
B $\text{H}_2(\text{g}) + \frac{1}{2} \text{O}_2(\text{g}) \rightarrow \text{H}_2\text{O}(\text{l})$
C $2\text{H}_2(\text{g}) + \text{O}_2(\text{g}) \rightarrow 2\text{H}_2\text{O}(\text{g})$
D $2\text{H}_2(\text{g}) + \text{O}_2(\text{g}) \rightarrow 2\text{H}_2\text{O}(\text{l})$
-

245. 9701_s18_qp_11 Q: 7

Enthalpy changes of combustion can be used to determine enthalpy changes of formation. The following equation represents the enthalpy change of formation of butane.



By using the following standard enthalpy of combustion data, what is the value of the standard enthalpy change of formation, ΔH_f° , of butane?

substance	$\Delta H_c^\circ / \text{kJ mol}^{-1}$
C(s)	-394
H ₂ (g)	-286
C ₄ H ₁₀ (g)	-2877

- A** $-5883 \text{ kJ mol}^{-1}$
B -129 kJ mol^{-1}
C $+129 \text{ kJ mol}^{-1}$
D $+2197 \text{ kJ mol}^{-1}$
-

246. 9701_s18_qp_12 Q: 7

The enthalpy change of reaction 1 is -114 kJ mol^{-1} .



By using this information, what is the most likely value for the enthalpy change of reaction 2?



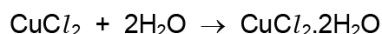
- A** -57 kJ mol^{-1} **B** -76 kJ mol^{-1} **C** -114 kJ mol^{-1} **D** -228 kJ mol^{-1}
-

247. 9701_s18_qp_13 Q: 7

Anhydrous copper(II) chloride, CuCl_2 , combines with water to form $\text{CuCl}_2 \cdot 2\text{H}_2\text{O}$. The standard enthalpy changes of formation for this reaction are shown in the table.

	$\Delta H_f^\circ / \text{kJ mol}^{-1}$
H_2O	-286
CuCl_2	-206
$\text{CuCl}_2 \cdot 2\text{H}_2\text{O}$	-808

What is the standard enthalpy change of the reaction shown?



- A -1586 kJ mol⁻¹
B -316 kJ mol⁻¹
C -110 kJ mol⁻¹
D -30 kJ mol⁻¹
-

248. 9701_w18_qp_11 Q: 6

A butane burner is used to heat water. The M_r of butane is 58.

- ΔH_c° of butane is -2877 kJ mol⁻¹.
- 250 g of water is heated from 12 °C to 100 °C.
- The burner transfers 47% of the heat released from the burning fuel to the water.

Assume that the butane undergoes complete combustion and none of the water evaporates.

What is the minimum mass of butane that must be burnt?

- A 0.068 g B 1.85 g C 3.94 g D 4.48 g
-

249. 9701_w18_qp_12 Q: 1

Which statement about enthalpy changes is correct?

- A Enthalpy changes of atomisation are always negative.
B Enthalpy changes of combustion are always positive.
C Enthalpy changes of formation are always positive.
D Enthalpy changes of neutralisation are always negative.
-

250. 9701_w18_qp_12 Q: 7

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}
-

251. 9701_m17_qp_12 Q: 7

A student mixed 25.0 cm^3 of 4.00 mol dm^{-3} hydrochloric acid with an equal volume of 4.00 mol dm^{-3} sodium hydroxide. The initial temperature of both solutions was 15.0°C . The maximum temperature recorded was 30.0°C .

Using these results, what is the enthalpy change of neutralisation of hydrochloric acid?

- A** $-62.7 \text{ kJ mol}^{-1}$
 - B** $-31.4 \text{ kJ mol}^{-1}$
 - C** $-15.7 \text{ kJ mol}^{-1}$
 - D** $-3.14 \text{ kJ mol}^{-1}$
-

252. 9701_m17_qp_12 Q: 9

All the reactants and products of an exothermic reaction are gaseous.

Which statement about this reaction is correct?

- A** The total bond energy of the products is less than the total bond energy of the reactants, and ΔH for the reaction is negative.
 - B** The total bond energy of the products is less than the total bond energy of the reactants, and ΔH for the reaction is positive.
 - C** The total bond energy of the products is more than the total bond energy of the reactants, and ΔH for the reaction is negative.
 - D** The total bond energy of the products is more than the total bond energy of the reactants, and ΔH for the reaction is positive.
-

253. 9701_s17_qp_11 Q: 7

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

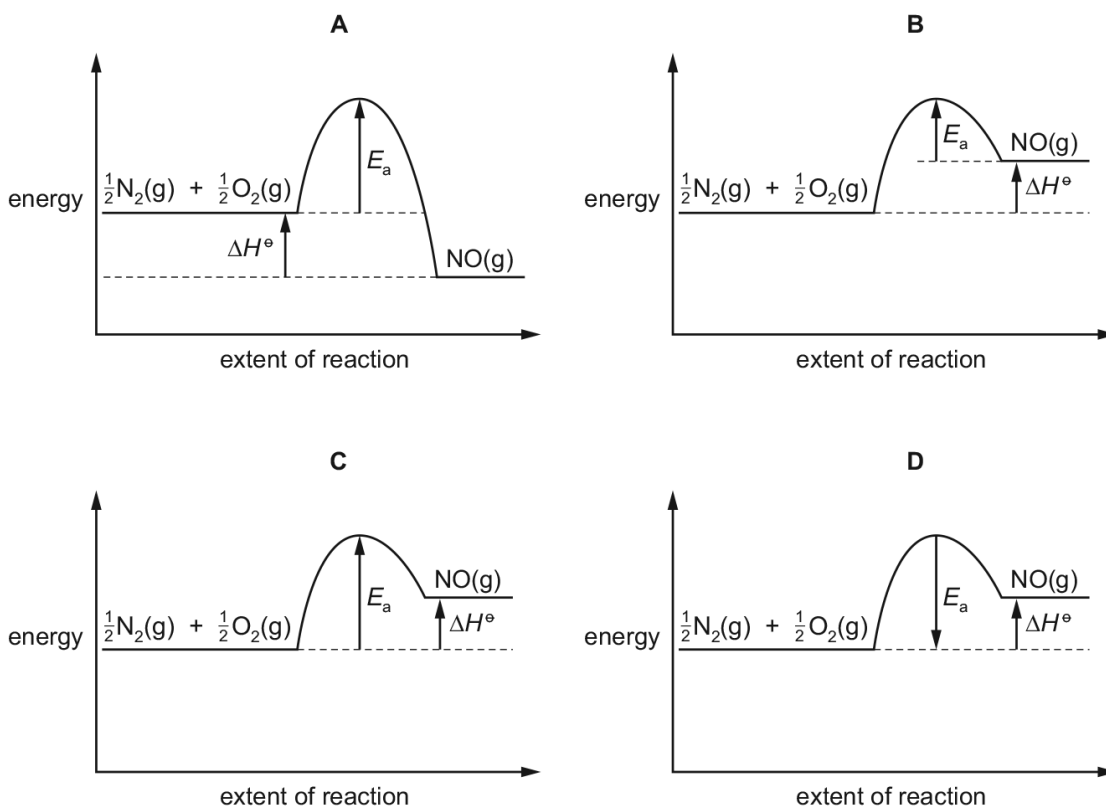
254. 9701_s17_qp_12 Q: 7

In the high temperatures of car engines, nitrogen reacts with oxygen to give nitrogen monoxide.



This reaction has activation energy E_a .

Which reaction pathway diagram could correctly represent this reaction?



255. 9701_s17_qp_13 Q: 6

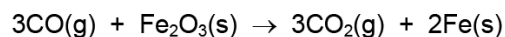
The following data are needed for this question.

$$\Delta H_f^\circ(\text{CO(g)}) = -111 \text{ kJ mol}^{-1}$$

$$\Delta H_f^\circ(\text{CO}_2\text{(g)}) = -394 \text{ kJ mol}^{-1}$$

$$\Delta H_f^\circ(\text{Fe}_2\text{O}_3\text{(s)}) = -822 \text{ kJ mol}^{-1}$$

Carbon monoxide reacts with iron(III) oxide.

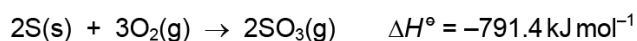


What is the enthalpy change when 55.8 g of iron are produced by this reaction?

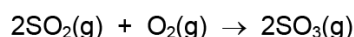
- A** -27.0 kJ **B** -13.5 kJ **C** +13.5 kJ **D** +27.0 kJ
-

256. 9701_w17_qp_11 Q: 8

Sulfur can be oxidised in two ways.



Sulfur trioxide can be made from sulfur dioxide and oxygen.



What is the standard enthalpy change for this reaction?

- A** -1384.4 kJ mol⁻¹
B -989.8 kJ mol⁻¹
C -494.9 kJ mol⁻¹
D -198.4 kJ mol⁻¹
-

257. 9701_w17_qp_11 Q: 11

200 g of water are at 25 °C.

The water is heated to 75 °C by burning 2 g of ethanol.

What is the amount of energy transferred to the water?

- A** 0.418 kJ **B** 10.4 kJ **C** 41.8 kJ **D** 62.7 kJ
-

258. 9701_w17_qp_12 Q: 6

In calculating the enthalpy change, ΔH , of an experiment involving solutions, the mass of the solution, m , specific heat capacity of the solution, c , and the temperature change, ΔT , are needed.

$$\Delta T = T_{\text{final}} - T_{\text{initial}}$$

Which expression for ΔH is correct?

- A** $\Delta H = \frac{mc}{\Delta T}$ **B** $\Delta H = \frac{-mc}{\Delta T}$ **C** $\Delta H = mc\Delta T$ **D** $\Delta H = -mc\Delta T$
-

259. 9701_w17_qp_12 Q: 7

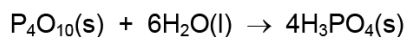
The following data are needed for this question.

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

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

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

What is ΔH° for the reaction shown?



- A** $-9844 \text{ kJ mol}^{-1}$
B -388 kJ mol^{-1}
C -97 kJ mol^{-1}
D $+2019 \text{ kJ mol}^{-1}$
-

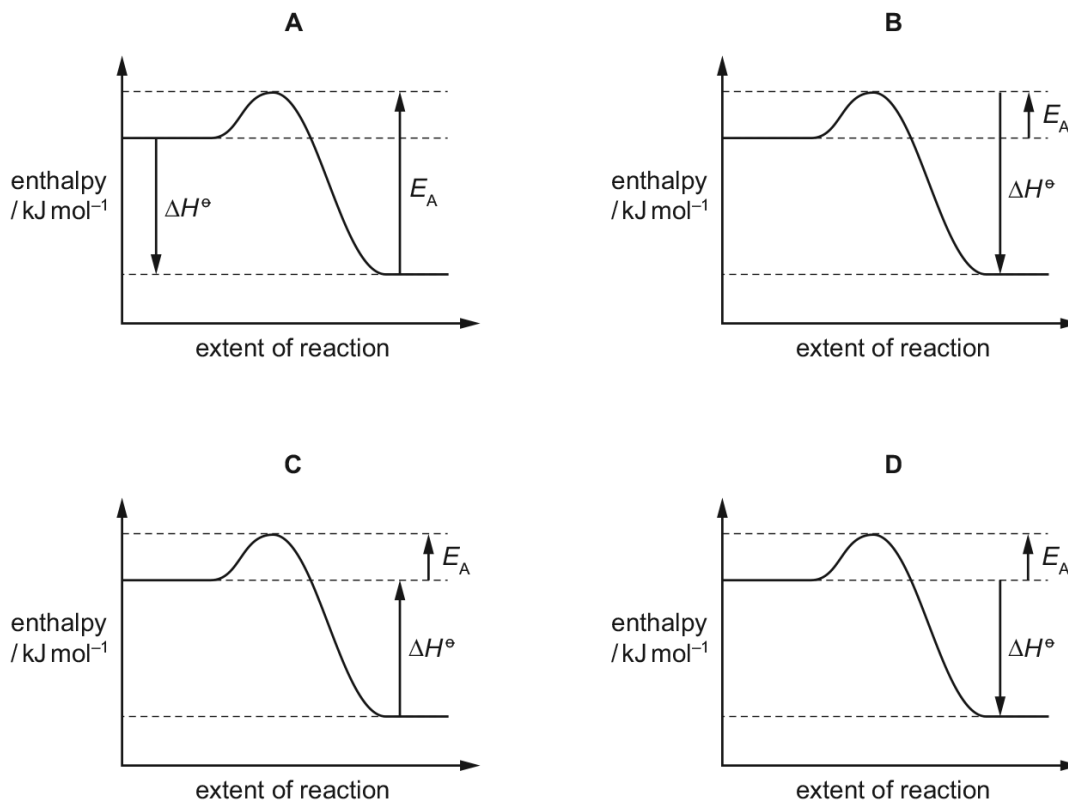
260. 9701_m16_qp_12 Q: 5

Nitric oxide, NO, and bromine vapour react together according to the following equation.



The reaction has an activation energy of $+5.4 \text{ kJ mol}^{-1}$.

What is the correct reaction pathway diagram for this reaction?



261. 9701_s16_qp_11 Q: 8

Gaseous phosphorus pentachloride can be decomposed into gaseous phosphorus trichloride and chlorine by heating. The table gives the bond energies.

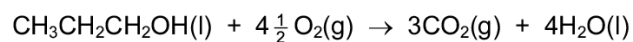
bond	bond energy / kJ mol^{-1}
P–Cl (in both chlorides)	330
Cl–Cl	242

What is the enthalpy change for the decomposition of PCl_5 to PCl_3 and Cl_2 ?

- A** -418 kJ mol^{-1}
- B** -88 kJ mol^{-1}
- C** $+88 \text{ kJ mol}^{-1}$
- D** $+418 \text{ kJ mol}^{-1}$

262. 9701_s16_qp_12 Q: 8

The equation for the complete combustion of propan-1-ol is shown.



Standard enthalpy changes of formation are given.

compound	$\text{CH}_3\text{CH}_2\text{CH}_2\text{OH}(\text{l})$	$\text{CO}_2(\text{g})$	$\text{H}_2\text{O}(\text{l})$
$\Delta H_f^\ominus$	-303 kJ mol^{-1}	-394 kJ mol^{-1}	-286 kJ mol^{-1}

What is the standard enthalpy change of combustion of propan-1-ol, in kJ mol^{-1} ?

- A** $-394 - 286 - 303$
B $303 - (4 \times 286) - (3 \times 394)$
C $394 + 286 - 303$
D $(3 \times 394) + (4 \times 286) + 303$
-

263. 9701_s16_qp_13 Q: 1

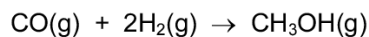
Enthalpy changes, ΔH , can be positive or negative.

Which row is correct?

	ΔH positive	ΔH negative
A	atomisation	bond breaking
B	bond breaking	neutralisation
C	bond making	combustion
D	combustion	bond making

264. 9701_s16_qp_13 Q: 8

Methanol may be prepared by the reaction between carbon monoxide and hydrogen.



The relevant average bond energies are given below.

$$E(\text{C}\equiv\text{O}) \quad 1077 \text{ kJ mol}^{-1}$$

$$E(\text{C}-\text{O}) \quad 360 \text{ kJ mol}^{-1}$$

$$E(\text{C}-\text{H}) \quad 410 \text{ kJ mol}^{-1}$$

$$E(\text{H}-\text{H}) \quad 436 \text{ kJ mol}^{-1}$$

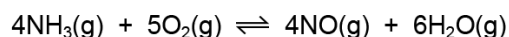
$$E(\text{O}-\text{H}) \quad 460 \text{ kJ mol}^{-1}$$

What is the enthalpy change of this reaction?

- A** -537 kJ mol^{-1}
 - B** -101 kJ mol^{-1}
 - C** $+101 \text{ kJ mol}^{-1}$
 - D** $+537 \text{ kJ mol}^{-1}$
-

265. 9701_w16_qp_11 Q: 8

An important reaction in the manufacture of nitric acid is the catalytic oxidation of ammonia.



For every mole of O_2 that reacts in this way, 181.8 kJ of energy are released.

A factory makes $2.50 \times 10^5 \text{ mol}$ of NO every day.

How much energy, in kJ, is released every day?

- A** 3.64×10^7 **B** 4.55×10^7 **C** 5.68×10^7 **D** 2.27×10^8
-

266. 9701_w16_qp_12 Q: 9

In a calorimetric experiment 1.60 g of a fuel are burnt. 45.0% of the energy released is absorbed by 200 g of water. The temperature of the water rises from 18.0°C to 66.0°C .

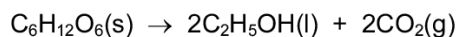
What is the total energy released per gram of fuel burnt (to 3 significant figures)?

- A** 25 100 J **B** 55 700 J **C** 89 200 J **D** 143 000 J
-

267. 9701_s15_qp_11 Q: 7

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.



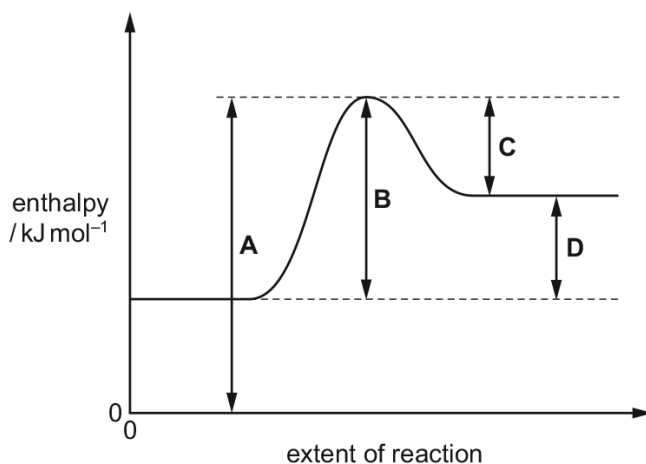
What is the standard enthalpy change for this reaction?

- A $-1452 \text{ kJ mol}^{-1}$
- B -84 kJ mol^{-1}
- C $+84 \text{ kJ mol}^{-1}$
- D $+1452 \text{ kJ mol}^{-1}$

268. 9701_s15_qp_11 Q: 11

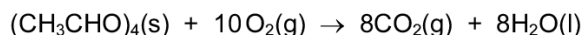
The diagram shows a reaction pathway for an endothermic reaction.

Which arrow represents the activation energy for the forward reaction?



269. 9701_s15_qp_12 Q: 6

Metaldehyde, $(\text{CH}_3\text{CHO})_4$, is used as a solid fuel for camping stoves. The equation for the complete combustion of metaldehyde is shown.



$\Delta H_c^\ominus$ = standard enthalpy change of combustion.

Which expression will give a correct value for the enthalpy change of formation of metaldehyde?

- A** $\Delta H_c^\ominus \text{metaldehyde} - (8\Delta H_c^\ominus \text{carbon} + 8\Delta H_c^\ominus \text{hydrogen})$
 - B** $\Delta H_c^\ominus \text{metaldehyde} - (8\Delta H_c^\ominus \text{carbon} + 16\Delta H_c^\ominus \text{hydrogen})$
 - C** $(8\Delta H_c^\ominus \text{carbon} + 8\Delta H_c^\ominus \text{hydrogen}) - \Delta H_c^\ominus \text{metaldehyde}$
 - D** $(8\Delta H_c^\ominus \text{carbon} + 16\Delta H_c^\ominus \text{hydrogen}) - \Delta H_c^\ominus \text{metaldehyde}$
-

270. 9701_s15_qp_13 Q: 3

A student performed an experiment to measure the enthalpy change of combustion of ethane.

He used the following values for the standard enthalpy changes of combustion of carbon and hydrogen.

$$\Delta H_c^\ominus \text{carbon} = -394 \text{ kJ mol}^{-1}$$

$$\Delta H_c^\ominus \text{hydrogen} = -286 \text{ kJ mol}^{-1}$$

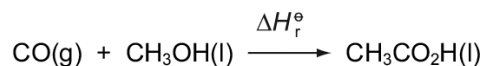
He calculated the enthalpy change of formation of ethane to be -140 kJ mol^{-1} .

What was his experimental value for the standard enthalpy change of combustion of ethane?

- A** $-2364 \text{ kJ mol}^{-1}$
 - B** $-1506 \text{ kJ mol}^{-1}$
 - C** $-1112 \text{ kJ mol}^{-1}$
 - D** -540 kJ mol^{-1}
-

271. 9701_s15_qp_13 Q: 7

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, ΔH_c°
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 ΔH_r° 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 $+1883.1 \text{ kJ mol}^{-1}$
-

272. 9701_w15_qp_11 Q: 6

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 , $\Delta H_c^\circ \text{S}_8(\text{s}) = -2376 \text{ kJ mol}^{-1}$

energy required to break 1 mole $\text{S}_8(\text{s})$ 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}
-

273. 9701_w15_qp_11 Q: 7

Use of the Data Booklet is relevant for this question.

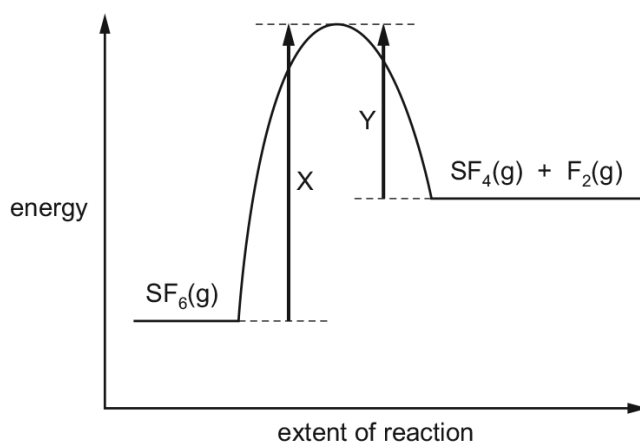
In an experiment, the burning of 1.45 g (0.025 mol) of propanone was used to heat 100 g of water. The initial temperature of the water was 20.0 °C and the final temperature of the water was 78.0 °C.

Which experimental value for the enthalpy change of combustion for propanone can be calculated from these results?

- A $-1304 \text{ kJ mol}^{-1}$
- B -970 kJ mol^{-1}
- C -352 kJ mol^{-1}
- D $-24.2 \text{ kJ mol}^{-1}$

274. 9701_w15_qp_12 Q: 10

The decomposition reaction $\text{SF}_6(\text{g}) \rightarrow \text{SF}_4(\text{g}) + \text{F}_2(\text{g})$ can be described by the reaction pathway diagram shown.



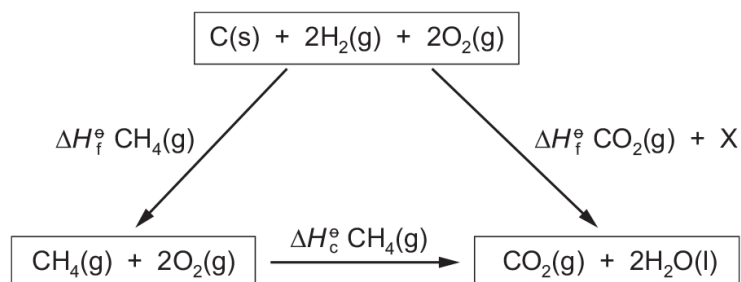
What are the values of ΔH° and E_a for this reaction?

	ΔH°	E_a
A	X	X + Y
B	X	Y
C	X - Y	X
D	Y - X	X

5.2 Hess's Law

275. 9701_s21_qp_13 Q: 8

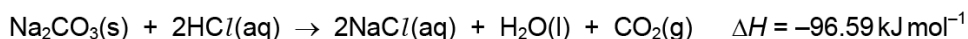
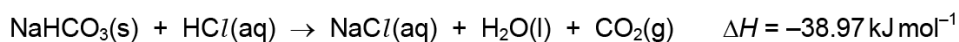
Which enthalpy change is indicated by X in the enthalpy cycle shown?



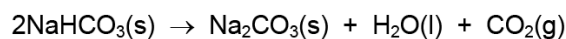
- A $-4 \times$ the enthalpy of combustion of hydrogen
- B $+4 \times$ the enthalpy of combustion of hydrogen
- C $-2 \times$ the enthalpy of formation of water
- D $+2 \times$ the enthalpy of formation of water

276. 9701_m20_qp_12 Q: 4

The following data are needed for this question.



On heating, sodium hydrogencarbonate decomposes as shown.

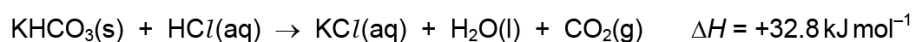
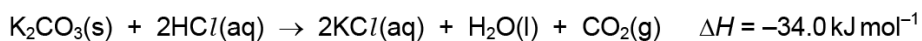


What is the enthalpy change for this decomposition?

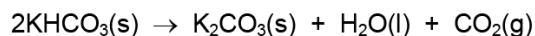
- A $-57.62 \text{ kJ mol}^{-1}$
- B $-18.65 \text{ kJ mol}^{-1}$
- C $18.65 \text{ kJ mol}^{-1}$
- D $57.62 \text{ kJ mol}^{-1}$

277. 9701_s20_qp_13 Q: 4

The enthalpy changes of two reactions are shown.



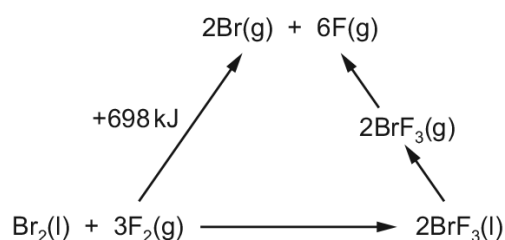
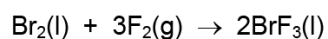
What is the enthalpy change for the reaction shown?



- 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}
-

278. 9701_w20_qp_11 Q: 7

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 Br–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}
-

279. 9701_m18_qp_12 Q: 9

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.

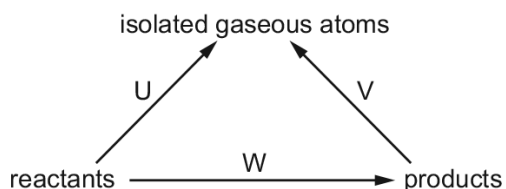


What is the enthalpy change for this reaction?

- A -674 kJ mol^{-1}
 - B -64 kJ mol^{-1}
 - C $+186 \text{ kJ mol}^{-1}$
 - D $+346 \text{ kJ mol}^{-1}$
-

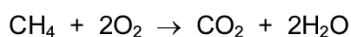
280. 9701_w15_qp_12 Q: 6

Hess' law may be used to determine enthalpy changes using average bond energies, as shown in the diagram.



U is the sum of the average bond energies of the reactants, and V is the sum of the average bond energies of the products.

For the reaction shown below, which expression will give a value for W, the enthalpy change of combustion of methane?



- A $U - V$
 - B $U + V$
 - C $2(U - V)$
 - D $V - U$
-

Paper 1 Multiple Choice Answers: Chemical Energetics

Question	Paper	Q. No.	Answer
228	9701_m22_qp_12	8	D
229	9701_m22_qp_12	9	A
230	9701_m21_qp_12	7	A
231	9701_s21_qp_11	4	D
232	9701_s21_qp_13	7	A
233	9701_w21_qp_12	9	B
234	9701_w21_qp_13	8	C
235	9701_s20_qp_11	5	C
236	9701_m19_qp_12	8	C
237	9701_m19_qp_12	9	D
238	9701_s19_qp_11	8	D
239	9701_s19_qp_12	8	B
240	9701_s19_qp_13	6	C
241	9701_w19_qp_11	7	A
242	9701_w19_qp_11	8	D
243	9701_w19_qp_12	6	D
244	9701_m18_qp_12	8	B
245	9701_s18_qp_11	7	B
246	9701_s18_qp_12	7	C
247	9701_s18_qp_13	7	D
248	9701_w18_qp_11	6	C
249	9701_w18_qp_12	1	D
250	9701_w18_qp_12	7	B
251	9701_m17_qp_12	7	B
252	9701_m17_qp_12	9	C
253	9701_s17_qp_11	7	D
254	9701_s17_qp_12	7	C
255	9701_s17_qp_13	6	B
256	9701_w17_qp_11	8	D
257	9701_w17_qp_11	11	C
258	9701_w17_qp_12	6	D
259	9701_w17_qp_12	7	B
260	9701_m16_qp_12	5	D
261	9701_s16_qp_11	8	D
262	9701_s16_qp_12	8	B
263	9701_s16_qp_13	1	B
264	9701_s16_qp_13	8	B
265	9701_w16_qp_11	8	C
266	9701_w16_qp_12	9	B
267	9701_s15_qp_11	7	B
268	9701_s15_qp_11	11	B
269	9701_s15_qp_12	6	C
270	9701_s15_qp_13	3	B
271	9701_s15_qp_13	7	B
272	9701_w15_qp_11	6	D
273	9701_w15_qp_11	7	B

Paper 1 Multiple Choice Answers: Chemical Energetics (continued)

Question	Paper	Q. No.	Answer
274	9701_w15_qp_12	10	C
275	9701_s21_qp_13	8	D
276	9701_m20_qp_12	4	C
277	9701_s20_qp_13	4	D
278	9701_w20_qp_11	7	B
279	9701_m18_qp_12	9	B
280	9701_w15_qp_12	6	A

Chapter 5

Chemical energetics

5.1 Enthalpy change, ΔH

20. 9701_w16_qp_21 Q: 2

For many compounds the enthalpy change of formation cannot be calculated directly. An indirect method based on enthalpy changes of combustion can be used.

The enthalpy change of combustion can be found by a calorimetry experiment in which the heat energy given off during combustion is used to heat a known mass of water and the temperature change recorded.

(a) (i) Explain the meaning of the term *standard enthalpy change of combustion*.

.....
.....
..... [3]

(ii) Write the equation for the complete combustion of ethanol, C_2H_5OH .

..... [1]

(b) In an experiment to determine the enthalpy change of combustion of ethanol, 0.23 g of ethanol was burned and the heat given off raised the temperature of 100 g of water by $16.3^\circ C$.

(i) Calculate the heat energy change, q , during the combustion of 0.23 g of ethanol.

$q = \dots\dots\dots J$ [1]

(ii) Calculate the enthalpy change on burning 1 mole of ethanol. Include a sign in your answer.

$\Delta H = \dots\dots\dots kJ mol^{-1}$ [1]

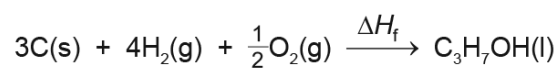
(iii) Suggest **two** reasons why the value for the enthalpy change of combustion of ethanol determined by a simple laboratory calorimetry experiment is likely to be lower than the true value.

.....
.....
.....
..... [2]

(c) The table gives some enthalpy change of combustion values.

substance	enthalpy change of combustion / kJ mol^{-1}
C(s)	-393.5
H ₂ (g)	-285.8
C ₃ H ₇ OH(l)	-2021.0

- (i) Construct a labelled energy cycle to show how these values could be used to calculate the enthalpy change of formation of C₃H₇OH(l), ΔH_f .



[3]

- (ii) Calculate the enthalpy change of formation, ΔH_f , of C₃H₇OH(l).

$$\Delta H_f = \dots\dots\dots \text{kJ mol}^{-1} \quad [2]$$

[Total: 13]

21. 9701_w15_qp_22 Q: 2

Chemical reactions are accompanied by enthalpy changes.

(a) Explain the meaning of the term *standard enthalpy change* of reaction.

.....
.....
..... [2]

(b) The enthalpy change of hydration of anhydrous magnesium sulfate, ΔH_{hyd} MgSO_4 , can be calculated by carrying out two separate experiments.

In the first experiment 45.00g of water was weighed into a polystyrene cup and 3.01g of MgSO_4 was added and stirred until it was completely dissolved. The temperature of the water rose from 23.4 °C to 34.7 °C.

(i) Calculate the amount of heat energy transferred to the water during this dissolving process.

You can assume that the specific heat capacity of the solution is the same as that of water, $4.18 \text{ J g}^{-1} \text{ K}^{-1}$.

heat energy = ... J [1]

(ii) Calculate the amount, in moles, of MgSO_4 dissolved.

amount = ... mol [1]

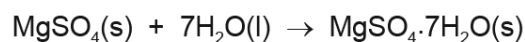
- (iii) Calculate the enthalpy change of solution, ΔH_{soln} , of $\text{MgSO}_4(\text{s})$.

You must include a sign with your answer.

$$\Delta H_{\text{soln}} \text{ of } \text{MgSO}_4(\text{s}) = \dots\dots\dots \text{ kJ mol}^{-1} \quad [1]$$

In the second experiment, the enthalpy change of solution for the hydrated salt, $\text{MgSO}_4 \cdot 7\text{H}_2\text{O}(\text{s})$, was calculated and found to be $+9.60 \text{ kJ mol}^{-1}$.

- (iv) Use the equation below for the hydration of anhydrous magnesium sulfate to construct a suitable, fully labelled energy cycle that will allow you to calculate the enthalpy change for this reaction, ΔH_{hyd} MgSO_4 .



[1]

- (v) Calculate the enthalpy change for this reaction, ΔH_{hyd} MgSO_4 . Include a sign in your answer.

$$\Delta H_{\text{hyd}} \text{ MgSO}_4 = \dots\dots\dots \text{ kJ mol}^{-1} \quad [1]$$

[Total: 7]

5.2 Hess' Law, including Born-Haber cycles

22. 9701_m19_qp_22 Q: 2

The elements in Group 17 of the Periodic Table are called the halogens. They form stable compounds with both metals and non-metals.

The table gives some data about F_2 , HCl and CaF_2 .

	F_2	HCl	CaF_2
boiling point/K	85	188	2773
relative formula mass	38.0	36.5	78.1

- (a) (i) State what is meant by the term *relative formula mass*.

.....
.....
..... [2]

- (ii) F_2 and HCl are both covalent molecules.

Suggest why the boiling point of HCl is higher than that of F_2 .

.....
.....
..... [2]

- (iii) Explain why CaF_2 has a very high boiling point.

.....
..... [1]

- (iv) $CaF_2(aq)$ can be made by the reaction of calcium carbonate with hydrofluoric acid, $HF(aq)$.

Write an equation for this reaction. Include state symbols.

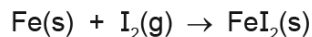
..... [2]

- (b) (i) Complete the electronic configuration of a chloride ion.

1s² [1]

- (ii) When Cl₂ is passed over hot iron, FeCl₃ is formed.

However, when I₂(g) is passed over hot iron, the following reaction occurs.



State what you would observe during the reaction between Fe and I₂. Explain why FeI₂(s) is formed rather than FeI₃(s).

observation

.....

explanation

.....

.....

[2]

- (iii) FeI₂ is soluble in water.

A student carries out a chemical test to confirm that a solution of FeI₂ contains aqueous iodide ions, I⁻(aq). The student adds a single reagent and a precipitate forms.

Identify the reagent the student uses. State the colour of the precipitate that forms.

reagent

colour of precipitate

[2]

- (iv) Compounds containing I⁻ are often contaminated by bromide ions, Br⁻.

Identify a further reagent that the student could use to show that the precipitate formed in (iii) contained iodide ions.

..... [1]

(c) HOF is the only known molecule that contains only the elements hydrogen, oxygen and fluorine.

(i) Draw a 'dot-and-cross' diagram to represent the bonding in a molecule of HOF.

Show the outer shell electrons only.

[2]

(ii) HOF can be made by the reaction of F_2 with ice at -40°C . The reaction is similar to the reaction of Cl_2 with cold water.

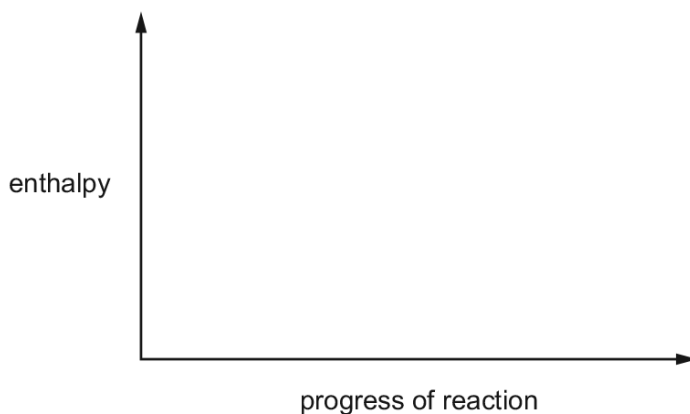
Suggest an equation for the reaction of F_2 with ice.

..... [1]

(iii) HOF is an unstable compound and decomposes to form HF and O_2 .



Draw a fully labelled reaction pathway diagram on the axes provided to show the decomposition of HOF into HF and O_2 .



[2]

- (iv) Pure HF is a colourless liquid at 273 K. The liquid contains HF molecules that have strong hydrogen bonds between them.

Draw a fully labelled diagram to suggest how a hydrogen bond can form between two HF molecules.

[3]

- (d) Interhalogen compounds, such as BrCl or IF_5 , contain two or more different halogen atoms that are covalently bonded.

D is an interhalogen compound that contains only chlorine and fluorine.

At 0°C and 101 325 Pa, 1 dm^3 of **D** has a mass of 4.13 g.

- (i) Use the general gas equation to calculate the relative molecular mass, M_r , of **D**.

$M_r = \dots\dots\dots$
[3]

- (ii) Use your answer to (i) to determine the molecular formula of **D**.

If you were unable to calculate the M_r in (i), assume that the M_r is 130.5. This is **not** the correct value.

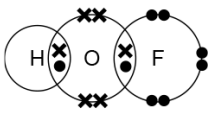
molecular formula of **D** = $\dots\dots\dots$
[1]

[Total: 25]

21. 9701_w15_ms_22 Q: 2

(a)	M1 <u>Heat</u> (energy) change (or $H_{\text{prod}} - H_{\text{react}}$) measured at constant pressure OR enthalpy change when the amount/moles of reactants as shown in a (reaction) <u>equation</u> react together to give products M2 measured at standard conditions	[1]
(b) (i)	$q = 2125.53$	[1]
(ii)	amount = 0.025(0)	[1]
(iii)	-85.(0)	[1]
(iv)	$(\text{MgSO}_4(\text{s}) + 7\text{H}_2\text{O}(\text{l}) \rightarrow \text{MgSO}_4 \cdot 7\text{H}_2\text{O}(\text{s}))$ $-85.0 \text{ (kJ mol}^{-1}\text{)}$ $(+)9.60 \text{ (kJ mol}^{-1}\text{)}$ $\text{MgSO}_4(\text{aq})$	[1]
(v)	$\Delta H + 9.6 = -85.0$ $\Delta H = -85.0 - 9.6 = -94.6 \text{ (kJ mol}^{-1}\text{)}$	[1]

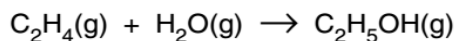
22. 9701_m19_ms_22 Q: 2

(a)(i)	M1 ① mass of a molecule OR ② (weighted) average / mean mass of the molecules OR ③ mass of one mole of molecules M2 ① / ② compared to $\frac{1}{12}$ (the mass) of an atom of carbon-12 OR on a scale in which a carbon-12 atom / isotope has a mass of (exactly) 12 (units) ③ relative / compared to $\frac{1}{12}$ (the mass) of 1 mole of carbon-12 OR on a scale in which 1 mole of carbon-12 (atoms / isotope) has a mass of (exactly) 12 g	2
(a)(ii)	M1 identification of the IMF between F₂ molecules and between HCl molecules HCl has (permanent) dipoles and / or induced dipoles F₂ has induced dipoles M2 comparison of strength of IMF's in F₂ and HCl Intermolecular forces in HCl are stronger than F₂	2
(a)(iii)	strong (electrostatic) forces of attraction between (oppositely charged) ions	1
(a)(iv)	CaCO₃(s) + 2HF(aq) → CaF₂(aq) + CO₂(g) + H₂O(l) M1 species and balancing M2 state symbols	2
(b)(i)	1s ² 2s ² 2p ⁶ 3s ² 3p ⁶	1
(b)(ii)	M1 purple gas / vapour disappears M2 iodine is not a strong enough oxidising agent OR A	2
(b)(iii)	M1 silver nitrate / AgNO₃ M2 yellow	2
(b)(iv)	(aqueous) ammonia / NH ₃ (aq) / ammonium hydroxide / NH ₄ OH(aq)	1
(c)(i)	 M1 bonding pairs correct M2 rest of molecule, incl. lone pairs.	2
(c)(ii)	F ₂ + H ₂ O → HF + HOF	1
(c)(iii)	M1 labelled reactants AND products lower on right M2 labelled enthalpy change with correct arrow	2
(c)(iv)	δ^+ δ^- δ^+ δ^- H—F : : : : : H—F M1 H-bond labelled / shown as distinct from H—F bond M2 correct sequence of three correct dipoles M3 lone pair on F in line with H-bond	3
(d)(i)	$pV = nRT \therefore n = \frac{pV}{RT} = \frac{101\,325 \times 0.001}{8.31 \times 273} = 0.0447 \text{ mol}$ $\therefore M_r = \frac{m}{n} = \frac{4.13}{0.0447} = 92.4 \text{ or } 92.5$ M1 Use of $T = 273 \text{ K}$, $V = 0.001 \text{ m}^3$ and $p = 101325 \text{ Pa}$ M2 correct use of $pV = nRT$ using values from M1 M3 correct calculation of M_r using $4.13 \div$ moles from M2	3
(d)(ii)	ClF ₃	1

Q:1 [M/J 2002 (2)]

- 2** Ethanol, C₂H₅OH, is a most important industrial chemical and is used as a solvent, a fuel and an intermediate in large scale organic synthesis.

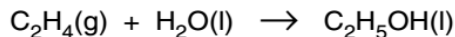
Ethanol is prepared industrially by the reaction of ethene and steam in the presence of a catalyst.



The standard enthalpy change of the reaction can be determined by using the standard enthalpy changes of combustion, $\Delta H_c^\ominus$, at 298 K.

	$\Delta H_c^\ominus / \text{kJ mol}^{-1}$
C ₂ H ₄ (g)	-1411
C ₂ H ₅ OH(l)	-1367

- (a)** Calculate the standard enthalpy change for the following reaction.



[2]

- (b) (i)** Define the term *standard enthalpy change of combustion*.

.....
.....
.....

- (ii)** Explain why the state symbols for water and ethanol given in the equation in **(a)** have been changed from those quoted in the industrial process.

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.....
.....

- (iii)** Write the equation for the complete combustion of ethanol.

.....

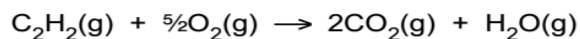
[4]

- (c) Ethanol is miscible with water because of hydrogen bonding between molecules of ethanol and water. Draw a diagram, including dipoles, to show the hydrogen bonding between a molecule of ethanol and a molecule of water.

[2]

Q:2 [MJ 2006 (2: d)]

- (d) The equation for the complete combustion of ethyne is given below.
Use appropriate bond energy data from the *Data Booklet* to calculate a value for the enthalpy change of combustion of ethyne.



[3]

- (e) The value for the standard enthalpy change of combustion of ethyne is $-1300 \text{ kJ mol}^{-1}$.

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

.....

.....

.....

- (ii) Explain why your answer to (d) does not have the same value as the standard enthalpy change of combustion.

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.....

[3]

Q:3 [M/J 2010 - 23 (1)]

- 1 Hydrazine, N_2H_4 , can be used as a rocket fuel and is stored as a liquid. It reacts exothermically with oxygen to give only gaseous products.

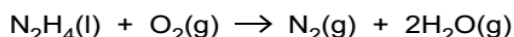
The enthalpy change of a reaction such as that between hydrazine and oxygen may be calculated by using standard enthalpy changes of formation.

- (a) Define the term *standard enthalpy change of formation*, ΔH_f° .

.....

 [3]

- (b) Hydrazine reacts with oxygen according to the following equation.



- (i) Use the data in the table to calculate the standard enthalpy change of this reaction.

compound	$\Delta H_f^\circ/\text{kJ mol}^{-1}$
$\text{N}_2\text{H}_4(\text{l})$	50.6
$\text{H}_2\text{O}(\text{g})$	-241.8

$$\Delta H^\circ = \dots\dots\dots \text{kJ mol}^{-1}$$

- (ii) Although the above reaction is highly exothermic, hydrazine does not burn spontaneously in oxygen. Suggest a reason for this.

.....

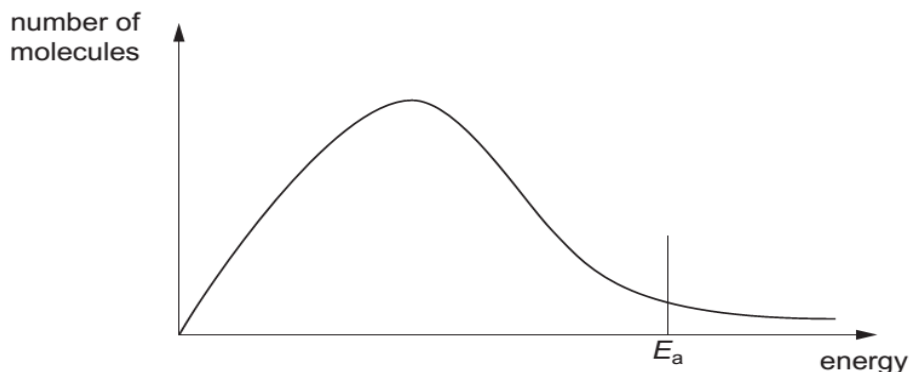
- (iii) Suggest why using hydrazine as a rocket fuel could be regarded as being 'environmentally friendly'.

.....

[4]

Q:4 [MJ 2010 – 21 (2)]

- 2 The diagram below shows, for a given temperature T , a Boltzmann distribution of the kinetic energy of the molecules of a mixture of two gases that will react together, such as nitrogen and hydrogen.
The activation energy for the reaction, E_a , is marked.



(a) On the graph above,

- (i) draw a new distribution curve, **clearly labelled T'** , for the same mixture of gases at a higher temperature, T' ;
- (ii) **mark clearly, as H**, the position of the activation energy of the reaction at the higher temperature, T' .

[3]

(b) Explain the meaning of the term *activation energy*.

.....

.....

.....

..... [2]

Q:5 [M/J 2011 – 21 (5 :d)]

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

Values of relevant standard enthalpy changes of formation, $\Delta H_{\text{f}}^{\ominus}$, measured at 298 K, are given in the table.

substance	$\Delta H_{\text{f}}^{\ominus} / \text{kJ mol}^{-1}$
$\text{CO}_2(\text{g})$	-394
$\text{H}_2\text{O}(\text{l})$	-286

- (i) Write balanced equations, with state symbols, that represent the standard enthalpy change of combustion, $\Delta H_{\text{c}}^{\ominus}$, of C_2H_2 , and

.....

the standard enthalpy change of formation, $\Delta H_{\text{f}}^{\ominus}$, of C_2H_2 .

.....

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

[6]

Q:6 [M/J 12 – 21 (3)]

- 3 Methanol, CH₃OH, is considered to be a possible alternative to fossil fuels, particularly for use in vehicles.

Methanol can be produced from fossil fuels and from agricultural waste. It can also be synthesised from carbon dioxide and hydrogen.

- (a) Define, with the aid of an equation which includes state symbols, the standard enthalpy change of formation of carbon dioxide.

equation

definition

.....

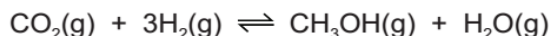
..... [3]

- (b) Relevant ΔH_f° values for the reaction that synthesises methanol are given in the table.

compound	$\Delta H_f^\circ / \text{kJ mol}^{-1}$
CO ₂ (g)	–394
CH ₃ OH(g)	–201
H ₂ O(g)	–242

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

Include a sign in your answer.



$$\Delta H_{\text{reaction}}^\circ = \dots\dots\dots \text{kJ mol}^{-1}$$

- (ii) Suggest **one** possible environmental advantage of this reaction. Explain your answer.

.....

.....

[5]

Q:7 [M/J 2012 – 22 (2)]

- 2** Alcohols such as methanol, CH₃OH, are considered to be possible replacements for fossil fuels because they can be used in car engines.

(a) Define, with the aid of an equation which includes state symbols, the standard enthalpy change of combustion, $\Delta H_c^\ominus$, for methanol at 298 K.

equation

definition

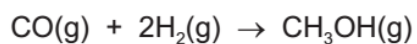
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..... [3]

Methanol may be synthesised from carbon monoxide and hydrogen. Relevant $\Delta H_c^\ominus$ values for this reaction are given in the table below.

compound	$\Delta H_c^\ominus / \text{kJ mol}^{-1}$
CO(g)	–283
H ₂ (g)	–286
CH ₃ OH(g)	–726

(b) Use these values to calculate $\Delta H_{\text{reaction}}^\ominus$ for the synthesis of methanol, using the following equation. Include a sign in your answer.



$$\Delta H_{\text{reaction}}^\ominus = \dots\dots\dots \text{kJ mol}^{-1}$$

[3]

Q:8 [M/J 2012 – 23 (3)]

- 3 With the prospect that fossil fuels will become increasingly scarce in the future, many compounds are being considered for use in internal combustion engines. One of these is DME or dimethyl ether, CH_3OCH_3 . DME is a gas which can be synthesised from methanol. Methanol can be obtained from biomass, such as plant waste from agriculture.

- (a) Define, with the aid of an equation which includes state symbols, the standard enthalpy change of combustion, $\Delta H_c^\ominus$, for DME at 298 K.

equation

definition

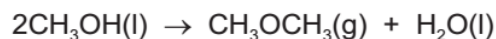
.....

..... [3]

- (b) DME may be synthesised from methanol. Relevant enthalpy changes of formation, $\Delta H_f^\ominus$, for this reaction are given in the table below.

compound	$\Delta H_f^\ominus / \text{kJ mol}^{-1}$
$\text{CH}_3\text{OH(l)}$	–239
$\text{CH}_3\text{OCH}_3\text{(g)}$	–184
$\text{H}_2\text{O(l)}$	–286

Use these values to calculate $\Delta H_{\text{reaction}}^\ominus$ for the synthesis of DME, using the following equation. Include a sign in your answer.

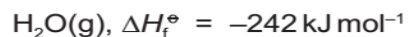
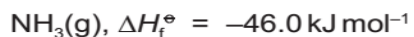


$$\Delta H_{\text{reaction}}^\ominus = \dots\dots\dots \text{kJ mol}^{-1}$$

[3]

Q:9 [M/J 2013 – 21 (2 :c)]

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



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

Include a sign in your answer.



[4]

Q:10 [M/J 2013 – 23 (1)]

- 1 Carbon disulfide, CS_2 , is a volatile, flammable liquid which is produced in small quantities in volcanoes.

(a) The sequence of atoms in the CS_2 molecule is sulfur to carbon to sulfur.

- (i) Draw a 'dot-and-cross' diagram of the carbon disulfide molecule.
Show outer electrons only.

(ii) Suggest the shape of the molecule and state the bond angle.

shape

bond angle

[3]

(b) Carbon disulfide is readily combusted to give CO_2 and SO_2 .

(i) Construct a balanced equation for the complete combustion of CS_2 .

.....

(ii) Define the term *standard enthalpy change of combustion*, ΔH_c° .

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.....

.....

[3]

(c) Calculate the standard enthalpy change of formation of CS_2 from the following data. Include a sign in your answer.

standard enthalpy change of combustion of $\text{CS}_2 = -1110 \text{ kJ mol}^{-1}$

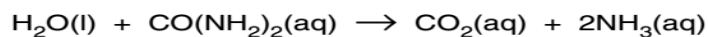
standard enthalpy change of formation of $\text{CO}_2 = -395 \text{ kJ mol}^{-1}$

standard enthalpy change of formation of $\text{SO}_2 = -298 \text{ kJ mol}^{-1}$

[3]

Q:11 [O/N 2002 (4: e)]

- (e) Urea, $\text{CO}(\text{NH}_2)_2$, is a naturally occurring substance which can be hydrolysed with water to form ammonia according to the following equation.



The standard enthalpy changes of formation of water, urea, carbon dioxide and ammonia (in aqueous solution) are given below.

compound	$\Delta H_f^\ominus / \text{kJ mol}^{-1}$
$\text{H}_2\text{O}(\text{l})$	-287.0
$\text{CO}(\text{NH}_2)_2(\text{aq})$	-320.5
$\text{CO}_2(\text{aq})$	-414.5
$\text{NH}_3(\text{aq})$	-81.0

Use these data to calculate the standard enthalpy change for the hydrolysis of urea.

[2]

Q: 12 [O/N 2003 (3)]

- 3 (a) (i) What is meant by the *standard enthalpy change of formation*, $\Delta H_f^\ominus$, of a compound? Explain what is meant by the term *standard*.

.....

- (ii) Write an equation, with state symbols, for the $\Delta H_f^\ominus$ of water.

.....

- (iii) Explain why the $\Delta H_f^\ominus$ for water is identical to the standard enthalpy change of combustion of hydrogen.

.....

.....[4]

(b) When calcium is placed in water, aqueous calcium hydroxide is formed and hydrogen is given off.

(i) Write the equation for the reaction of calcium with water.

.....

(ii) When 1.00 g of calcium is placed in 200 g of water, the temperature increases by 12.2 °C when the reaction is completed. The specific heat capacity of water, c , is $4.2 \text{ J g}^{-1} \text{ K}^{-1}$.

Calculate the heat released in the experiment.

(iii) Calculate the standard enthalpy change of reaction in kJ mol^{-1} for your equation in **(b)(i)**.

[4]

(c) (i) State *Hess' Law*.

.....

.....

.....

(ii) Use Hess' Law and your result in **(b)(iii)** to calculate the ΔH_f° of Ca(OH)_2 (aq). You also need the ΔH_f° of water which is -286 kJ mol^{-1} .

[4]

- (d) Calculate the volume of hydrogen, measured at room temperature and pressure, liberated in the experiment described in (b)(ii).

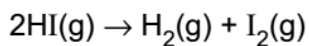
[2]

Q:13 [O/N 2004 (1: d)]

- (d) (i) Explain how enthalpy changes, ΔH values, for covalent bonded molecules can be calculated from bond energies.

.....
.....

- (ii) Use bond energies from the *Data Booklet* to calculate ΔH for the following dissociation.



[3]

Q:14 [O/N 2005 (2)]

- 2 Carbon disulphide, CS_2 , is a volatile, stinking liquid which is used to manufacture viscose rayon and cellophane.

(a) The carbon atom is in the centre of the CS_2 molecule.

Draw a 'dot-and-cross' diagram of the carbon disulphide molecule.

Show outer electrons only.

[2]

(b) Suggest the shape of the molecule and give its bond angle.

shape

bond angle

[2]

(c) Explain the term *standard enthalpy change of formation*, $\Delta H_f^\ominus$.

.....
.....
..... [3]

(d) Calculate the standard enthalpy change of formation of CS_2 from the following data.

standard enthalpy change of formation of SO_2 = -298 kJ mol^{-1}

standard enthalpy change of formation of CO_2 = -395 kJ mol^{-1}

standard enthalpy change of combustion of CS_2 = $-1110 \text{ kJ mol}^{-1}$

[3]

Q: 15 [O/N 2006 (4: d,e)]

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

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

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

.....
..... [2]

When 0.47 g of **Z** were completely burnt in air, the heat produced raised the temperature of 200 g of water by 27.5°C .

(e) **(i)** Calculate the amount of heat released in this experiment.

(ii) Use the data above and your answer to **(i)** to calculate the relative molecular mass of **Z**.

[4]

Q: 16 [O/N 2007 (1: e)]

(e) Carbon, hydrogen and ethene each burn exothermically in an excess of air.



Use the data to calculate the standard enthalpy change of formation, ΔH_f° , in kJ mol^{-1} , of ethene at 298 K.



$$\Delta H_f^\circ = \dots\dots\dots \text{ kJ mol}^{-1}$$

[3]

Q: 17 [O/N 2008 (2: c)]

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

.....

.....

.....

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

	$\Delta H^\ominus/\text{kJ mol}^{-1}$
standard enthalpy change of formation of CO_2	-395
standard enthalpy change of combustion of H_2	-286
standard enthalpy change of combustion of $\text{CH}_2=\text{C}=\text{O}$	-1028

[6]

Q:18 [O/N 2009 – 21 (3: a, c)]

- 3 Alkanes such as methane, 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, CH_3Cl , are given below.

	$\Delta H_f^\ominus/\text{kJ mol}^{-1}$
CH_4	-75
CH_3Cl	-82
HCl	-92

- (a) (i) Use the data to calculate $\Delta H_{\text{reaction}}^\ominus$ for the formation of CH_3Cl .



- (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.

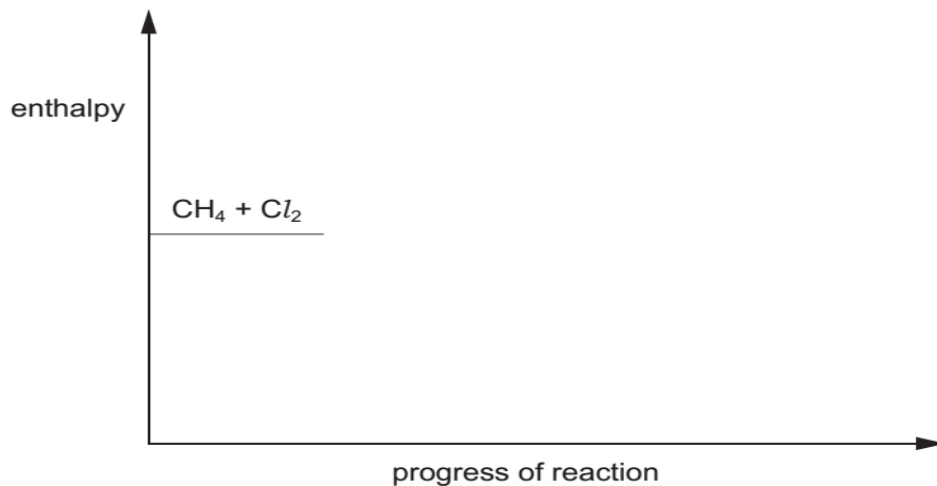


- (iii) Suggest why this reaction does **not** in fact occur.

.....
.....

[5]

- (c) The energy of activation for the formation of CH_3Cl is 16 kJ mol^{-1} .
Use this figure and your answer to (a)(i) to complete the reaction pathway diagram below showing the formation of CH_3Cl from CH_4 and Cl_2 .
Show clearly the intermediate organic species and the final products.
Indicate on your sketch the relevant enthalpy changes and their values.



[4]

Q: 19 [O/N 2010 – 22 (3: d,e,f)]

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*.

.....
..... [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°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.

(ii) Use the data above and your answer to **(i)** to calculate the relative molecular mass, M_r , of **E**.

[4]

(f) Deduce the molecular formula of **E**.

[1]

Q: 20 [O/N 2011 – 22 (3)]

- 3** For some chemical reactions, such as the thermal decomposition of potassium hydrogencarbonate, 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]

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

experiment 1

30.0 cm³ of 2.00 mol dm⁻³ 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, K₂CO₃, 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.

(iii) Use your answer to (ii) to calculate the enthalpy change per mole of K₂CO₃.
Give your answer in kJ mol⁻¹ and include a sign in your answer.

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

.....

..... [4]

experiment 2

The experiment was repeated with 0.0200 mol of potassium hydrogencarbonate, KHCO_3 . All other conditions were the same.

In the second experiment, the temperature fell from 21.0°C to 17.3°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 KHCO_3 . Give your answer in kJ mol^{-1} and include a sign in your answer.

[3]

(d) When KHCO_3 is heated, it decomposes into K_2CO_3 , CO_2 and H_2O .



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

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

[2]

Q:21 [O/N 2013 – 21 (5: d)]

- (c) Propane and butane have different values of standard enthalpy change of combustion.

Define the term *standard enthalpy change of combustion*.

.....
.....
..... [2]

- (d) A 125 cm³ sample of propane gas, measured at 20 °C and 101 kPa, was completely burnt in air.

The heat produced raised the temperature of 200 g of water by 13.8 °C.

Assume no heat losses occurred during this experiment.

- (i) Use the equation $pV = nRT$ to calculate the mass of propane used.

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

- (iii) Use the data above and your answers to (i) and (ii) to calculate the energy produced by the burning of 1 mol of propane.

[5]

Q:22 [O/N 2013 – 23 (2: c, d)]

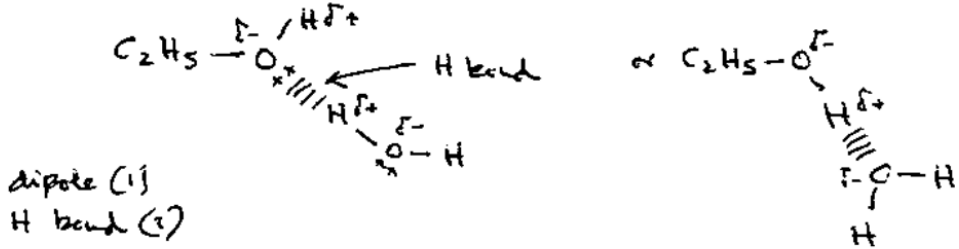
- (c) Define the term *standard enthalpy change of combustion*.

.....
.....
..... [2]

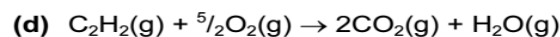
- (d) A 1.00 cm^3 sample of $\text{C}_{14}\text{H}_{30}$ was completely burnt in air.
The heat produced raised the temperature of 250 g of water by 34.6°C .
Assume no heat losses occurred during this experiment.
The density of $\text{C}_{14}\text{H}_{30}$ is 0.763 g cm^{-3} .
- (i) Use relevant data from the *Data Booklet* to calculate the amount of heat released in this experiment.
- (ii) Use the data above and your answer to (i) to calculate the energy produced by the combustion of 1 mol of $\text{C}_{14}\text{H}_{30}$.

[5]

Q:1

Question Number	Mark Scheme Details	Part Mark
2 (a)	$\begin{array}{ccc} \text{C}_2\text{H}_4 & \rightarrow \text{H}_2\text{O} & \rightarrow \text{C}_2\text{H}_5\text{OH} \\ -1411 & & -1367 \\ \Delta H = & (1) & (1) \\ & 44 & \text{kJ mol}^{-1} \end{array}$	[2]
(b) (i)	* ΔH when 1 mol of ^{element or compound (1)} a substance is completely combusted (1)	
(ii)	Under standard conditions H_2O & $\text{C}_2\text{H}_5\text{OH}$ are liquids (1)	
(iii)	$\text{C}_2\text{H}_5\text{OH} + 3\text{O}_2 \rightarrow 2\text{CO}_2 + 3\text{H}_2\text{O}$ (1)	4
(c)	 dipole (1) H bond (1) [Total 8] * Some energy reference required.	2

Q:2



bonds broken: $2(\text{H}-\text{C}) \quad 2 \times 410 = 820$
 $\text{C}\equiv\text{C} \quad 840 = 840$
 $\frac{5}{2}(\text{O}=\text{O}) \quad \frac{5}{2} \times 496 = 1240$
 2900 kJ mol⁻¹ (1)

bonds made: $4(\text{C}=\text{O}) \quad 4 \times 740 = 2960$
 $2(\text{O}-\text{H}) \quad 2 \times 460 = 920$
 3880 kJ mol⁻¹ (1)

$\Delta H_{\text{comb}} = -3880 + 2900 = -980 \text{ kJ mol}^{-1}$ (1)
 allow e.c.f. on incorrect bonds made/broken

[3]

- (e) (i) the enthalpy/energy change when one mole of a substance (1)
 is burned in an excess of air/oxygen
 or completely combusted
 under standard conditions (1)
- (ii) calculation in (d) includes $\text{H}_2\text{O}(\text{g})$ whereas ΔH_{comb} involves $\text{H}_2\text{O}(\text{l})$
 or average bond energy terms are used in the *Data Booklet* (1) [3]

Q:3

- 1 (a) enthalpy change when 1 mol of a compound is formed (1)
 from its elements (1)
 in their standard states under standard conditions (1) [3]
- (b) (i)
$$\begin{array}{rcl} \text{N}_2\text{H}_4(\text{l}) + \text{O}_2(\text{g}) & \rightarrow & \text{N}_2(\text{g}) + 2\text{H}_2\text{O}(\text{g}) \\ \Delta H_f^\circ/\text{kJ mol}^{-1} & +50.6 & -241.8 \\ \Delta H_{\text{reaction}}^\circ & = 2(-241.8) - (+50.6) & (1) \\ & = -534.2 \text{ kJ mol}^{-1} & (1) \end{array}$$
- (ii) E_{a} is too high (1)
- (iii) products are H_2O and N_2 which are harmless/non toxic
 or are already present in the atmosphere (1) [4]

Q:4

- 2 (a) (i) new graph has **lower** maximum (1)
 maximum is **to the right of** previous maximum (1)
- (ii) H is at E_{a} (1) [3]
- (b) the minimum amount of energy molecules must have or energy required (1)
 in order for the reaction to take place (1) [2]

Q:5

- (d) (i) **combustion**
 $\text{C}_2\text{H}_2(\text{g}) + \frac{5}{2}\text{O}_2(\text{g}) \rightarrow 2\text{CO}_2(\text{g}) + \text{H}_2\text{O}(\text{l})$ or
 equation must be for the combustion of one mole of C_2H_2
 H_2O must be shown as liquid (1)
 correct state symbols in this equation (1)
- formation**
 $2\text{C}(\text{s}) + \text{H}_2(\text{g}) \rightarrow \text{C}_2\text{H}_2(\text{g})$
 no mark for state symbols here (1)

(ii) let **Z** be ΔH°_f of C_2H_2

$$C_2H_2 + \frac{5}{2}O_2 \rightarrow 2CO_2 + H_2O$$

ΔH°_f	Z	0	2(-394)	-286	
--------------------	----------	---	---------	------	--

$$\Delta H^\circ_c = -1300 = 2(-394) + (-286) - \mathbf{Z} \quad (1)$$

whence **Z** = $2(-394) + (-286) - (-1300)$

= +226 kJ mol⁻¹

value (1)

sign (1)

allow ecf on wrong equation [6]

Q:6

- 3 (a) $C(s) + O_2(g) \rightarrow CO_2(g)$ (1)
- the enthalpy change/energy change/heat change when
one mole of a compound/ CO_2 (1)
- is formed from its elements in their standard states (1)

- (b) (i)
- | | | | | | | | |
|--|-----------|---|-----------|----------------------|-------------|---|-----------|
| ΔH°_f /kJ mol ⁻¹ | $CO_2(g)$ | + | $3H_2(g)$ | $\rightleftharpoons$ | $CH_3OH(g)$ | + | $H_2O(g)$ |
| | -394 | | 0 | | -201 | | -242 |
- $\Delta H^\circ_{\text{reaction}} = -201 + (-242) - (-394)$ (1)
- 49 kJ mol⁻¹ (1)
- correct sign (1)
- (ii) removal of CO_2 from the atmosphere (1)
- CO_2 is a greenhouse gas/causes global warming (1)

Q:7

- 2 (a) $CH_3OH(l) + \frac{3}{2}O_2(g) \rightarrow CO_2(g) + 2H_2O(l)$ (1)
- the enthalpy change/heat change/heat evolved when
one mole of CH_3OH (1)
- is completely burned **or** (1)
- is burned in an excess of air/oxygen (1)
- (b) $\Delta H^\circ_{\text{reaction}} = -283 + 2(-286) - (-726)$ (1)
- = -129 kJ mol⁻¹ (1)
- correct sign (1)

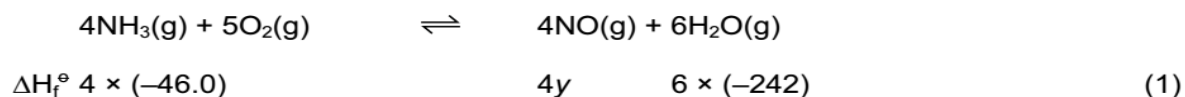
Q:8

- (a) $\text{CH}_3\text{OCH}_3(\text{l}) + 3\text{O}_2(\text{g}) \rightarrow 2\text{CO}_2(\text{g}) + 3\text{H}_2\text{O}(\text{l})$ (1)
 the enthalpy change/heat change/heat evolved when
 one mole of CH_3OCH_3 /a compound (1)
 is completely burned **or**
 burned in an excess of air/oxygen (1)

- (b)
$$\begin{array}{l} \Delta H_f^\ominus / \text{kJ mol}^{-1} \quad 2\text{CH}_3\text{OH}(\text{l}) \quad \rightarrow \quad \text{CH}_3\text{OCH}_3(\text{g}) \quad + \quad \text{H}_2\text{O}(\text{l}) \\ \quad \quad \quad 2(-239) \quad \quad \quad -184 \quad \quad \quad -286 \\ \Delta H_{\text{reaction}}^\ominus = -184 + (-286) - 2(-239) \\ \quad \quad \quad = +8 \text{ kJ mol}^{-1} \end{array}$$
 (1)
 correct sign (1)
 (1)

Q:9

- (c) let $\Delta H_f^\ominus$ for NO be $y \text{ kJ mol}^{-1}$



$$\begin{aligned} \Delta H_{\text{reaction}}^\ominus &= 4y + [6 \times (-242)] - [4 \times (-46.0)] \\ &= 4y - 1452 + 184 \end{aligned} \quad (1)$$

$\Delta H_{\text{reaction}}^\ominus$ is -906 kJ mol^{-1} so (1)
 $4y = -906 + 1452 - 184 = 362$ (1)
 whence $y = \Delta H_f^\ominus$ for NO = $+90.5 \text{ kJ mol}^{-1}$
 + sign is required (1)

Q:10

1 (a) (i)



S atom has 6 **and** C atom has 4 electrons (1)

S=C double bonds (4 electrons) clearly shown (1)

(ii) linear **and** 180° (1)

(b) (i) $\text{CS}_2 + 3\text{O}_2 \rightarrow \text{CO}_2 + 2\text{SO}_2$ (1)

(ii) enthalpy change when 1 mol of a substance (1)

is burnt in an excess of oxygen/air

or is completely combusted

under standard conditions (1)

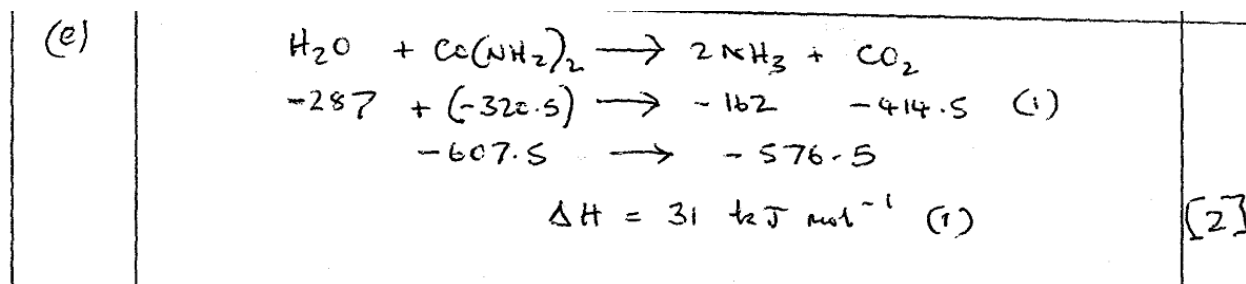
(c)

$$\begin{array}{rclcl} \text{CS}_2 + 3\text{O}_2 & \rightarrow & \text{CO}_2 & + & 2\text{SO}_2 \\ \Delta H_f^\circ/\text{kJ mol}^{-1} & \times & -395 & & 2(-298) \end{array} \quad (1)$$

$$\Delta H_{\text{reaction}} = -395 + 2(-298) - x = -1110 \text{ kJ mol}^{-1} \quad (1)$$

$$\text{gives } x = -395 + (-596) + 1110 = +119 \text{ kJ mol}^{-1} \quad (1)$$

Q:11



Q:12

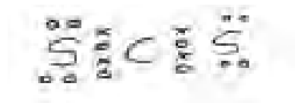
- 3 (a) (i)** energy/enthalpy change when 1 mol of a compound is formed from its elements (1)
 at 25°C and 1 atm (1)
- (ii)** $\text{H}_2(\text{g}) + \frac{1}{2}\text{O}_2(\text{g}) \rightarrow \text{H}_2\text{O}(\text{l})$ (1)
- (b) (i)** $\text{Ca} + 2\text{H}_2\text{O} \rightarrow \text{Ca}(\text{OH})_2 + \text{H}_2$ (1)
- (ii)** heat released = $mc\Delta T$ (1)
 $= 200 \times 4.2 \times 12.2 = 10.25 \text{ kJ}$ (1)
- (iii)** $\Delta H_{\text{reacn}} = 40.1 \times (-10.25) = -411 \text{ kJ mol}^{-1}$ sign necessary
 for ecf, $\Delta H_{\text{reacn}} = 40.1 \times [\text{answer to (b)(ii)}]$ (1) **[4]**
- (c) (i)** The enthalpy (energy) change for converting reactants into products (1)
 is the same regardless of the route taken (1)
- (ii)** $\text{Ca}(\text{s}) + 2\text{H}_2\text{O}(\text{l}) \rightarrow \text{Ca}(\text{OH})_2(\text{aq}) + \text{H}_2(\text{g}) \quad \Delta H = -411$
 $\Delta H_{\text{f}}^{\ominus} \quad 2 \times (-286) \quad \quad \quad x$
- $\Delta H_{\text{reacn}} = x - 2(-286) = -411$ (1)
 $x = -411 + 2(-286) = -983 \text{ kJ mol}^{-1}$ (1)
 sign necessary
 for ecf, $x = \text{ans. to (b)(iii)} + (-572)$ **[4]**
- (d)** 40.1 g of Ca give 24000 cm³ of H₂ (1)
 1 g of Ca gives $\frac{24000}{40.1} = 598.5 \text{ cm}^3$ units needed
 allow 40 g of Ca giving 600 cm³ (1) **[2]**

Q: 13

- (d) (i)** $\Delta H_{\text{reacn}} = \Delta H$ for bonds broken – ΔH for bonds made (1)
- (ii)** $2\text{H} - \text{I} \rightarrow \text{H} - \text{H} + \text{I} - \text{I}$
- 2 x 299 436 151 values (1)
- $\Delta H = 2 \times 299 - (436 + 151)$
- $= + 11 \text{ kJ mol}^{-1}$ (1) **[3]**

Q: 14

2 (a)



sulphur atom has 6 /carbon atom has 4 electrons (1)

S=C double bonds (4 electrons) clearly shown (1) **[2]**

(b) linear (1)

180° (1) **[2]**

(c) the enthalpy change when 1 mol of a compound (1)

is formed from its elements in their standard states (1)

under standard conditions (may be quoted) (1) **[3]**

(d) $C + O_2 \rightarrow CO_2$ -395

$S + O_2 \rightarrow SO_2$ -298

$CS_2 + 3O_2 \rightarrow CO_2 + 2SO_2$ -1110

$C + 2S \rightarrow CS_2$ $\Delta H = -395 + 2(-298) -(-1110)$
 $= +119 \text{ kJ mol}^{-1}$

cycle (1) use of 2 for S/SO₂ (1) answer (1) **[3]**

Q: 15

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

is burnt in an excess of oxygen/air
 or undergoes complete combustion
 under standard conditions (1)

(e) (i) heat released = $m c \delta T = 200 \times 4.18 \times 27.5$ (1)

= 22990 J = 23.0 kJ

(If candidate uses 4.2 answer is 23.1 kJ.) (1)

(ii) 23.0 kJ produced from 0.47 g

2059 kJ produced from $\frac{0.47 \times 2059}{23.0} \text{ g}$ (1)

= 42.08g

(Use of 4.2 gives 41.89 g.)

allow ecf from **(i)** (1)

Q: 16

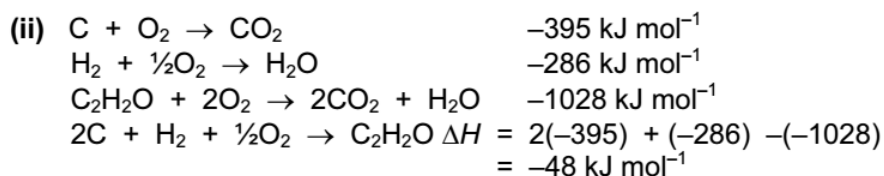
(e) $\Delta H_f^\circ = 2(-393.7) + 2(-285.9) - (-1411)$

$= +51.8 \text{ kJ mol}^{-1}$ (units given in qu.) (3)

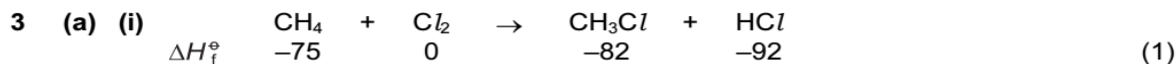
penalise errors: no 2 for -393.7
 no 2 for -285.9
 wrong sign for $-(-1411)$ [3]

Q: 17

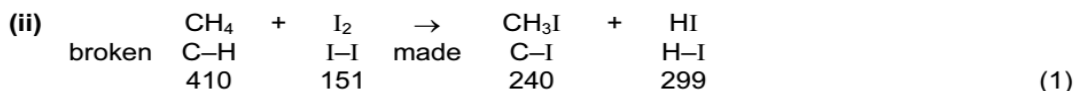
- (c) (i) enthalpy change when
 1 mol of a compound is formed (1)
 from its elements (1)
 in their standard states under standard conditions (1)



correct cycle (1) use of 2 for C/CO₂ (1) answer (1) [6]

Q: 18

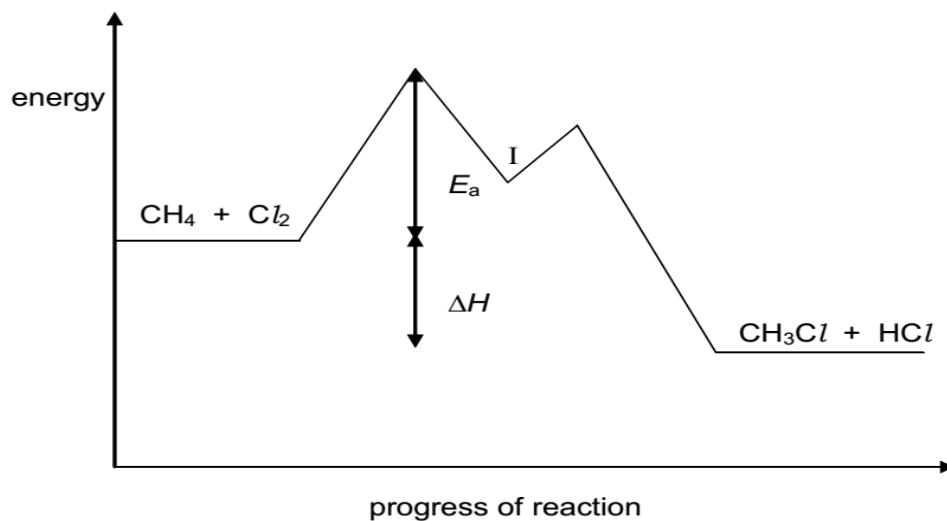
$\Delta H^\circ_{\text{reaction}} = -82 + (-92) - (-75)$
 $= -99 \text{ kJ mol}^{-1}$ (1)



$\Delta H^\circ_{\text{reaction}} = -240 + (-299) + 410 + 151$
 $= +22 \text{ kJ mol}^{-1}$ (1)

- (iii) activation energy is too great (1) [5]

(c)



correct placement of 16 kJ

correct placement of -99 kJ (allow ecf on wrong calculation in (a) (i))

intermediate clearly shown at I

correct 'double peak' shape

second peak lower than first

(1)

(1)

(1)

(1)

(1)

[5]

Q:19

(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]

(e) (i) heat released = $m c \delta T = 200 \times 4.18 \times 27.5$ (1)

= 22990 J = 23.0 kJ (1)

(ii) 23.0 kJ produced from 0.47 g of E

2059 kJ produced from $\frac{0.47 \times 2059}{23.0}$ g of E (1)

= 42.08 g of E (1)

allow ecf in (i) or (ii) on candidate's expressions

[4]

(f) $\text{C}_3\text{H}_6 = 42$

E is C_3H_6

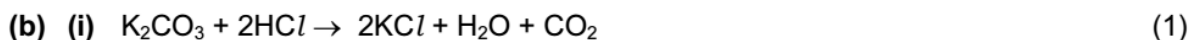
for ecf, E must be unsaturated and be no larger than C_5 (1)

[1]

Q:20

- 3 (a)** the overall enthalpy change/energy change/ ΔH 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)



(ii) heat produced = $m \times c \times \delta T = 30.0 \times 4.18 \times 5.2$
= 652.08 J per 0.0200 mol of K_2CO_3 (1)

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

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

enthalpy change = $-32.60 \text{ kJ mol}^{-1}$ (1)

(iv) to prevent the formation of KHCO_3 **or**
to ensure complete neutralisation (1)



(ii) heat absorbed = $m \times c \times \delta T = 30.0 \times 4.18 \times 3.7$
= 463.98 J per 0.0200 mol of KHCO_3 (1)

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

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

enthalpy change = $+23.20 \text{ kJ mol}^{-1}$ (1)

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

Q:21

$$(d) (i) \quad m = \frac{pVM_r}{RT} = \frac{1.01 \times 10^5 \times 125 \times 10^{-6} \times 44}{8.31 \times 293} \text{ g} \quad (1)$$

$$= 0.228147345 \text{ g} \\ = 0.23 \text{ g} \quad (1)$$

$$(ii) \quad \text{heat released} = m c \delta T = 200 \times 4.18 \times 13.8 \text{ J} \quad (1) \\ = 11536.8 \text{ J} = 11.5 \text{ kJ} \quad (1)$$

$$(iii) \quad 0.23 \text{ g of propane produce } 11.5 \text{ kJ} \\ 44 \text{ g of propane produce } \frac{11.5 \times 44}{0.23} \text{ kJ} \\ = 2200 \text{ kJ mol}^{-1} \quad (1)$$

Q:22

- (c) 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]

(d) working **must** be shown

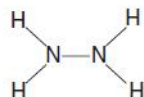
$$(i) \quad \text{heat released} = m c \delta T = 250 \times 4.18 \times 34.6 \quad (1) \\ = 36157 \text{ J} = 36.2 \text{ kJ} \quad (1)$$

$$(ii) \quad M_r \text{ of } C_{14}H_{30} = 198 \quad (1) \\ \text{mass of } C_{14}H_{30} = 1.00 \times 0.763 = 0.763 \text{ g} \quad (1) \\ 0.763 \text{ g of } C_{14}H_{30} \text{ produce } 36.2 \text{ kJ} \\ 198 \text{ g of } C_{14}H_{30} \text{ produce } \frac{36.2 \times 198}{0.763} \\ = 9394 \text{ kJ mol}^{-1} \quad (1) \quad [5]$$

1. Which statement about the standard enthalpy change of formation of carbon dioxide is correct?
- A It is equal to the standard enthalpy change of combustion of carbon.
 - B It is equal to twice the bond energy of the C=O bond.
 - C It is the energy released when one mole of carbon dioxide is formed from carbon at the temperature of combustion of the carbon.
 - D It is the same for carbon dioxide produced from graphite and from diamond.
- [2002 M/J (8)]

2. *Use of the Data Booklet is relevant to this question.*

Hydrazine was used as a fuel for the Messerschmidt 163 rocket fighter in World War II and for the American Gemini and Apollo spacecraft. It has the following formula.



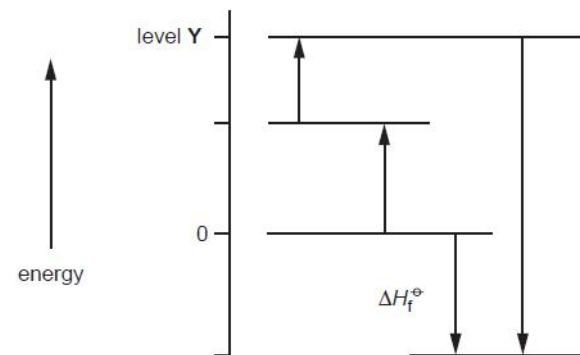
What is the enthalpy change of atomisation of 1 mol of gaseous hydrazine?

- A 550 kJ
- B 1720 kJ
- C 1970 kJ
- D 2554 kJ

[2002 M/J (9)]

3. The following energy cycle represents the enthalpy changes in the formation of carbon dioxide from its constituent elements in their standard states.

What substances are present at level Y in this diagram?



- A $\text{C(g)} + 2\text{O(g)}$
- B $\text{C(g)} + \text{O}_2\text{(g)}$
- C $\text{C(s)} + \text{O}_2\text{(g)}$
- D $\text{CO}_2\text{(g)}$

[2002 O/N (9)]

4. At 600 °C oxides of nitrogen react with unburnt hydrocarbons in a catalytic converter in a car exhaust. The equation using methane as representative of a hydrocarbon molecule would be as follows.



Which statement is likely to be true about the energy change of this reaction?

- A It is endothermic as heat energy is converted into chemical energy.
- B It is exothermic as a high temperature is required.
- C It is exothermic as the triple bond $\text{N} \equiv \text{O}$ is broken.
- D It is exothermic as the products have large negative enthalpy changes of formation.

[2002 O/N (10)]

5. Gaseous phosphorus pentachloride can be decomposed into gaseous phosphorus trichloride and chlorine by heating. The table below gives the bond energies.

bond	bond energy / kJ mol ⁻¹
P-Cl (in both chlorides)	330
Cl-Cl	240

What is the enthalpy change in the decomposition of PCl_5 to PCl_3 and Cl_2 ?

- A -120 kJ mol^{-1} B -90 kJ mol^{-1} C $+90 \text{ kJ mol}^{-1}$ D $+120 \text{ kJ mol}^{-1}$

[2003 M/J (7)]

6. The 'flash' produced by nineteenth century photographers to take indoor photographs was obtained from the following reaction.



The standard enthalpy changes of formation are given below.

	$\Delta H_f^\circ / \text{kJ mol}^{-1}$
MgO	-602
KCl	-437
KClO_3	-391

What is the standard enthalpy change of the 'flash' reaction?

- A $-3(-602) + (-437) - (-391)$
 B $(-602) + (-437) - (-391)$
 C $3(-602) + (-437) - (-391)$
 D $(-602) + 3(-437) - 3(-391)$

[2003 O/N (11)]

7. Why does the exothermic reaction



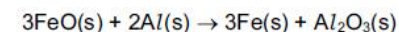
not occur spontaneously?

- A A tetrahedral configuration is always more stable than a planar one.
 B Diamond has only strong covalent bonds whereas graphite has both covalent bonds and van der Waals' forces.
 C The change from diamond to graphite has a high activation energy.
 D The density of graphite is less than that of diamond.

[2003 O/N (12)]

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 kJ mol^{-1} and $-1676 \text{ kJ mol}^{-1}$ respectively.

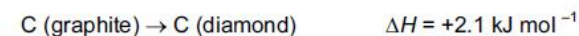
What is the enthalpy change under standard conditions for the following reaction?



- A $+878 \text{ kJ}$ B -878 kJ C -1942 kJ D -2474 kJ

[2004 M/J (8)]

9. The conversion of graphite has only a small positive value of ΔH .



However, the production of synthetic diamonds using this reaction is very difficult.

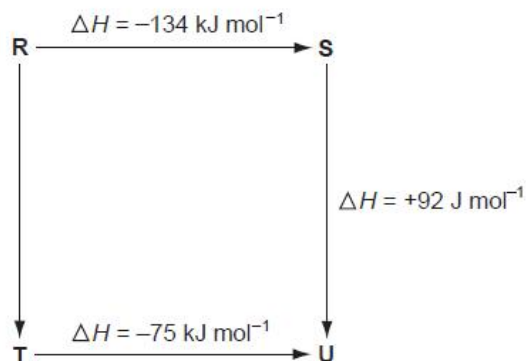
Which statements help to explain this?

- 1 The activation energy of the reaction is large.
 2 An equilibrium exists between diamond and graphite.
 3 Only exothermic reactions can be made to occur readily.

[2004 M/J (32)]

10.

The diagram illustrates the energy changes of a set of reactions.



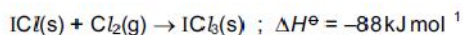
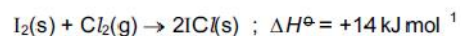
Which of the following statements are correct?

- 1 The enthalpy change for the transformation $U \longrightarrow R$ is $+42 \text{ kJ mol}^{-1}$.
- 2 The enthalpy change for the transformation $T \longrightarrow S$ is endothermic.
- 3 The enthalpy change for the transformation $R \longrightarrow T$ is -33 kJ mol^{-1} .

[2004 O/N (31)]

11.

Iodine trichloride, ICl_3 , is made by reacting iodine with chlorine.



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

- A -60 kJ mol^{-1}
- B -74 kJ mol^{-1}
- C -81 kJ mol^{-1}
- D -162 kJ mol^{-1}

[2005 M/J (7)]

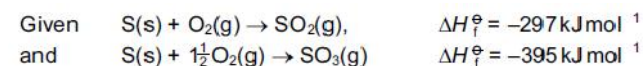
12.

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 $CuSO_4 \cdot 5H_2O$.
- 2 The formation of methane from its elements.
- 3 The combustion of glucose, $C_6H_{12}O_6$.

[2005 M/J (33)]

13.



what is the enthalpy change of reaction, $\Delta H^\ominus$, of $2SO_2(g) + O_2(g) \rightarrow 2SO_3(g)$?

- A -196 kJ mol^{-1}
- B -98 kJ mol^{-1}
- C $+98 \text{ kJ mol}^{-1}$
- D $+196 \text{ kJ mol}^{-1}$

[2005 O/N (6)]

14.

The table shows the enthalpy change of neutralisation per mole of water formed, ΔH , for various acids and bases.

acid	base	$\Delta H / \text{kJ mol}^{-1}$
hydrochloric acid	sodium hydroxide	-57.0
P	sodium hydroxide	-54.0
hydrochloric acid	Q	-52.0
nitric acid	R	-57.0

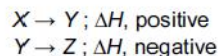
What are **P**, **Q** and **R**?

	P	Q	R
A	ethanoic acid	ammonia	potassium hydroxide
B	ethanoic acid	sodium hydroxide	ammonia
C	sulphuric acid	ammonia	potassium hydroxide
D	sulphuric acid	sodium hydroxide	ammonia

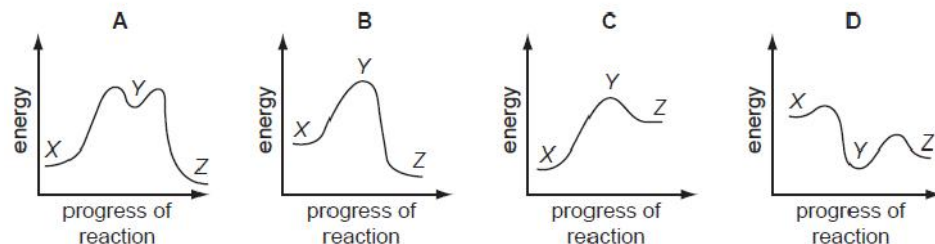
[2005 O/N (7)]

15.

In the conversion of compound X into compound Z, it was found that the reaction proceeded by way of compound Y, which could be isolated. The following steps were involved.



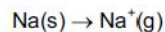
Which reaction profile fits these data?



[2006 M/J (8)]

16.

Sodium ions can be formed from sodium atoms.



Which quantities are required to calculate the enthalpy change of formation of gaseous sodium ions?

- 1 enthalpy change of atomisation of sodium
- 2 first ionisation energy of sodium
- 3 enthalpy change of formation of sodium

[2006 M/J (32)]

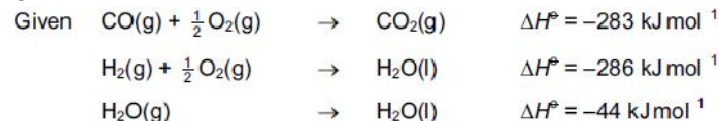
17.

For which equation is the enthalpy change correctly described as an enthalpy change of formation?

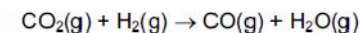
- A $2\text{NO(g)} \rightarrow \text{N}_2\text{(g)} + \text{O}_2\text{(g)}$
- B $2\text{CO(g)} + \text{O}_2\text{(g)} \rightarrow 2\text{CO}_2\text{(g)}$
- C $\text{H}_2\text{O(l)} + \text{NaCl(s)} \rightarrow \text{NaCl(aq)}$
- D $\text{K(s)} + \text{Mn(s)} + 2\text{O}_2\text{(g)} \rightarrow \text{KMnO}_4\text{(s)}$

[2006 O/N (8)]

18.



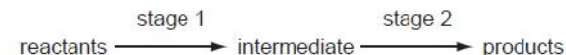
what is the change in enthalpy, ΔH° , for the following reaction?



- A -525 kJ mol^{-1} B -41 kJ mol^{-1} C $+41 \text{ kJ mol}^{-1}$ D $+525 \text{ kJ mol}^{-1}$
[2006 O/N (9)]

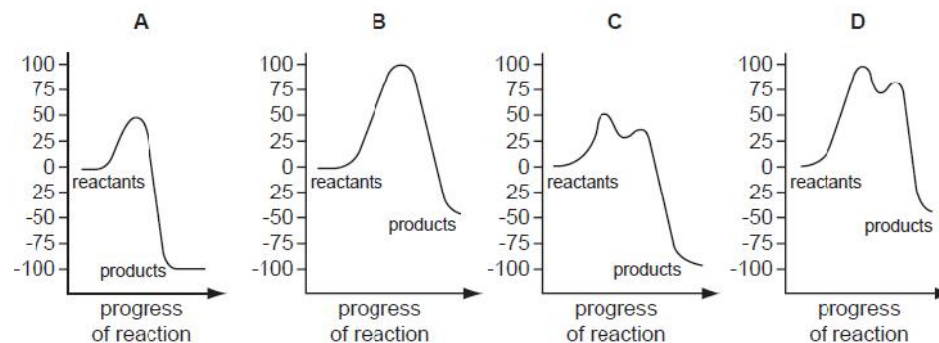
19.

An exothermic chemical reaction proceeds by two stages.



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

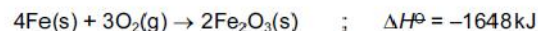
Which diagram represents the reaction pathway for this reaction?



[2007 M/J (7)]

20.

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 kJ mol^{-1}
- B -824 kJ mol^{-1}
- C -1648 kJ mol^{-1}
- D -3296 kJ mol^{-1}

[2007 M/J (8)]

21.

Slaked lime, Ca(OH)_2 , may be made from limestone, CaCO_3 .

On heating in a lime kiln at 1000°C , limestone decomposes as follows.



Water is then reacted with calcium oxide, CaO , as follows.



What are the enthalpy changes of these reactions?

	reaction 1	reaction 2
A	endothermic	endothermic
B	endothermic	exothermic
C	exothermic	endothermic
D	exothermic	exothermic

[2007 M/J (14)]

22.

The standard enthalpy changes of formation of HCl and HI are -92 kJ mol^{-1} and $+26\text{ kJ mol}^{-1}$ respectively.

Which statement is **most** important in explaining this difference?

- A Chlorine is more electronegative than iodine.
- B The activation energy for the H_2/Cl_2 reaction is much less than that for the H_2/I_2 reaction.
- C The bond energy of HI is smaller than the bond energy of HCl .
- D The bond energy of I_2 is smaller than the bond energy of Cl_2 .

[2007 M/J (16)]

23.

Which equation represents the standard enthalpy change of atomisation of bromine?

- A $\text{Br}_2\text{(l)} \rightarrow 2\text{Br(g)}$
- B $\text{Br}_2\text{(g)} \rightarrow 2\text{Br(g)}$
- C $\frac{1}{2}\text{Br}_2\text{(l)} \rightarrow \text{Br(g)}$
- D $\frac{1}{2}\text{Br}_2\text{(g)} \rightarrow \text{Br(g)}$

[2007 O/N (8)]

24.

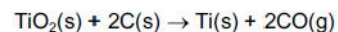
For which equation does the enthalpy change correspond to the enthalpy change of atomisation of iodine?

- A $\frac{1}{2}\text{I}_2\text{(s)} \rightarrow \text{I(s)}$
- B $\frac{1}{2}\text{I}_2\text{(s)} \rightarrow \text{I(g)}$
- C $\text{I}_2\text{(g)} \rightarrow 2\text{I(g)}$
- D $\text{I}_2\text{(s)} \rightarrow 2\text{I(g)}$

[2008 M/J (9)]

25.

Titanium occurs naturally as the mineral rutile, TiO_2 . One possible method of extraction of titanium is to reduce the rutile by heating with carbon.



The standard enthalpy changes of formation of $\text{TiO}_2(\text{s})$ and $\text{CO}(\text{g})$ are -940 kJ mol^{-1} and -110 kJ mol^{-1} respectively.

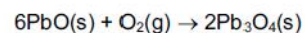
What is the standard enthalpy change of this reaction?

- A -830 kJ mol^{-1}
- B -720 kJ mol^{-1}
- C $+720 \text{ kJ mol}^{-1}$
- D $+830 \text{ kJ mol}^{-1}$

[2008 M/J (10)]

26.

Red lead oxide, Pb_3O_4 , is used in metal priming paints. It can be made by heating PbO in air.



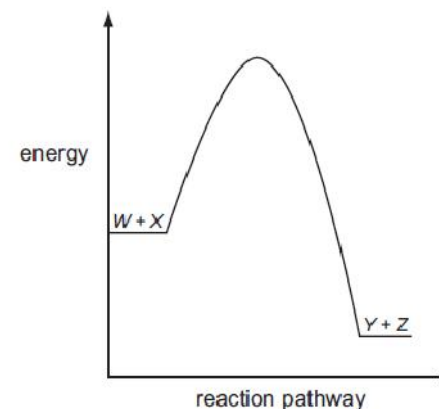
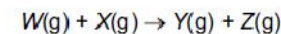
Which two values are needed to calculate the enthalpy change for this reaction?

- A enthalpy change of combustion of lead and enthalpy change of formation of Pb_3O_4
- B enthalpy change of combustion of PbO and enthalpy change of formation of Pb_3O_4
- C enthalpy change of formation of PbO and enthalpy change of atomisation of O_2
- D enthalpy change of formation of PbO and enthalpy change of formation of Pb_3O_4

[2008 O/N (8)]

27.

The diagram represents the reaction pathway for the following reaction.



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

- A It will have a larger activation energy and a positive ΔH .
- B It will have a larger activation energy and a negative ΔH .
- C It will have a smaller activation energy and a positive ΔH .
- D It will have a smaller activation energy and a negative ΔH .

[2008 O/N (9)]

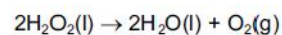
28.

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

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

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

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



- A +98 kJ mol⁻¹
- B -98 kJ mol⁻¹
- C -196 kJ mol⁻¹
- D -947.2 kJ mol⁻¹

[2009 M/J (8)]

29.

For which reactions does the value of ΔH° represent **both** a standard enthalpy change of combustion **and** a standard enthalpy change of formation?

- 1 C(s) + O₂(g) → CO₂(g)
- 2 2C(s) + O₂(g) → 2CO(g)
- 3 CO(g) + $\frac{1}{2}$ O₂(g) → CO₂(g)

[2009 M/J (33)]

30.

The first stage in the industrial production of nitric acid from ammonia can be represented by the following equation.



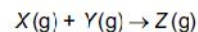
Using the following standard enthalpy change of formation data, what is the value of the standard enthalpy change, ΔH° , for this reaction?

compound	$\Delta H_f^\circ / \text{kJ mol}^{-1}$
NH ₃ (g)	-46.1
NO(g)	+90.3
H ₂ O(g)	-241.8

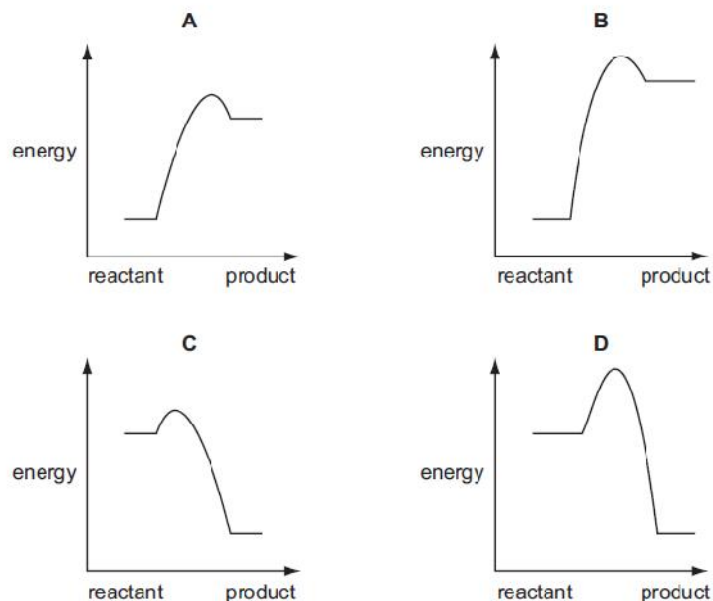
- A +905.2 kJ mol⁻¹
- B -105.4 kJ mol⁻¹
- C -905.2 kJ mol⁻¹
- D -1274.0 kJ mol⁻¹

[2009 O/N-11 (6)]

31. Four reactions of the type shown are studied at the same temperature.

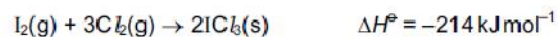


Which is the correct reaction pathway diagram for the reaction that would proceed **most** rapidly and with the **highest** yield?



[2009 O/N-11 (10)]

32. Given the following enthalpy changes,



What is the standard enthalpy change of formation of iodine trichloride, $ICl_3(s)$?

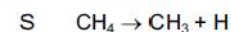
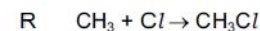
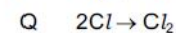
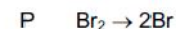
- A +176 kJ mol⁻¹
 B -88 kJ mol⁻¹
 C -176 kJ mol⁻¹
 D -214 kJ mol⁻¹

[2010 M/J-11 (5)]

33. Some bond energy values are listed below.

bond	bond energy / 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.

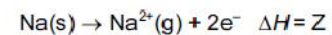
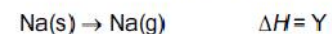
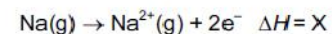
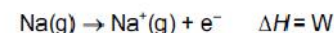


What is the order of enthalpy changes of these reactions from most negative to most positive?

- A P → Q → R → S
 B Q → R → S → P
 C R → Q → P → S
 D S → P → Q → R

[2010 M/J-13 (5)]

34. Equations involving four enthalpy changes are shown.



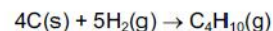
What is the second ionisation energy of sodium?

- A 2W B X - W C Y - W D Z - Y

[2010 O/N-11 (3)]

35.

Enthalpy changes of combustion can be used to determine enthalpy changes of formation. The following equation represents the enthalpy change of formation of butane.



By using the following standard enthalpy of combustion data, what is the value of the standard enthalpy change of formation, $\Delta H_f^\ominus$, for this reaction?

compound	$\Delta H_c^\ominus / \text{kJ mol}^{-1}$
carbon	-394
hydrogen	-286
butane	-2877

- A -5883 kJ mol⁻¹
- B -129 kJ mol⁻¹
- C +129 kJ mol⁻¹
- D +2197 kJ mol⁻¹

[2010 O/N-11 (8)]

36.

In a calorimetric experiment 1.60 g of a fuel is burnt. 45% of the energy released is absorbed by 200 g of water whose temperature rises from 18 °C to 66 °C. The specific heat capacity of water is 4.2 J g⁻¹ K⁻¹.

What is the total energy released per gram of fuel burnt?

- A 25 200 J
- B 56 000 J
- C 89 600 J
- D 143 360 J

[2010 O/N-11 (9)]

37.

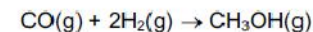
Which equation represents the change corresponding to the enthalpy change of atomisation of iodine?

- A $\frac{1}{2} \text{I}_2\text{(g)} \rightarrow \text{I(g)}$
- B $\text{I}_2\text{(g)} \rightarrow 2\text{I(g)}$
- C $\frac{1}{2} \text{I}_2\text{(s)} \rightarrow \text{I(g)}$
- D $\text{I}_2\text{(s)} \rightarrow 2\text{I(g)}$

[2010 O/N-11 (11)]

38.

Methanol may be prepared by the reaction between carbon monoxide and hydrogen.



The relevant average bond energies are given below.

$E(\text{C}\equiv\text{O})$	1077 kJ mol ⁻¹
$E(\text{C}-\text{O})$	360 kJ mol ⁻¹
$E(\text{C}-\text{H})$	410 kJ mol ⁻¹
$E(\text{H}-\text{H})$	436 kJ mol ⁻¹
$E(\text{O}-\text{H})$	460 kJ mol ⁻¹

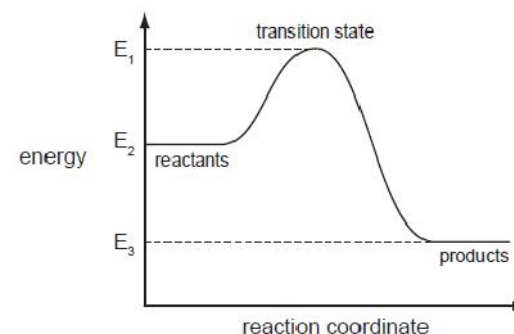
What is the enthalpy change of this reaction?

- A -537 kJ mol⁻¹
- B -101 kJ mol⁻¹
- C +101 kJ mol⁻¹
- D +537 kJ mol⁻¹

[2010 O/N-12 (4)]

39.

The reaction pathway diagram below illustrates the energies of reactants, products and the transition state of a reaction.



Which expression represents the activation energy of the forward reaction?

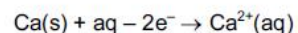
- A $E_1 - E_2$
- B $E_1 - E_3$
- C $E_2 - E_3$
- D $(E_1 - E_2) - (E_2 - E_3)$

[2010 O/N-12 (6)]

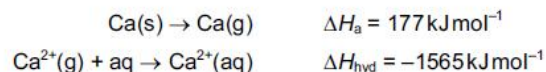
40.

Use of the Data Booklet is relevant to this question.

The enthalpy change of formation, ΔH_f , of hydrated calcium ions is the enthalpy change of the following reaction.



The following enthalpy changes are **not** quoted in the Data Booklet.



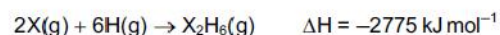
What is the enthalpy change of formation of hydrated calcium ions?

- A $-1388 \text{ kJ mol}^{-1}$
- B -798 kJ mol^{-1}
- C -238 kJ mol^{-1}
- D $+352 \text{ kJ mol}^{-1}$

[2010 O/N-12 (8)]

41.

The equation below represents the combination of gaseous atoms of non-metal X and of hydrogen to form gaseous X_2H_6 molecules.



The bond energy of an X–H bond is 395 kJ mol^{-1} .

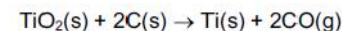
What is the bond energy of an X–X bond?

- A $-405.0 \text{ kJ mol}^{-1}$
- B $-202.5 \text{ kJ mol}^{-1}$
- C $+202.5 \text{ kJ mol}^{-1}$
- D $+405.0 \text{ kJ mol}^{-1}$

[2011 M/J-11 (8)]

42.

Titanium occurs naturally as the mineral rutile, TiO_2 . One possible method of extraction of titanium is to reduce the rutile by heating with carbon.



The standard enthalpy changes of formation of $\text{TiO}_2(\text{s})$ and CO(g) are -940 kJ mol^{-1} and -110 kJ mol^{-1} respectively.

What is the standard enthalpy change of this reaction?

- A -830 kJ mol^{-1}
- B -720 kJ mol^{-1}
- C $+720 \text{ kJ mol}^{-1}$
- D $+830 \text{ kJ mol}^{-1}$

[2011 M/J-12 (7)]

43.

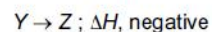
Which reaction has an enthalpy change equal to the standard enthalpy change of formation of propane?

- A $3\text{C(g)} + 4\text{H}_2(\text{g}) \rightarrow \text{C}_3\text{H}_8(\text{g})$
- B $3\text{C(g)} + 8\text{H(g)} \rightarrow \text{C}_3\text{H}_8(\text{g})$
- C $3\text{C(s)} + 4\text{H}_2(\text{g}) \rightarrow \text{C}_3\text{H}_8(\text{g})$
- D $3\text{C(s)} + 4\text{H}_2(\text{g}) \rightarrow \text{C}_3\text{H}_8(\text{l})$

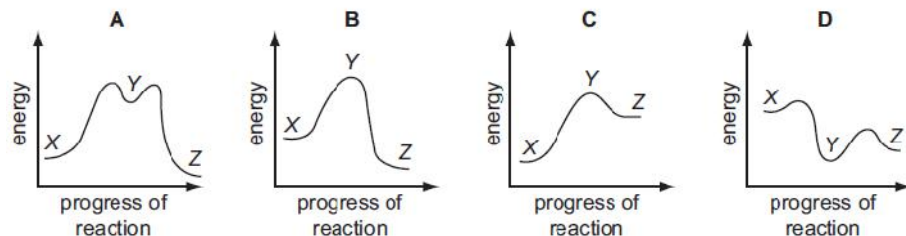
[2011 M/J-12 (8)]

44.

In the conversion of compound X into compound Z, it was found that the reaction proceeded by way of compound Y, which could be isolated. The following steps were involved.



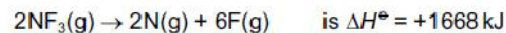
Which reaction profile fits these data?



[2011 M/J-12 (9)]

45.

The standard enthalpy change for the reaction



What is the bond energy of the N–F bond?

- A -556 kJ mol^{-1}
- B -278 kJ mol^{-1}
- C $+278 \text{ kJ mol}^{-1}$
- D $+556 \text{ kJ mol}^{-1}$

[2011 O/N-11 (6)]

46.

Hess's Law can be used to calculate the average C–H bond energy in methane.

$\Delta H_{\text{at}}^\ominus$ = standard enthalpy change of atomisation

$\Delta H_f^\ominus$ = standard enthalpy change of formation

$\Delta H_c^\ominus$ = standard enthalpy change of combustion

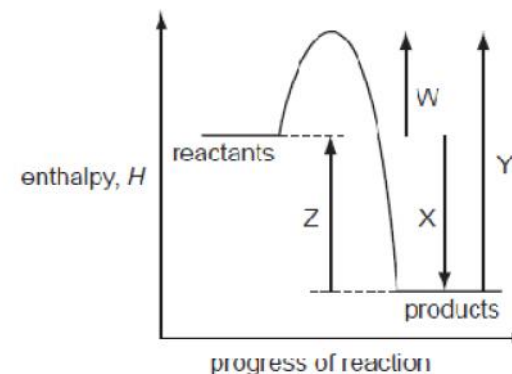
Which data values are needed in order to perform the calculation?

- A $\Delta H_{\text{at}}^\ominus (\text{C}), \Delta H_{\text{at}}^\ominus (\text{H}), \Delta H_f^\ominus (\text{CH}_4)$
- B $\Delta H_c^\ominus (\text{C}), \Delta H_c^\ominus (\text{H}_2), \Delta H_c^\ominus (\text{CH}_4)$
- C $\Delta H_c^\ominus (\text{C}), \Delta H_c^\ominus (\text{H}_2), \Delta H_f^\ominus (\text{CH}_4)$
- D $\Delta H_f^\ominus (\text{CH}_4)$ only, as $\Delta H_f^\ominus (\text{C})$, and $\Delta H_f^\ominus (\text{H}_2)$, are defined as zero

[2011 O/N-12 (10)]

47.

An energy profile diagram is shown.



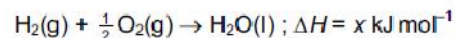
What do the labels on the diagram represent?

- 1 $W = \Delta H$ of the forward reaction, $Y = E_a$ of the backward reaction
- 2 $Z = \Delta H$ of the backward reaction, $Y = E_a$ of the backward reaction
- 3 $X = \Delta H$ of the forward reaction, $W = E_a$ of the forward reaction

[2011 O/N-12 (32)]

48.

The equation for a reaction is shown.



Which pair of descriptions is fully correct for this reaction?

	type(s) of enthalpy change	value of x
A	formation only	positive
B	formation only	negative
C	combustion, formation	positive
D	combustion, formation	negative

[2012 M/J-11 (3)]

49.

Propanone has the molecular formula $\text{C}_3\text{H}_6\text{O}$.

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

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

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

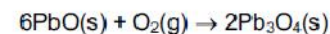
Using this information, what is the enthalpy change of formation of propanone?

- A** $-1106 \text{ kJ mol}^{-1}$
- B** -540 kJ mol^{-1}
- C** -254 kJ mol^{-1}
- D** $+1106 \text{ kJ mol}^{-1}$

[2012 M/J-11 (7)]

50.

Red lead oxide, Pb_3O_4 , is used in metal priming paints. It can be made by heating PbO in air.



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

- A** enthalpy change of atomisation of O_2 and enthalpy change of formation of Pb_3O_4
- B** enthalpy change of formation of O_2 and enthalpy change of formation of Pb_3O_4
- C** enthalpy change of formation of PbO and enthalpy change of atomisation of O_2
- D** enthalpy change of formation of PbO and enthalpy change of formation of Pb_3O_4

[2012 M/J-12 (12)]

51.

Use of the Data Booklet is relevant to this question.

A reaction which causes the presence of oxides of nitrogen in car exhausts is the formation of NO .



What is the bond energy in kJ mol^{-1} of the bond between the atoms in NO ?

- A** 655
- B** 835
- C** 1310
- D** 1670

[2012 O/N-11 (4)]

52.

In the table below,

- '+' means that this type of standard enthalpy change can **only** have positive values,
- '-' means that this type of standard enthalpy change can **only** have negative values,
- '+/-' means that **either** positive **or** negative values are possible.

Which row is correct?

	atomisation	formation	solution
A	+	+	+/-
B	+	+/-	+/-
C	-	+/-	-
D	-	-	+

[2012 O/N-11 (5)]

53.

A student calculated the standard enthalpy change of formation of ethane, C_2H_6 , using a method based on standard enthalpy changes of combustion.

He used correct values for the standard enthalpy change of combustion of ethane ($-1560 \text{ kJ mol}^{-1}$) and hydrogen (-286 kJ mol^{-1}) but he used an incorrect value for the standard enthalpy change of combustion of carbon. He then performed his calculation correctly. His final answer was -158 kJ mol^{-1} .

What did he use for the standard enthalpy change of combustion of carbon?

- A** $-1432 \text{ kJ mol}^{-1}$
B -860 kJ mol^{-1}
C -430 kJ mol^{-1}
D -272 kJ mol^{-1}

[2012 O/N-11 (10)]

54.

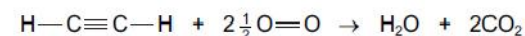
Which process could be used to calculate the bond energy for the covalent bond X-Y by dividing its ΔH by n ?

- A** $XY_n(g) \rightarrow X(g) + nY(g)$
B $2XY_n(g) \rightarrow 2XY_{n-1}(g) + Y_2(g)$
C $Y(g) + XY_{n-1}(g) \rightarrow XY_n(g)$
D $nXY(g) \rightarrow nX(g) + \frac{n}{2}Y_2(g)$

[2012 O/N-11 (11)]

55.

Ethyne, C_2H_2 , completely combusts, as shown in the equation.



Using the average bond enthalpies in the table, what is the enthalpy change of combustion of ethyne?

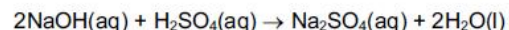
bond	average bond enthalpy / kJ mol^{-1}
C—H	410
C $\equiv$ C	840
O=O	496
C=O	740
O—H	460
C—O	360

- A** -980 kJ mol^{-1} **B** -540 kJ mol^{-1} **C** $+540 \text{ kJ mol}^{-1}$ **D** $+980 \text{ kJ mol}^{-1}$

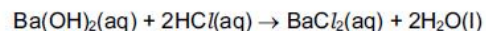
[2012 O/N-13 (5)]

56.

The enthalpy change of the neutralisation given below is -114 kJ mol^{-1} .



By using this information, what is the most likely value for the enthalpy change of the following neutralisation?

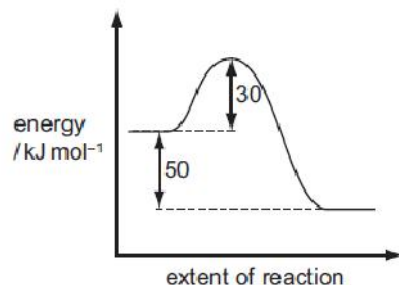


- A -57 kJ mol^{-1} B -76 kJ mol^{-1} C -114 kJ mol^{-1} D -228 kJ mol^{-1}

[2012 O/N-13 (10)]

57.

The reaction pathway for a reversible reaction is shown below.



Which statement is correct?

- A The activation energy of the reverse reaction is $+80 \text{ kJ mol}^{-1}$.
 B The enthalpy change for the forward reaction is $+30 \text{ kJ mol}^{-1}$.
 C The enthalpy change for the forward reaction is $+50 \text{ kJ mol}^{-1}$.
 D The enthalpy change for the reverse reaction is $+30 \text{ kJ mol}^{-1}$.

[2013 M/J-11 (7)]

58.

Use of the Data Booklet is relevant to this question.

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



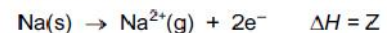
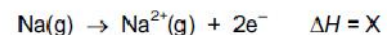
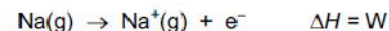
What is the enthalpy change of combustion of methane?

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

[2013 M/J-11 (12)]

59.

Equations involving four enthalpy changes are shown.



What is the second ionisation energy of sodium?

- A X B $X - W$ C $Y - W$ D $Z - Y$

[2013 M/J-12 (2)]

60.

Use of the Data Booklet is relevant to this question.

A student mixed 25 cm³ of 0.10 mol dm⁻³ sodium hydroxide solution with 25 cm³ of 0.10 mol dm⁻³ hydrochloric acid and noted a temperature rise of 2.5 °C.

What is the enthalpy change of the reaction per mole of NaOH?

- A -209 kJ mol⁻¹
- B -104.5 kJ mol⁻¹
- C -209 J mol⁻¹
- D -522.5 J mol⁻¹

[2013 M/J-12 (10)]

61.

Which energy change corresponds to the enthalpy change of atomisation of hydrogen at 298 K?

- A the bond energy of a H–H bond
- B half the bond energy of a H–H bond
- C minus half the bond energy of a H–H bond
- D minus the bond energy of a H–H bond

[2013 M/J-12 (11)]

62.

Propanone has molecular formula C₃H₆O.

The enthalpy change of combustion of hydrogen is -286 kJ mol⁻¹.

The enthalpy change of combustion of carbon is -394 kJ mol⁻¹.

The enthalpy change of formation of propanone is -254 kJ mol⁻¹.

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

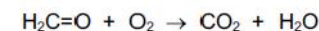
- A -2644 kJ mol⁻¹
- B -2294 kJ mol⁻¹
- C -1786 kJ mol⁻¹
- D -426 kJ mol⁻¹

[2013 M/J-12 (12)]

63.

Use of the Data Booklet is relevant to this question.

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



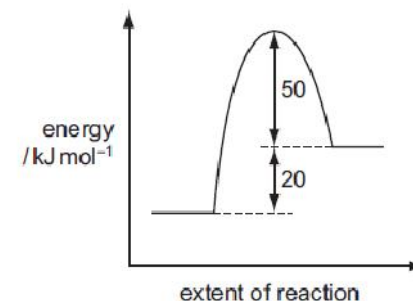
What is the enthalpy change of combustion of methanal?

- A +416 kJ mol⁻¹
- B +396 kJ mol⁻¹
- C -344 kJ mol⁻¹
- D -690 kJ mol⁻¹

[2013 M/J-13 (11)]

64.

The reaction pathway for a reversible reaction is shown below.



Which statements are correct?

- 1 The enthalpy change for the backward reaction is -20 kJ mol⁻¹.
- 2 The forward reaction is endothermic.
- 3 The activation energy for the forward reaction is +70 kJ mol⁻¹.

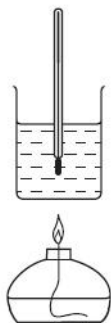
[2013 M/J-13 (33)]

65.

Use of the Data Booklet is relevant to this question.

A student carried out an experiment to determine the enthalpy change for the combustion of methanol.

The following results were obtained by the student.



start temperature of the water	20 °C
final temperature of the water	53 °C
mass of alcohol burner before burning	259.65 g
mass of alcohol burner after burning	259.15 g
mass of glass beaker plus water	150.00 g
mass of glass beaker	50.00 g

How much of the heat energy produced by the burning of methanol went into the water?

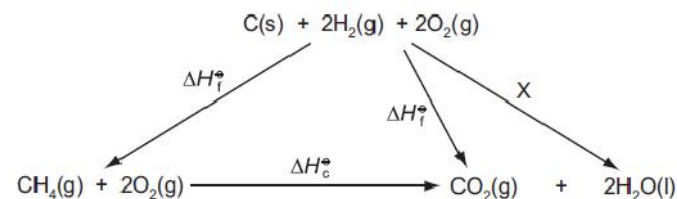
- A 209 J B 13 794 J C 20 691 J D 22 154 J

[2013 O/N-11 (11)]

66.

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

[2014 M/J-11 (3)]

67.

A student mixed 25.0 cm³ of 0.350 mol dm⁻³ sodium hydroxide solution with 25.0 cm³ of 0.350 mol dm⁻³ hydrochloric acid. The temperature rose by 2.50 °C. Assume that no heat was lost to the surroundings.

The final mixture had a specific heat capacity of 4.20 J cm⁻³ K⁻¹.

What is the molar enthalpy change for the reaction?

- A -150 kJ mol^{-1}
 B $-60.0 \text{ kJ mol}^{-1}$
 C $-30.0 \text{ kJ mol}^{-1}$
 D $-0.150 \text{ kJ mol}^{-1}$

[2014 M/J-11 (5)]

68.

Use of the Data Booklet is relevant to this question.

When the liquid N_2F_4 is heated, it decomposes into a single product, X.

Which statements are correct?

- 1 N–F bonds are broken during this decomposition.
- 2 The enthalpy change when N_2F_4 decomposes into X is approximately $+160 \text{ kJ mol}^{-1}$.
- 3 Molecules of X are non-linear.

[2014 M/J-11 (31)]

69.

The enthalpy change of formation of carbon dioxide is -394 kJ mol^{-1} .

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

The enthalpy change of formation of methane is -74 kJ mol^{-1} .

What is the enthalpy change of combustion of methane?

- A -892 kJ mol^{-1}
- B -606 kJ mol^{-1}
- C $+606 \text{ kJ mol}^{-1}$
- D $+892 \text{ kJ mol}^{-1}$

[2014 M/J-12 (3)]

70.

Which equation represents the standard enthalpy change of formation of ethanol, $\text{C}_2\text{H}_5\text{OH}$?

- A $2\text{C(g)} + 3\text{H}_2\text{(g)} + \frac{1}{2}\text{O}_2\text{(g)} \rightarrow \text{C}_2\text{H}_5\text{OH(l)}$
- B $2\text{C(s)} + 3\text{H}_2\text{(g)} + \frac{1}{2}\text{O}_2\text{(g)} \rightarrow \text{C}_2\text{H}_5\text{OH(l)}$
- C $2\text{C(s)} + 3\text{H}_2\text{(g)} + \frac{1}{2}\text{O}_2\text{(g)} \rightarrow \text{C}_2\text{H}_5\text{OH(g)}$
- D $2\text{C(g)} + 6\text{H(g)} + \text{O(g)} \rightarrow \text{C}_2\text{H}_5\text{OH(l)}$

[2014 M/J-12 (8)]

71.

The diagram shows the skeletal formula of cyclopropane.



The enthalpy change of formation of cyclopropane is $+53.3 \text{ kJ mol}^{-1}$ and the enthalpy change of atomisation of graphite is $+717 \text{ kJ mol}^{-1}$.

The bond enthalpy of H–H is 436 kJ mol^{-1} and of C–H is 410 kJ mol^{-1} .

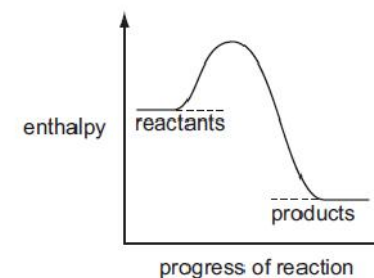
What value for the average bond enthalpy of the C–C bond in cyclopropane can be calculated from this data?

- A 187 kJ mol^{-1}
- B 315 kJ mol^{-1}
- C 351 kJ mol^{-1}
- D 946 kJ mol^{-1}

[2014 M/J-12 (11)]

72.

A reaction pathway diagram is shown.



Which enthalpy change could the diagram **not** apply to?

- A enthalpy of atomisation
- B enthalpy of combustion
- C enthalpy of formation
- D enthalpy of neutralisation

[2014 M/J-13 (3)]

73.

The enthalpy change of formation of $\text{Mn}(\text{NO}_3)_2(\text{s})$ is -696 kJ mol^{-1} .
The enthalpy change of formation of $\text{MnO}_2(\text{s})$ is -520 kJ mol^{-1} .
The enthalpy change of formation of $\text{NO}_2(\text{g})$ is $+33 \text{ kJ mol}^{-1}$.

On heating, $\text{Mn}(\text{NO}_3)_2$ decomposes into MnO_2 and NO_2 .



What is the value of the standard enthalpy change of this reaction?

- A -242 kJ mol^{-1}
- B -209 kJ mol^{-1}
- C $+209 \text{ kJ mol}^{-1}$
- D $+242 \text{ kJ mol}^{-1}$

[2014 M/J-13 (9)]

74.

Which reaction has an enthalpy change equal to the standard enthalpy change of formation of propane?

- A $3\text{C}(\text{g}) + 4\text{H}_2(\text{g}) \rightarrow \text{C}_3\text{H}_8(\text{g})$
- B $3\text{C}(\text{g}) + 8\text{H}(\text{g}) \rightarrow \text{C}_3\text{H}_8(\text{g})$
- C $3\text{C}(\text{s}) + 4\text{H}_2(\text{g}) \rightarrow \text{C}_3\text{H}_8(\text{g})$
- D $3\text{C}(\text{s}) + 4\text{H}_2(\text{g}) \rightarrow \text{C}_3\text{H}_8(\text{l})$

[2014 M/J-13 (11)]

75.

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}

[2014 O/N-11 (3)]

76.

In an experiment to calculate the enthalpy change of combustion of a fuel, 1.5 g (0.0326 mol) of the fuel was used to heat 200 g of water. The temperature of the water rose from 25°C to 55°C . The specific heat capacity of water is $4.18 \text{ J g}^{-1} \text{ K}^{-1}$.

There is significant heat loss in this experiment. Therefore, the experimental value for the enthalpy change of combustion, ΔH_c , of the fuel will be different from the theoretical value.

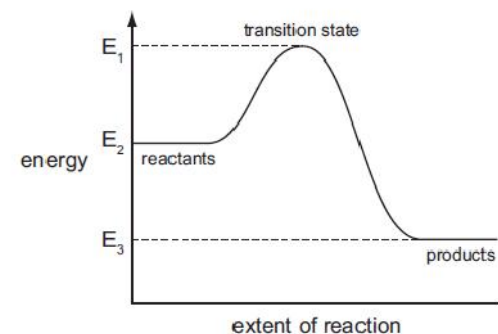
Using the information above, what is the experimental value for the enthalpy change of combustion, ΔH_c , of the fuel?

- A $-1410 \text{ kJ mol}^{-1}$
- B -769 kJ mol^{-1}
- C $-30.7 \text{ kJ mol}^{-1}$
- D $-16.7 \text{ kJ mol}^{-1}$

[2014 O/N-11 (7)]

77.

The reaction pathway diagram below illustrates the energies of the reactants, the products and the transition state of a reaction.



Which expression represents the activation energy of the forward reaction?

- A $E_1 - E_2$
- B $E_2 - E_1$
- C $E_2 - E_3$
- D $E_3 - E_2$

[2014 O/N-11 (8)]

78.

Use of the Data Booklet is relevant to this question.

The bond energy of the Br–O bond is 235 kJ mol^{-1} .

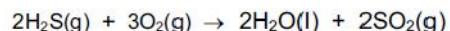
Which reactions are exothermic?

- 1 $\text{OH}\cdot + \text{HBr} \rightarrow \text{H}_2 + \text{BrO}\cdot$
- 2 $\text{OH}\cdot + \text{HBr} \rightarrow \text{H}_2\text{O} + \text{Br}\cdot$
- 3 $\text{H}\cdot + \text{HBr} \rightarrow \text{H}_2 + \text{Br}\cdot$

[2014 O/N-11 (32)]

79.

Hydrogen sulfide, H_2S , is released from volcanoes. It reacts with oxygen in the air to form sulfur dioxide.



$$\Delta H_f^\circ [\text{H}_2\text{S}(\text{g})] = -21 \text{ kJ mol}^{-1}$$

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

$$\Delta H_f^\circ [\text{SO}_2(\text{g})] = -297 \text{ kJ mol}^{-1}$$

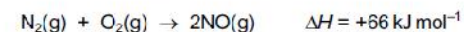
What is the standard enthalpy change of this reaction?

- A $-1208 \text{ kJ mol}^{-1}$
- B $-1124 \text{ kJ mol}^{-1}$
- C -562 kJ mol^{-1}
- D -541 kJ mol^{-1}

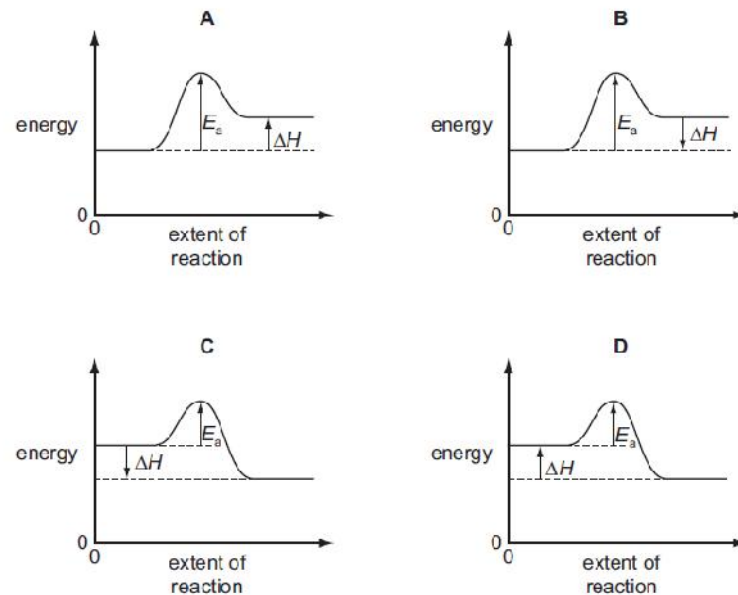
[2014 O/N-13 (5)]

80.

Nitrogen monoxide is an atmospheric pollutant that is formed inside car engines by an endothermic reaction between nitrogen and oxygen.



Which labelled diagram correctly represents the energy profile for this reaction?



[2014 O/N-13 (10)]

81.

Use of the Data Booklet is relevant to this question.

When 0.47 g of a hydrocarbon was completely burnt in air, the energy released heated 200 g of water from 23.7°C to 41.0°C .

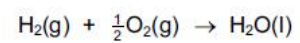
What was the amount of energy absorbed by the water?

- A $0.47 \times 4.18 \times 17.3 \text{ J}$
- B $0.47 \times 4.18 \times (273 + 17.3) \text{ J}$
- C $200 \times 4.18 \times 17.3 \text{ J}$
- D $200 \times 4.18 \times (273 + 17.3) \text{ J}$

[2014 O/N-13 (11)]

82.

Which names can be applied to the enthalpy change of the reaction shown?



- 1 enthalpy change of formation
- 2 enthalpy change of combustion
- 3 enthalpy change of hydration

[2014 O/N-13 (34)]

Lattice energy - 2021

1. Nov/2020/Paper_41/No.2

(a) The lattice energies of three ionic compounds are given.

compound	lattice energy / kJ mol^{-1}
LiF(s)	-1022
CaO(s)	-3513
SrO(s)	-3310

(i) Define the term *lattice energy*.

.....
.....
..... [2]

(ii) Explain why the lattice energy of CaO is more exothermic than the lattice energy of LiF.

.....
.....
..... [1]

(iii) Use the data in the table to estimate approximate values for the lattice energies of magnesium oxide and barium oxide.

$$\Delta H_{\text{latt}} \text{MgO(s)} = \dots\dots\dots \text{kJ mol}^{-1}$$

$$\Delta H_{\text{latt}} \text{BaO(s)} = \dots\dots\dots \text{kJ mol}^{-1}$$

[1]

(b) (i) Write an equation for the reaction between BaO and H_2O .
Include state symbols.

..... [1]

- (ii) State and explain how the solubilities of the hydroxides of the Group 2 elements vary down the group.

.....

.....

.....

.....

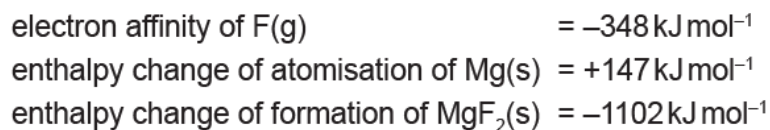
.....

.....

..... [4]

- (c) Use the following data and relevant data from the *Data Booklet* to calculate a value for the lattice energy of magnesium fluoride, $\text{MgF}_2(\text{s})$.

You might find it helpful to construct an energy cycle.
Show your working.



$$\Delta H_{\text{latt}} \text{MgF}_2(\text{s}) = \dots\dots\dots [3]$$

- (d) (i) Define the term *electron affinity*.

.....
..... [2]

- (ii) The electron affinity of carbon, C(g) , is -120 kJ mol^{-1} .

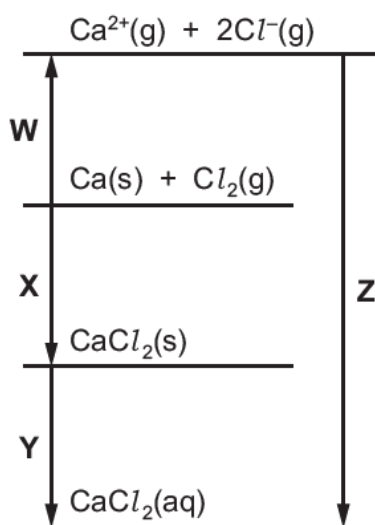
Suggest an explanation for the difference between the electron affinity of fluorine and the electron affinity of carbon.

.....
.....
.....
..... [1]

[Total: 15]

- (a) The energy cycle shown can be used, along with suitable data, to calculate the enthalpy change of hydration of $\text{Ca}^{2+}(\text{g})$.

Each arrow indicates a transformation, **W**, **X**, **Y** and **Z**. Each transformation consists of one or more steps.



The following data and data from the *Data Booklet* should be used.

electron affinity of $\text{Cl}(\text{g})$	$= -349 \text{ kJ mol}^{-1}$
enthalpy change of atomisation of $\text{Ca}(\text{s})$	$= +193 \text{ kJ mol}^{-1}$
enthalpy change of formation of $\text{CaCl}_2(\text{s})$	$= -795 \text{ kJ mol}^{-1}$
enthalpy change of solution of $\text{CaCl}_2(\text{s})$	$= -83 \text{ kJ mol}^{-1}$
enthalpy change of hydration of $\text{Cl}^{-}(\text{g})$	$= -364 \text{ kJ mol}^{-1}$

- (i) Calculate the value of the enthalpy change corresponding to transformation **W**. Show your working.

enthalpy change **W** = ... kJ mol^{-1} [2]

- (ii) Use your answer to (a)(i) and other data to calculate the value of the enthalpy change corresponding to transformation **Z**.

enthalpy change **Z** = ... kJ mol^{-1} [2]

- (iii) Use your answer to (a)(ii) to calculate the enthalpy change of hydration of $\text{Ca}^{2+}(\text{g})$.

enthalpy change of hydration of $\text{Ca}^{2+}(\text{g})$ = ... kJ mol^{-1} [2]

- (iv) Write an expression, in terms of **W**, **X**, **Y** and/or **Z**, to show how the enthalpy changes of **two** of the transformations can be used to calculate the lattice energy of $\text{CaCl}_2(\text{s})$.

lattice energy of $\text{CaCl}_2(\text{s})$ = ... [1]

- (v) State whether the lattice energy of $\text{CaCl}_2(\text{s})$ is more or less exothermic than the lattice energy of $\text{MgF}_2(\text{s})$.

Explain your answer.

.....
.....
..... [1]

(b) The sulfates of the Group 2 elements vary in solubility down Group 2.

(i) Give the names of **two** solutions that could be mixed to form barium sulfate.

..... [1]

(ii) State and explain how the solubilities of the sulfates of the Group 2 elements vary down Group 2.

.....
.....
.....
.....
.....
.....
..... [4]

[Total: 13]

3. June/2020/Paper_42/No.7b,7c

- (b) Use the following data and relevant data from the *Data Booklet* to calculate a value for the enthalpy change of formation of zinc bromide, $\text{ZnBr}_2(\text{s})$.

You might find it helpful to construct an energy cycle.

electron affinity of $\text{Br}(\text{g})$ $= -325 \text{ kJ mol}^{-1}$

enthalpy change of atomisation of $\text{Zn}(\text{s})$ $= +131 \text{ kJ mol}^{-1}$

enthalpy change of vaporisation of $\text{Br}_2(\text{l})$ $= +31 \text{ kJ mol}^{-1}$

lattice energy of $\text{ZnBr}_2(\text{s})$ $= -2678 \text{ kJ mol}^{-1}$

enthalpy change of formation of $\text{ZnBr}_2(\text{s}) = \dots\dots\dots \text{ kJ mol}^{-1}$ [4]

(c) The lattice energies of ZnBr_2 , ZnCl_2 and ZnO are shown.

compound	lattice energy / kJ mol^{-1}
ZnBr_2	-2678
ZnCl_2	-2734
ZnO	-3971

(i) Explain why there is a difference between the lattice energies of ZnBr_2 and ZnCl_2 .

.....
..... [1]

(ii) Explain why there is a difference between the lattice energies of ZnCl_2 and ZnO .

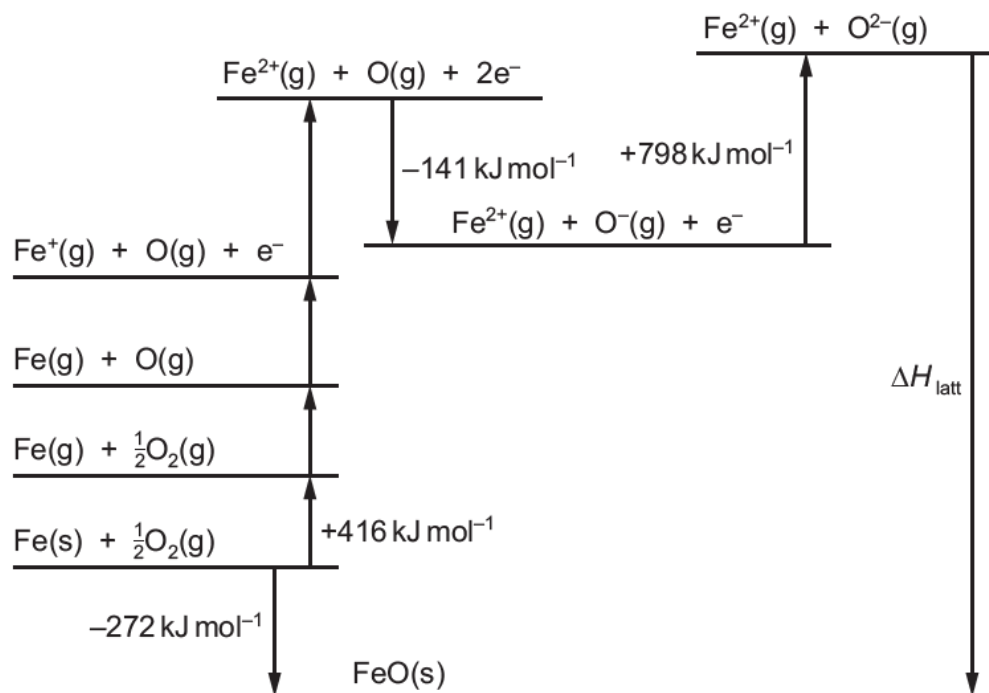
.....
..... [1]

1. March/2021/Paper_42/No.2

(a) Iron(II) compounds are generally only stable in neutral, non-oxidising conditions.

It is difficult to determine the lattice energy of FeO experimentally.

(i) Use data from the *Data Booklet* and this Born–Haber cycle to calculate the lattice energy, ΔH_{latt} , of FeO(s) in kJ mol^{-1} .



$\Delta H_{\text{latt}} \text{FeO(s)} = \dots\dots\dots \text{ kJ mol}^{-1}$ [2]

(ii) Most naturally occurring samples of iron(II) oxide are found as the mineral wüstite.

Wüstite has formula Fe_{20}O_x . It contains both Fe^{2+} and Fe^{3+} ions.

90% of the iron is present as Fe^{2+} and 10% is present as Fe^{3+} .

Deduce the value of x .

$x = \dots\dots\dots$ [1]

(iii) State and explain how the lattice energy of FeO(s) compares to the lattice energy of CaO(s) .

.....
.....
.....
.....
..... [2]

(b) Heating of FeO results in the formation of Fe₃O₄, as shown.



Each formula unit of Fe₃O₄ contains one Fe²⁺ and two Fe³⁺ ions.

(i) Show how reaction 1 can be described as a disproportionation reaction.

.....
.....
..... [1]

Fe₃O₄(l) can be electrolysed using inert electrodes to form Fe.

(ii) Write the half-equation for the reaction that occurs at the anode during the electrolysis of Fe₃O₄(l).

..... [1]

(iii) Calculate the maximum mass of iron metal formed when Fe₃O₄(l) is electrolysed for six hours using a current of 50A.

Assume the one Fe²⁺ and two Fe³⁺ ions are discharged at the same rate.

mass of iron = ... g [3]

(c) LiFePO_4 can be used in lithium-ion rechargeable batteries.

When the cell is charging, lithium reacts with a graphite electrode to form LiC_6 .

When the cell is discharging, the half-equations for the two processes that occur are as follows.



- (i) State one possible advantage of developing cells such as lithium-ion rechargeable batteries.

..... [1]

- (ii) Use the cathode half-equation to determine the change, if any, in oxidation states of lithium and iron at the **cathode** during discharging.

metal	change in oxidation state during discharging	
	from	to
lithium		
iron		

[1]

- (iii) Write the equation for the overall reaction that occurs when this cell is discharging.

..... [1]

[Total: 13]

(a) (i) Define the term *lattice energy*.

.....

 [2]

(ii) Use the following data to calculate a value for the enthalpy change of solution of copper(II) chloride, $\text{CuCl}_2(\text{s})$. You might find it helpful to construct an energy cycle.

enthalpy change of hydration of Cl^- = -378 kJ mol^{-1}
 enthalpy change of hydration of Cu^{2+} = $-2099 \text{ kJ mol}^{-1}$
 lattice energy of $\text{CuCl}_2(\text{s})$ = $-2824 \text{ kJ mol}^{-1}$

enthalpy change of solution of $\text{CuCl}_2(\text{s})$ = ... kJ mol^{-1} [2]

(iii) The enthalpy change of hydration of Ca^{2+} is $-1579 \text{ kJ mol}^{-1}$.

Use the *Data Booklet* to suggest why there is a big difference in the values of ΔH_{hyd} for Ca^{2+} and Cu^{2+} .

.....

 [2]

(b) (i) Identify the substances formed at the anode and at the cathode during the electrolysis of saturated $\text{CaCl}_2(\text{aq})$.

at the anode

at the cathode

[1]

- (ii) Calcium can be produced by the electrolysis of molten calcium chloride, $\text{CaCl}_2(\text{l})$.

Calculate the mass, in g, of Ca formed when a current of 0.75A passes through $\text{CaCl}_2(\text{l})$ for 60 minutes.

[A_r : Ca, 40.1]

mass of Ca = ... g [2]

3.

- (c) (i) Explain what is meant by the term *entropy of a system*.

.....

..... [1]

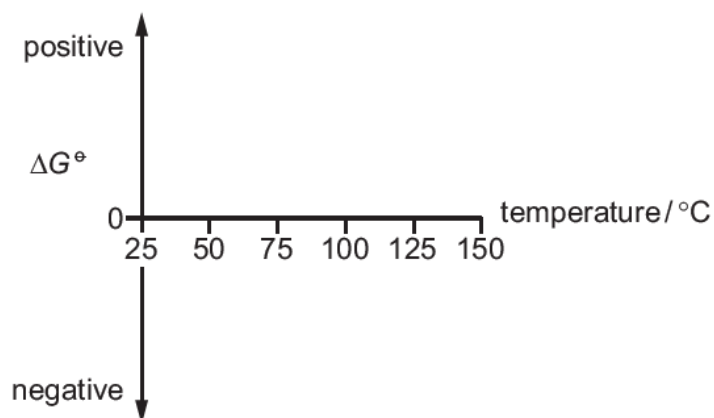
- (ii) Place one tick (✓) in each row of the table to show the sign of each entropy change, ΔS .

process	ΔS is negative	ΔS is zero	ΔS is positive
NaCl dissolving in water			
water solidifying to ice			

[1]

- (iii) The evaporation of one mole of water has a standard Gibbs free energy change, ΔG° , of +8.6 kJ at 25°C.

Sketch a graph on the axes to show how ΔG° changes for this process between 25°C and 150°C at 101 kPa.



[2]

- (d) The reaction between A and B is feasible at low temperatures but is **not** feasible at high temperatures.



Deduce the signs of ΔH and ΔS for this reaction and explain why the feasibility changes with temperature.

sign of ΔH = ... sign of ΔS = ...

.....
.....
.....
..... [2]

[Total: 15]

1. Nov/2021/Paper_42/No.3e

(e) The standard entropies, S° , of three species are given in the table.

species	$S^\circ/\text{JK}^{-1}\text{mol}^{-1}$
HCl(g)	+187
$\text{H}_2\text{(g)}$	+131
$\text{Cl}_2\text{(g)}$	+223

(i) Calculate ΔS° for the reaction $2\text{HCl(g)} \rightarrow \text{H}_2\text{(g)} + \text{Cl}_2\text{(g)}$.

$$\Delta S^\circ = \dots\dots\dots \text{JK}^{-1}\text{mol}^{-1} \quad [1]$$

(ii) ΔH° for the reaction $2\text{HCl(g)} \rightarrow \text{H}_2\text{(g)} + \text{Cl}_2\text{(g)}$ is $+185\text{kJ mol}^{-1}$.

Calculate ΔG° for this reaction at 298 K.

$$\Delta G^\circ = \dots\dots\dots \text{kJ mol}^{-1} \quad [2]$$

(iii) Predict the effect of increasing temperature on the spontaneity of this reaction. Explain your answer.

.....
..... [1]

1. June/2022/Paper_41/No.1(b- e)

- (b)** Describe what is observed when magnesium and barium are reacted separately with an excess of dilute sulfuric acid.

magnesium

barium

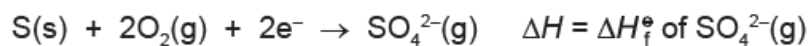
[1]

- (c)** The solubility product, K_{sp} , of BaSO_4 is $1.08 \times 10^{-10} \text{ mol}^2 \text{ dm}^{-6}$ at 298 K.

Calculate the solubility of BaSO_4 in g per 100 cm^3 of solution.

solubility of BaSO_4 = ... g per 100 cm^3 of solution
[2]

(d) (i) The equation for the formation of a gaseous sulfate ion is shown.



Calculate the standard enthalpy change of formation, ΔH_f° , of $\text{SO}_4^{2-}(\text{g})$. It may be helpful to draw a labelled energy cycle. Use relevant data from Table 1.1 in your calculations.

Table 1.1

energy change	value / kJ mol^{-1}
lattice energy of barium sulfate, $\text{BaSO}_4(\text{s})$	-2469
standard enthalpy change of formation of barium sulfate	-1473
standard enthalpy change of atomisation of barium	+180
first ionisation energy of barium	+503
second ionisation energy of barium	+965
standard enthalpy change of atomisation of sulfur	+279
standard enthalpy change for $\text{S}(\text{g}) \rightarrow \text{S}^{2-}(\text{g})$	+440
standard enthalpy change for $\text{O}(\text{g}) \rightarrow \text{O}^{2-}(\text{g})$	+657
O=O bond energy	+496

ΔH_f° of $\text{SO}_4^{2-}(\text{g}) = \dots\dots\dots \text{kJ mol}^{-1}$ [3]

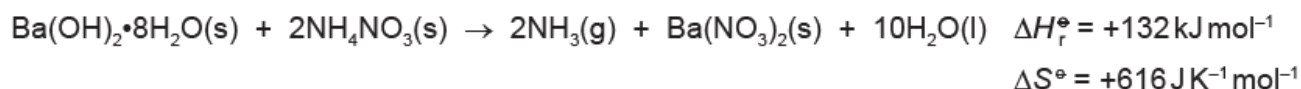
- (ii) Suggest how the lattice energy of $\text{BaSO}_4(\text{s})$ differs from the lattice energy of $\text{Cs}_2\text{SO}_4(\text{s})$. Explain your answer.

.....

 [2]

- (e) The reaction of solid hydrated barium hydroxide, $\text{Ba}(\text{OH})_2 \cdot 8\text{H}_2\text{O}$, with ammonium salts is endothermic.

- (i) Calculate the **minimum** temperature at which the reaction of $\text{Ba}(\text{OH})_2 \cdot 8\text{H}_2\text{O}$ with NH_4NO_3 becomes feasible. Show all your working.



temperature = ... °C [2]

- (ii) Barium hydroxide reacts readily with ammonium chloride on mixing at room temperature.



Some relevant standard entropies are given in Table 1.2.

Table 1.2

substance	$\text{Ba}(\text{OH})_2 \cdot 8\text{H}_2\text{O}(\text{s})$	$\text{NH}_4\text{Cl}(\text{s})$	$\text{NH}_3(\text{g})$	$\text{BaCl}_2 \cdot 2\text{H}_2\text{O}(\text{s})$	$\text{H}_2\text{O}(\text{l})$
$S^\circ / \text{J K}^{-1} \text{ mol}^{-1}$	427	95	192	203	70

Calculate the standard Gibbs free energy change, ΔG° , for this reaction at 25 °C.

$\Delta G^\circ = \dots\dots\dots \text{ kJ mol}^{-1}$ [3]

(b) The solubility of $\text{Be}(\text{OH})_2$ in water is $2.40 \times 10^{-6} \text{ g dm}^{-3}$ at 298 K.

(i) Write an expression for the solubility product, K_{sp} , of $\text{Be}(\text{OH})_2$ and state its units.

$$K_{\text{sp}} =$$

units = ...

[2]

(ii) Calculate the numerical value of K_{sp} for $\text{Be}(\text{OH})_2$ at 298 K.

$$K_{\text{sp}} = \dots\dots\dots [2]$$

(a) (i) Define first electron affinity.

.....

.....

..... [2]

(ii) The first electron affinity of an atom is usually an exothermic process, whereas the second electron affinity is an endothermic process.

Suggest why.

.....

..... [1]

(iii) Describe the general trend in first electron affinities for Cl, Br and I. Explain your answer.

.....

.....

..... [2]

(b) Table 3.1 shows energy changes to be used in this question and in (c).

Table 3.1

energy change	value / kJ mol ⁻¹
standard enthalpy change of atomisation of zinc	+131
first ionisation energy of zinc	+906
second ionisation energy of zinc	+1733
standard enthalpy change of formation of ZnI ₂ (s)	-208
lattice energy, $\Delta H_{\text{latt}}^{\circ}$, of zinc iodide, ZnI ₂ (s)	-2605
first ionisation energy of iodine	+1008
second ionisation energy of iodine	+1846
I-I bond energy	+151
enthalpy change of sublimation of iodine, I ₂ (s) → I ₂ (g)	+62

Calculate the first electron affinity for iodine. Use relevant data from Table 3.1 in your working. It may be helpful to draw a labelled energy cycle.
Show all working.

first electron affinity for iodine = ... kJ mol^{-1} [3]

- (c) Predict how $\Delta H_{\text{latt}}^\circ$ of $\text{CdI}_2(\text{s})$ differs from $\Delta H_{\text{latt}}^\circ$ of $\text{ZnI}_2(\text{s})$.
Place a tick (✓) in the appropriate box in Table 3.2.

Table 3.2

$\Delta H_{\text{latt}}^\circ$ of $\text{CdI}_2(\text{s})$ is less negative than $\Delta H_{\text{latt}}^\circ$ of $\text{ZnI}_2(\text{s})$	$\Delta H_{\text{latt}}^\circ$ of $\text{CdI}_2(\text{s})$ is the same as $\Delta H_{\text{latt}}^\circ$ of $\text{ZnI}_2(\text{s})$	$\Delta H_{\text{latt}}^\circ$ of $\text{CdI}_2(\text{s})$ is more negative than $\Delta H_{\text{latt}}^\circ$ of $\text{ZnI}_2(\text{s})$

Explain your answer.

.....
..... [1]

[Total: 9]

(a) Calcium carbonate decomposes on heating.



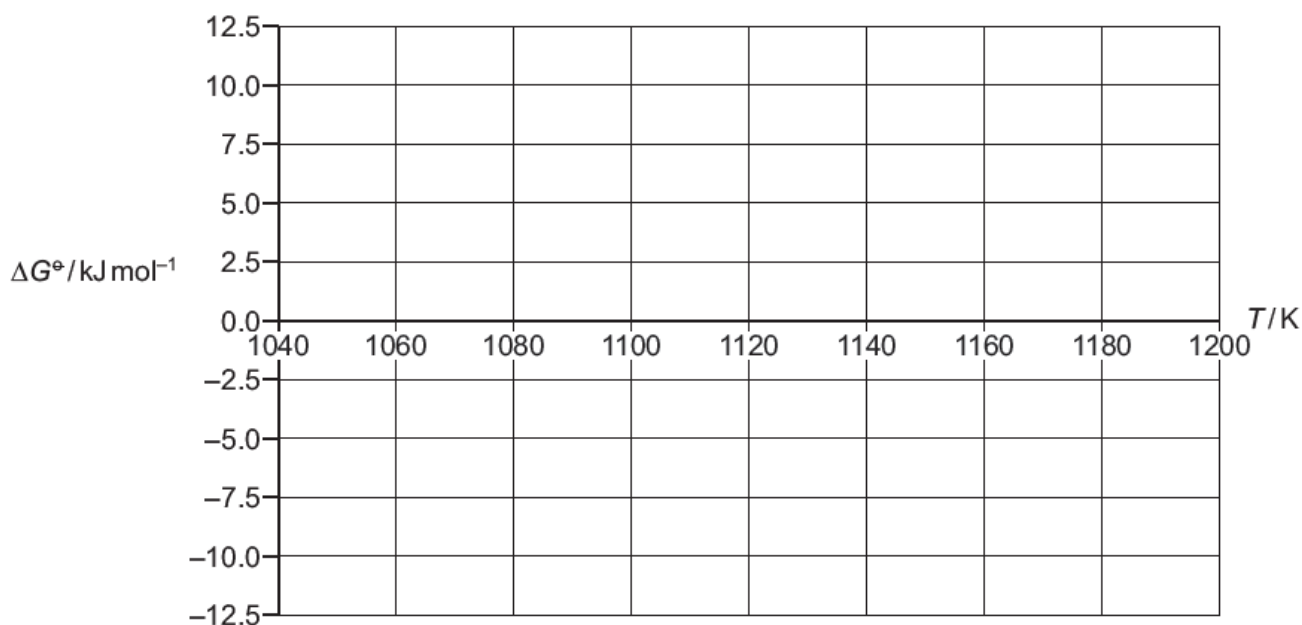
Table 4.1 shows the values of the Gibbs free energy change, ΔG° , for this reaction at various temperatures.

Table 4.1

T/K	$\Delta G^\circ/\text{kJ mol}^{-1}$
1050	9.9
1085	4.3
1120	-1.3
1148	-5.8
1176	-10.3

Assume the standard enthalpy change, ΔH° , and the standard entropy change, ΔS° , for this reaction remain constant over this temperature range.

(i) Use the data in Table 4.1 to plot a graph of ΔG° against T on the grid.



[2]

(ii) Calculate the gradient of your graph. Determine the ΔS° in $\text{JK}^{-1} \text{mol}^{-1}$ for this reaction. Show all working.

$\Delta S^\circ = \dots\dots\dots \text{JK}^{-1} \text{mol}^{-1}$ [2]

(b) Group 1 hydrogencarbonates, MHCO_3 , decompose on gentle heating to give the corresponding metal carbonate, carbon dioxide and water vapour.

(i) Write an ionic equation for the decomposition of the hydrogencarbonate ion.

..... [1]

(ii) The thermal stability of Group 1 hydrogencarbonates increases down the group.

Suggest an explanation for the trend in thermal stability of the Group 1 hydrogencarbonates.

.....
.....
.....
..... [2]

1. Nov/2022/Paper_41/No.1

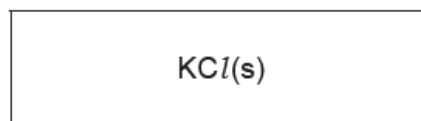
Potassium chloride, KCl , and magnesium chloride, MgCl_2 , are both ionic solids.

Table 1.1

energy change	value / kJ mol^{-1}
standard enthalpy change of solution, $\Delta H_{\text{sol}}^\circ$ of KCl	+15
lattice energy, $\Delta H_{\text{latt}}^\circ$ of KCl(s)	-701
standard enthalpy change of hydration, $\Delta H_{\text{hyd}}^\circ$ of K^+	-322
standard enthalpy change of hydration, $\Delta H_{\text{hyd}}^\circ$ of Cl^-	-364
standard enthalpy change of solution, $\Delta H_{\text{sol}}^\circ$ of MgCl_2	-155
lattice energy, $\Delta H_{\text{latt}}^\circ$ of $\text{MgCl}_2(\text{s})$	-2493

- (a) Complete the energy cycle involving the enthalpy change of solution and the lattice energy of potassium chloride, KCl , and the relevant enthalpy changes of hydration. Label your diagram.

State symbols should be used.



[2]

- (b) Use the data in Table 1.1 to calculate the enthalpy change of hydration of magnesium ions, Mg^{2+} . Show your working.

$\Delta H_{\text{hyd}}^\circ$ of magnesium ions, Mg^{2+} = ... kJ mol^{-1} [2]

(c) Explain the reasons why the lattice energy of MgCl_2 is more exothermic than the lattice energy of KCl .

.....

.....

.....

..... [2]

(d) Define the following terms.

(i) enthalpy change of atomisation [1]

(ii) first electron affinity [1]

(e) (i) Explain what is meant by entropy, S .

.....

..... [1]

(ii) Potassium chloride is very soluble in water at 20°C .

Explain the solubility of potassium chloride by reference to change in entropy, ΔS .

.....

..... [1]

(iii) Use the Gibbs equation and your answer to (e)(ii) to predict whether potassium chloride is more soluble in water at 20°C or at 80°C . Explain your answer.

.....

.....

..... [1]

[Total: 11]

Calcium chloride, CaCl_2 , is an ionic solid.

The values of some energy changes are shown in Table 1.1.

Table 1.1

energy change	value / kJ mol^{-1}
lattice energy, $\Delta H_{\text{latt}}^\circ$, $\text{CaCl}_2(\text{s})$	-2237
standard enthalpy change of atomisation of calcium	+193
first ionisation energy of calcium	+590
second ionisation energy of calcium	+1150
standard enthalpy change of atomisation of chlorine	+121
first electron affinity of chlorine	-364

(a) Define lattice energy.

.....
 [1]

(b) Use the data in Table 1.1 to calculate the standard enthalpy change of formation, ΔH_f° , of calcium chloride. It may be helpful to draw an energy cycle. Show all your working.

$$\Delta H_f^\circ(\text{CaCl}_2(\text{s})) = \dots\dots\dots \text{kJ mol}^{-1} \quad [2]$$

- (c) Three possible values for the first electron affinity of bromine are shown in Table 1.2. One of them is correct.

Place a tick by the correct value. Explain your choice.

Table 1.2

possible values	place one tick (✓) in this column
–342 kJ mol ^{–1}	
–364 kJ mol ^{–1}	
–386 kJ mol ^{–1}	

explanation
 [1]

- (d) The enthalpy change of hydration of the chloride ion can be calculated using the lattice energy of calcium chloride and the data shown in Table 1.3.

Table 1.3

energy change	value / kJ mol ^{–1}
standard enthalpy change of solution of CaCl ₂ (s)	–83
standard enthalpy change of hydration of Ca ²⁺ (g)	–1650

- (i) Define the following terms.

enthalpy change of solution

 enthalpy change of hydration
 [2]

- (ii) Calculate the standard enthalpy change of hydration of the chloride ion, Cl[–](g). It may be helpful to draw an energy cycle. Show all your working.

$$\Delta H_{\text{hyd}}^{\circ}(\text{Cl}^{-}(\text{g})) = \dots\dots\dots \text{kJ mol}^{-1} \quad [2]$$

(e) Calcium fluoride, $\text{CaF}_2(\text{s})$, can be synthesised directly from its elements.

The value of $\Delta H_f^\circ(\text{CaF}_2(\text{s}))$ is $-1214 \text{ kJ mol}^{-1}$.

(i) Predict the sign of the entropy change, ΔS° , for this synthesis. Explain your answer.

The sign of the entropy change is

explanation

..... [1]

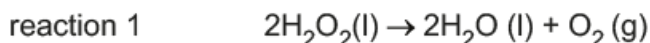
(ii) Use the value of $\Delta H_f^\circ(\text{CaF}_2(\text{s}))$ given in (e) and your answer to (e)(i) to predict how the feasibility for this synthesis will change with increasing temperature.

.....
.....
.....
..... [2]

[Total: 11]

1. Nov/2023/Paper_9701/41/No.3(a, b, c, g)

Hydrogen peroxide is a liquid at 298K. It is moderately stable under room conditions but will decompose quickly if a catalyst is added.



(a) (i) Define entropy.

.....
..... [1]

(ii) Predict the sign of the standard entropy change of reaction 1.

Explain your answer.

sign

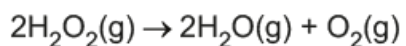
explanation
..... [1]

(b) Some bond energy data are shown in Table 3.1.

Table 3.1

type of bond	bond energy / kJ mol^{-1}
O–O	150
O–H	460
O=O	496

Use the data in Table 3.1 to show that the enthalpy change of the following reaction is -196 kJ mol^{-1} .



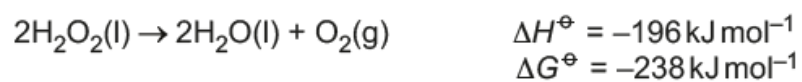
[1]

(c) Some standard entropies, $S^\ominus$, are shown in Table 3.2.

Table 3.2

substance	$S^\ominus / \text{JK}^{-1} \text{mol}^{-1}$
$\text{H}_2\text{O}_2(\text{l})$	+102
$\text{H}_2\text{O}(\text{l})$	+70

The enthalpy change and Gibbs free energy change for the following reaction are shown.



Use the data given to calculate the standard entropy of oxygen, $S^\ominus$, $\text{O}_2(\text{g})$.

$S^\ominus$, $\text{O}_2(\text{g}) = \dots\dots\dots \text{JK}^{-1} \text{mol}^{-1}$ [3]

(g) (i) Define enthalpy change of hydration, $\Delta H_{\text{hyd}}^{\ominus}$.

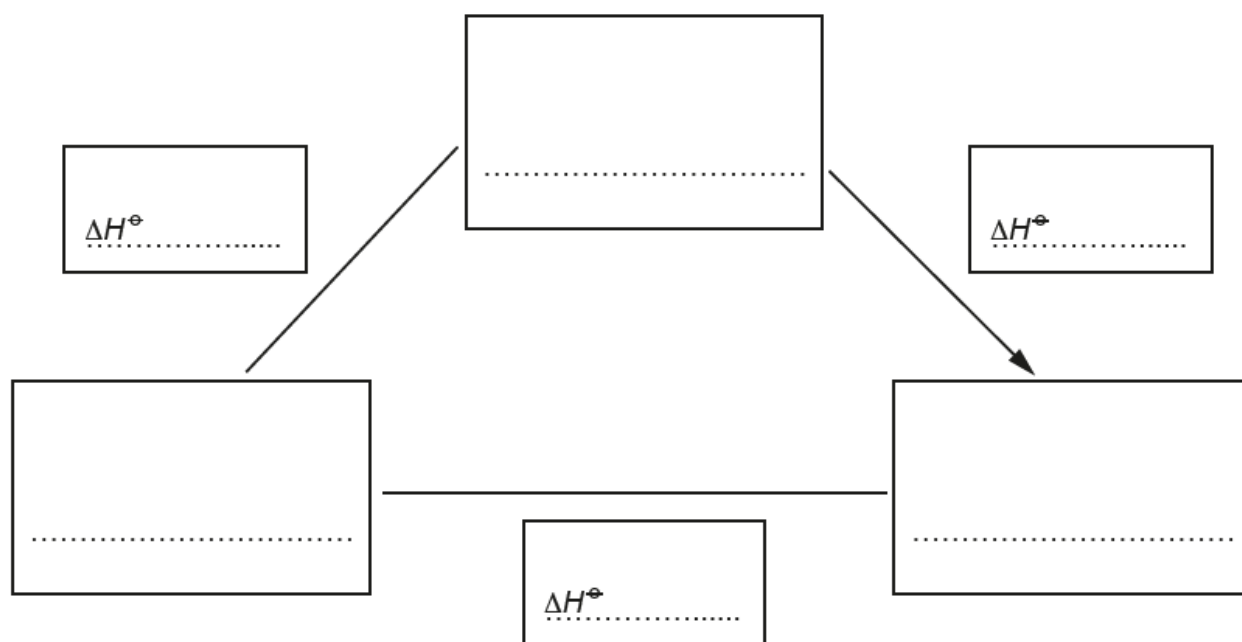
.....
..... [1]

(ii) Aluminium fluoride, AlF_3 , is an ionic solid.

Complete and label the energy cycle to show the relationship between:

- the enthalpy change of solution of AlF_3 , $\Delta H_{\text{sol}}^{\ominus}$
- the lattice energy of AlF_3 , $\Delta H_{\text{latt}}^{\ominus}$
- the enthalpy changes of hydration of Al^{3+} and F^- , $\Delta H_{\text{hyd}}^{\ominus}$.

Include state symbols for all substances and ions.



[2]

(iii) Relevant data for this question are given.

$$\Delta H_{\text{sol}}^{\ominus} \text{AlF}_3 = -209 \text{ kJ mol}^{-1}$$

$$\Delta H_{\text{hyd}}^{\ominus} \text{Al}^{3+} = -4690 \text{ kJ mol}^{-1}$$

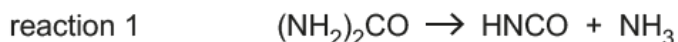
$$\Delta H_{\text{hyd}}^{\ominus} \text{F}^- = -506 \text{ kJ mol}^{-1}$$

Use these data and your energy cycle in (g)(ii) to calculate the $\Delta H_{\text{latt}}^{\ominus}$ of AlF_3 .

$$\Delta H_{\text{latt}}^{\ominus} \text{ of } \text{AlF}_3 = \dots\dots\dots \text{ kJ mol}^{-1} \quad [1]$$

- (b) The exhaust systems of many diesel-fuelled cars contain an additional system to reduce vehicle emissions. This uses a liquid that is added to the exhaust system.

This liquid contains urea, $(\text{NH}_2)_2\text{CO}$, which decomposes on heating to isocyanic acid, HNCO , and ammonia.



Isocyanic acid reacts with water vapour to form ammonia and carbon dioxide.



Some values for standard enthalpy changes of formation, $\Delta H_f^\ominus$, and standard entropies, $S^\ominus$, are given in Table 5.1.

Table 5.1

compound	$\Delta H_f^\ominus / \text{kJ mol}^{-1}$	$S^\ominus / \text{JK}^{-1} \text{mol}^{-1}$
$\text{HNCO}(\text{g})$	-101.7	+238.2
$\text{H}_2\text{O}(\text{g})$	-241.8	+188.8
$\text{NH}_3(\text{g})$	-45.9	+192.8
$\text{CO}_2(\text{g})$	-393.5	+213.8

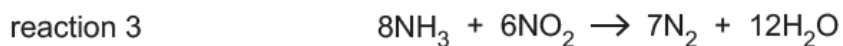
- (i) Explain what is meant by the term entropy of a system.

.....
 [1]

- (ii) Use the data in Table 5.1 to calculate $\Delta G^\ominus$ for **reaction 2** at 25 °C.
Show your working.

$$\Delta G^\ominus = \dots\dots\dots \text{kJ mol}^{-1} \quad [4]$$

- (c) The ammonia formed in reactions 1 and 2 can be used to remove nitrogen dioxide from exhaust emissions, as shown.



Use the equations for reactions 1, 2 and 3 to construct an overall equation for the reduction of NO_2 by $(\text{NH}_2)_2\text{CO}$.

..... [1]

- (a) Complete Table 8.1 by placing **one** tick (✓) in each row to indicate the sign of each type of energy change under standard conditions.

Table 8.1

energy change	always positive	always negative	can be either negative or positive
lattice energy			
enthalpy change of hydration			
enthalpy change of solution			

[1]

- (b) Define enthalpy change of hydration.

.....

.....

..... [1]

- (c) Table 8.2 shows various energy changes which can be used in the following questions.

Table 8.2

energy change	value / kJ mol ⁻¹
standard enthalpy change of atomisation of calcium	+178.2
first ionisation energy of calcium	+590
second ionisation energy of calcium	+1145
standard enthalpy change of atomisation of bromine	+111.9
Br–Br bond energy	+192.9
standard enthalpy change of solution of calcium bromide, CaBr ₂ (s)	–103.1
standard enthalpy change of formation of calcium bromide, CaBr ₂ (s)	–682.8
standard enthalpy change of hydration of Ca ²⁺	–1579
first electron affinity of bromine	–324.6
first ionisation energy of bromine	+1140

- (i) Select and use relevant data from Table 8.2 to calculate the lattice energy, $\Delta H_{\text{latt}}^{\ominus}$, of $\text{CaBr}_2(\text{s})$.

It may be helpful to draw a labelled energy cycle.

Show your working.

$$\Delta H_{\text{latt}}^{\ominus} \text{ of } \text{CaBr}_2(\text{s}) = \dots\dots\dots \text{ kJ mol}^{-1} \quad [3]$$

- (ii) Select and use relevant data from Table 8.2 and your answer to (c)(i) to calculate the standard enthalpy change of hydration, $\Delta H_{\text{hyd}}^{\ominus}$, of Br^- .

It may be helpful to draw a labelled energy cycle.

If you were not able to answer (c)(i), use $-2500 \text{ kJ mol}^{-1}$ as your value for $\Delta H_{\text{latt}}^{\ominus}$ of $\text{CaBr}_2(\text{s})$. This is **not** the correct value.

Show your working.

$$\Delta H_{\text{hyd}}^{\ominus} \text{ of } \text{Br}^- = \dots\dots\dots \text{ kJ mol}^{-1} \quad [2]$$

- (iii) The enthalpy change of hydration of the Br^- ion is more negative than the enthalpy change of hydration of the I^- ion. Explain why.

.....
.....
..... [2]

[Total: 9]

(a) Group 2 carbonates decompose when heated to form the metal oxide and carbon dioxide.

- (i) Suggest a mechanism for the decomposition of the carbonate ion by adding **two** curly arrows in Fig. 1.1.



Fig. 1.1

[1]

- (ii) Describe the variation in the thermal stability of Group 2 carbonates. Explain your answer.

.....

.....

.....

.....

..... [3]

- (b) (i) Define lattice energy.

.....

.....

..... [2]

- (ii) The lattice energy of the Group 2 carbonates, $\Delta H_{\text{latt}}^{\ominus}(\text{MCO}_3)$, becomes less exothermic down the group.

The lattice energy of the Group 2 oxides, $\Delta H_{\text{latt}}^{\ominus}(\text{MO})$, also becomes less exothermic down the group.

$\Delta H_{\text{latt}}^{\ominus}(\text{MCO}_3)$ and $\Delta H_{\text{latt}}^{\ominus}(\text{MO})$ change by **different** amounts going down the group.

Suggest how the standard enthalpy change of the decomposition reaction for Group 2 carbonates changes down the group.

Explain your reasoning in terms of the relative sizes of the anions and the relative changes in lattice energy down the group.

.....

.....

.....

.....

..... [2]

- (a) Complete Table 3.1 by placing **one** tick (✓) in each row to indicate the sign of each type of energy change under standard conditions.

Table 3.1

energy change	always positive	always negative	can be either negative or positive
bond energy			
enthalpy change of atomisation			
enthalpy change of formation			

[1]

- (b) Define standard enthalpy change of atomisation.

.....

.....

..... [2]

- (c) Table 3.2 shows some energy changes.

Table 3.2

energy change	value / kJ mol^{-1}
standard enthalpy change of atomisation of silver	+285
first ionisation energy of silver	+731
second ionisation energy of silver	+2074
bond energy of $\text{O}=\text{O}$	+496
bond energy of $\text{O}-\text{O}$	+150
first electron affinity of oxygen	-141
second electron affinity of oxygen	+798
first ionisation energy of oxygen	+1314
standard enthalpy change of formation of silver oxide, $\text{Ag}_2\text{O}(\text{s})$	-31

Calculate the lattice energy, $\Delta H_{\text{latt}}^{\ominus}$, of $\text{Ag}_2\text{O}(\text{s})$ using relevant data from Table 3.2.

It may be helpful to draw a labelled energy cycle.

Show your working.

$\Delta H_{\text{latt}}^{\ominus}$ of $\text{Ag}_2\text{O}(\text{s}) = \dots\dots\dots \text{kJ mol}^{-1}$ [3]

- (d) Suggest the trend in the magnitude of the lattice energies of the silver compounds Ag_2S , Ag_2O and Ag_2Se .

Explain your answer.

.....
least exothermic most exothermic
.....
.....
..... [2]

(e) Silver sulfite, $\text{Ag}_2\text{SO}_3(\text{s})$, is sparingly soluble in water.

(i) Give an expression for the solubility product, K_{sp} , of Ag_2SO_3 .

$$K_{\text{sp}} =$$

[1]

(ii) Calculate the equilibrium concentration of Ag^+ in a saturated solution of Ag_2SO_3 at 298 K.

[K_{sp} : Ag_2SO_3 , $1.50 \times 10^{-14} \text{ mol}^3 \text{ dm}^{-9}$ at 298 K]

$$[\text{Ag}^+] = \dots\dots\dots \text{ mol dm}^{-3} \quad [1]$$

(f) The standard enthalpy change of solution, $\Delta H_{\text{sol}}^\ominus$, of $\text{AgNO}_3(\text{s})$ in water is $+22.6 \text{ kJ mol}^{-1}$.

Suggest how the feasibility of dissolving $\text{AgNO}_3(\text{s})$ in water changes with temperature.

Explain your answer.

.....

.....

.....

..... [2]

[Total: 12]

(a) The most common zinc mineral contains zinc(II) sulfide, ZnS.

- (i) Complete the electrons in boxes diagram in Fig. 1.1 to show the electronic configuration of a zinc(II) ion.



Fig. 1.1

[1]

- (ii) Complete Fig. 1.2 to show the Born–Haber diagram for the ionic solid ZnS.

Include state symbols of relevant species.

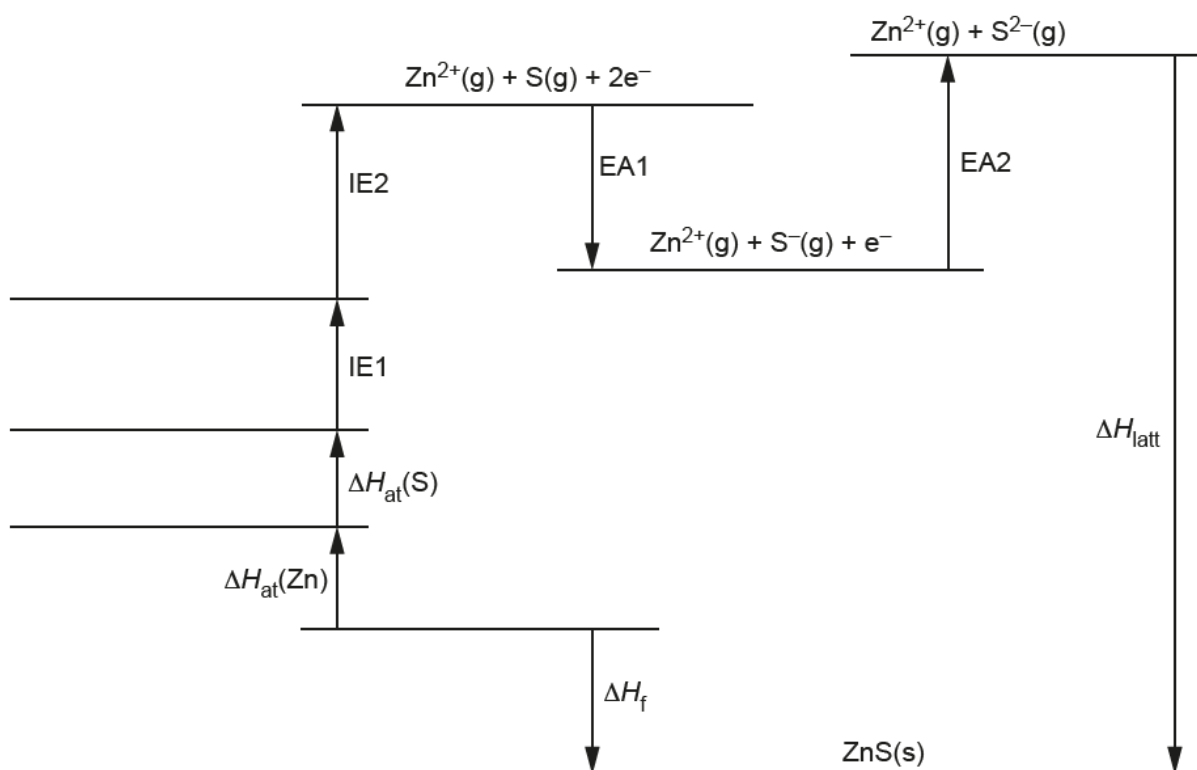


Fig. 1.2

[3]

(iii) Describe the trend in the first electron affinity of the Group 16 elements S to Te.

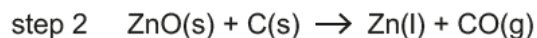
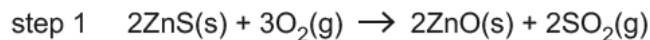
Explain your answer.

.....
.....
.....
..... [2]

(iv) Explain why the lattice energy, ΔH_{latt} , of ZnO is more exothermic than that of ZnS.

.....
.....
.....
..... [2]

(b) Zinc metal can be obtained in a two-step process as shown.



The reactions are carried out at 800 °C.

(i) Predict the sign of the entropy change, $\Delta S^\ominus$, of the reaction in **step 1**.

Explain your answer.

.....
..... [1]

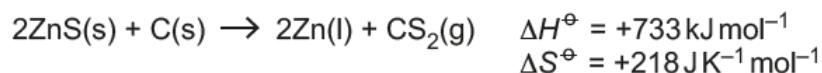
(ii) Use the data in Table 1.1 to calculate $\Delta S^\ominus$ of the reaction shown in **step 2**.

Table 1.1

chemical	ZnO(s)	C(s)	Zn(l)	CO(g)
$S^\ominus / \text{JK}^{-1} \text{mol}^{-1}$	43.7	5.7	50.8	197.7

$\Delta S^\ominus = \dots\dots\dots \text{JK}^{-1} \text{mol}^{-1}$ [1]

(iii) An equation for the direct reduction of ZnS by carbon is shown.



This reaction is **not** feasible at 800 °C.

Calculate $\Delta G^\ominus$ for this reaction at 800 °C.

$$\Delta G^\ominus = \dots\dots\dots \text{ kJ mol}^{-1} \quad [2]$$

(c) $\text{Zn(NO}_3)_2$ undergoes thermal decomposition when heated. The reaction is similar to the thermal decomposition of Group 2 nitrates.

(i) Construct an equation for the thermal decomposition of $\text{Zn(NO}_3)_2$.

..... [1]

(ii) The radii of some Group 2 cations and Zn^{2+} are shown in Table 1.2.

Table 1.2

cation	Mg^{2+}	Ca^{2+}	Sr^{2+}	Ba^{2+}	Zn^{2+}
radius/pm	65	99	113	135	74

State and explain the trend in thermal stability of the Group 2 nitrates down the group.

.....
.....
..... [2]

(iii) Use Table 1.2 to suggest which Group 2 nitrates are **less** thermally stable than zinc nitrate.

..... [1]

[Total: 16]

Chemical energetics – 2021 AS

1. Nov/2021/Paper_11/No.7

In order to determine the enthalpy of neutralisation of a strong acid and a strong alkali, 25.0 cm³ of 2.00 mol dm⁻³ sodium hydroxide is added to 25.0 cm³ of 2.00 mol dm⁻³ hydrochloric acid. The increase in temperature is 12 °C.

In a second experiment, the same method is used, but 50.0 cm³ of 2.00 mol dm⁻³ sodium hydroxide is added to 50.0 cm³ of 2.00 mol dm⁻³ hydrochloric acid.

What is the increase in temperature in the second experiment?

- A 6 °C B 12 °C C 24 °C D 48 °C

2. Nov/2021/Paper_11/No.8

Which equation represents the enthalpy change of atomisation of iodine?

- A $\frac{1}{2} \text{I}_2(\text{g}) \rightarrow \text{I}(\text{g})$
B $\text{I}_2(\text{g}) \rightarrow 2\text{I}(\text{g})$
C $\frac{1}{2} \text{I}_2(\text{s}) \rightarrow \text{I}(\text{g})$
D $\text{I}_2(\text{s}) \rightarrow 2\text{I}(\text{g})$

3. Nov/2021/Paper_11/No.9

Zinc atoms can be oxidised to Zn²⁺ ions by dichromate(VI) ions in acid solution. Chromium is reduced to Cr³⁺ in this reaction.

Which equation is correct?

- A $\text{Cr}_2\text{O}_7^{2-} + \text{Zn} + 14\text{H}^+ \rightarrow 2\text{Cr}^{3+} + \text{Zn}^{2+} + 7\text{H}_2\text{O}$
B $\text{Cr}_2\text{O}_7^{2-} + \text{Zn} + 14\text{H}^+ \rightarrow 2\text{Cr}^{3+} + 3\text{Zn}^{2+} + 7\text{H}_2\text{O}$
C $\text{Cr}_2\text{O}_7^{2-} + 3\text{Zn} + 14\text{H}^+ \rightarrow 2\text{Cr}^{3+} + 3\text{Zn}^{2+} + 7\text{H}_2\text{O}$
D $2\text{Cr}_2\text{O}_7^{2-} + 3\text{Zn} + 14\text{H}^+ \rightarrow 2\text{Cr}^{3+} + 3\text{Zn}^{2+} + 7\text{H}_2\text{O}$

4. Nov/2021/Paper_11/No.17

Z is a compound of sodium, chlorine and oxygen.

It contains 45.1% by mass of oxygen.

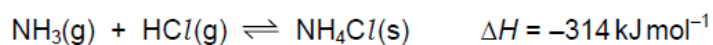
Z is prepared by reacting sodium hydroxide with chlorine.

Which row shows the conditions used for the reaction and the oxidation state of chlorine in Z?

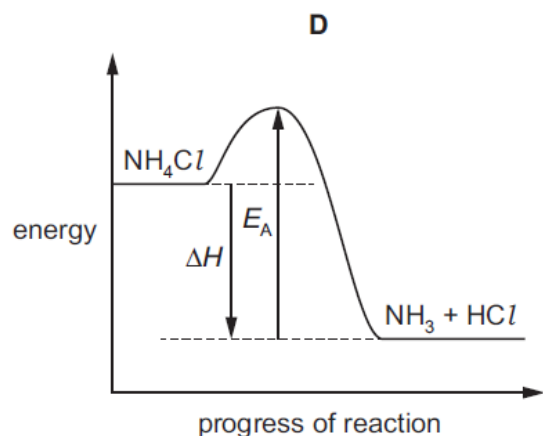
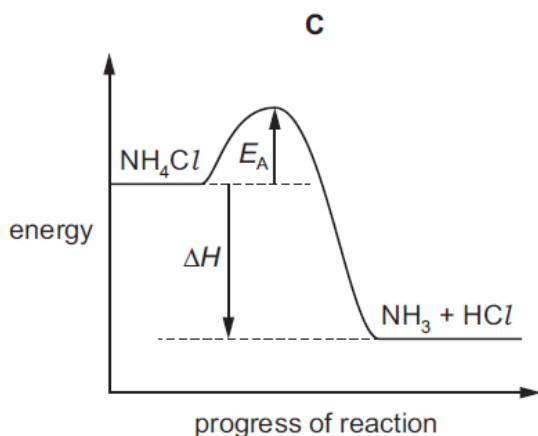
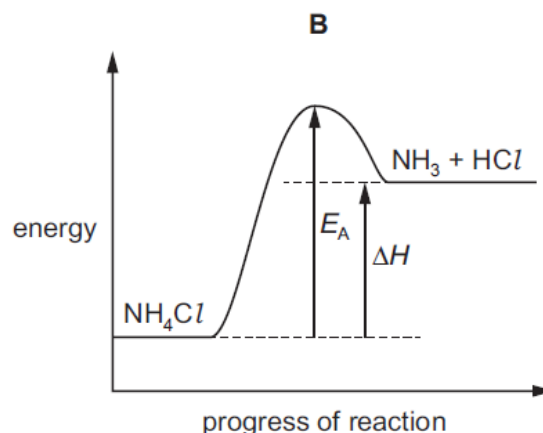
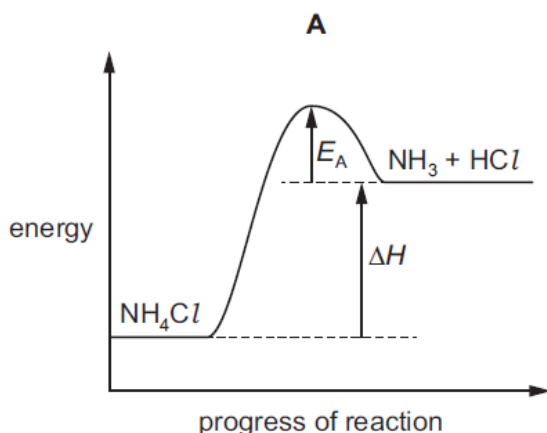
	reaction conditions	oxidation state of Cl in Z
A	cold dilute NaOH	+1
B	cold dilute NaOH	+5
C	hot concentrated NaOH	+1
D	hot concentrated NaOH	+5

5. Nov/2021/Paper_12/No.9

The equation for the formation of ammonium chloride is shown.



Which diagram shows the correctly labelled reaction pathway diagram for the decomposition of ammonium chloride?



6. Nov/2021/Paper_12/No.10

In a catalytic converter in the exhaust system of a car, carbon monoxide is oxidised to carbon dioxide, and nitrogen monoxide is reduced to nitrogen.

What are the changes in oxidation number of carbon and nitrogen in these two processes?

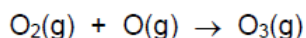
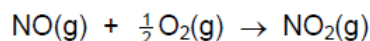
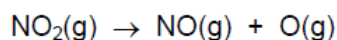
	carbon	nitrogen
A	−2	+2
B	−1	+1
C	+1	−1
D	+2	−2

7. Nov/2021/Paper_12/No.11

NO and NO₂ are both present in the lower atmosphere as pollutants.

The reaction sequence shows the production of ozone from oxygen in the lower atmosphere.

This sequence repeats many times.

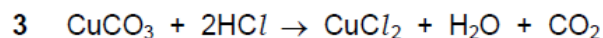
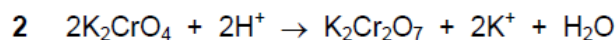
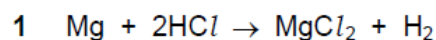


Which statement about this reaction sequence is correct?

- A** NO is acting as a catalyst, but NO₂ is not acting as a catalyst.
- B** NO₂ is acting as a catalyst, but NO is not acting as a catalyst.
- C** Neither NO nor NO₂ are acting as catalysts.
- D** Both NO and NO₂ are acting as catalysts.

8. Nov/2021/Paper_12/No.33

Which reactions are redox reactions?



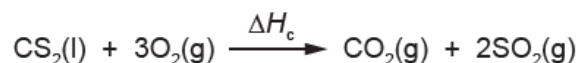
9. Nov/2021/Paper_13/No.8

Which equation represents the enthalpy change of atomisation of iodine?

- A $\frac{1}{2} \text{I}_2(\text{g}) \rightarrow \text{I}(\text{g})$
 B $\text{I}_2(\text{g}) \rightarrow 2\text{I}(\text{g})$
 C $\frac{1}{2} \text{I}_2(\text{s}) \rightarrow \text{I}(\text{g})$
 D $\text{I}_2(\text{s}) \rightarrow 2\text{I}(\text{g})$

10. Nov/2021/Paper_21/No.1(b)

(b) The enthalpy change of combustion of $\text{CS}_2(\text{l})$ is represented by the following equation.



(i) Define *enthalpy change of combustion*.

.....

 [2]

(ii) The table shows the enthalpy changes of formation of $\text{CS}_2(\text{l})$, $\text{CO}_2(\text{g})$ and $\text{SO}_2(\text{g})$.

compound	enthalpy change of formation, $\Delta H_f^\circ / \text{kJ mol}^{-1}$
$\text{CS}_2(\text{l})$	+89.7
$\text{CO}_2(\text{g})$	−394
$\text{SO}_2(\text{g})$	−297

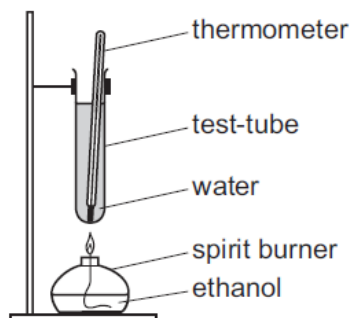
Use the data in the table to calculate the enthalpy change of combustion, ΔH_c , of $\text{CS}_2(\text{l})$, in kJ mol^{-1} .

Show your working.

ΔH_c of $\text{CS}_2(\text{l})$ = ... kJ mol^{-1}
 [2]

11. March/2021/Paper_12/No/.7

An experiment was performed to determine the enthalpy of combustion of ethanol.



The data collected are shown.

mass of water = W g

mass of ethanol burned = X g

temperature rise = $Y^{\circ}\text{C}$

molar mass of ethanol = Z g mol $^{-1}$

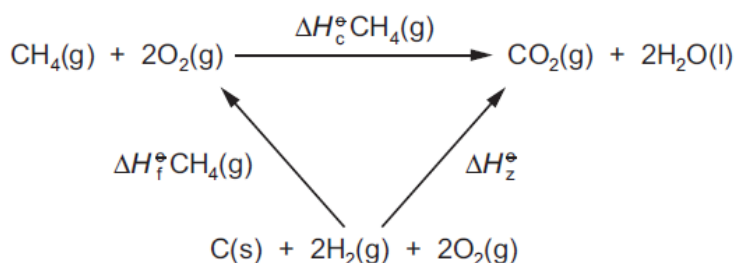
specific heat capacity of water = $4.2 \text{ J K}^{-1} \text{ g}^{-1}$

Which expression can be used to calculate the enthalpy of combustion of ethanol in kJ mol^{-1} ?

- A $\frac{-4.2WYZ}{1000X}$ B $\frac{-4.2WYX}{1000Z}$ C $\frac{-4.2XYZ}{1000W}$ D $\frac{-4.2X(Y + 273)Z}{1000W}$

12. March/2021/Paper_12/No/.32

An energy cycle for the combustion of methane is shown.



Which expressions can be used to calculate the energy change, ΔH_z° ?

- 1 $\Delta H_f^\circ \text{CH}_4(\text{g}) + \Delta H_c^\circ \text{CH}_4(\text{g})$
- 2 $\Delta H_c^\circ \text{C}(\text{s}) + 2\Delta H_c^\circ \text{H}_2(\text{g})$
- 3 $\Delta H_c^\circ \text{CO}(\text{g}) + 2\Delta H_c^\circ \text{H}_2(\text{g})$

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

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

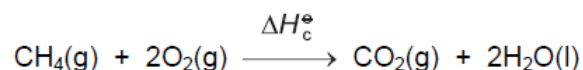
No other combination of statements is used as a correct response.

13. June/2021/Paper_11/No.4

ΔH_1° is the standard enthalpy of formation of methane.

ΔH_2° is the standard enthalpy of combustion of carbon.

ΔH_3° is the standard enthalpy of combustion of hydrogen.



Which expression is equivalent to ΔH_c° ?

A $\Delta H_1^\circ - \Delta H_2^\circ + \Delta H_3^\circ$

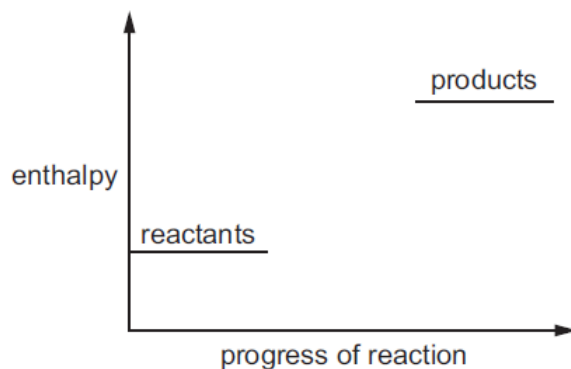
B $\Delta H_1^\circ - 2\Delta H_3^\circ - \Delta H_2^\circ$

C $\Delta H_2^\circ - \Delta H_3^\circ + \Delta H_1^\circ$

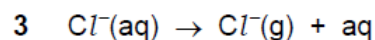
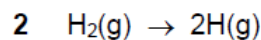
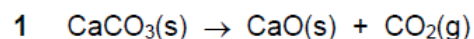
D $\Delta H_2^\circ + 2\Delta H_3^\circ - \Delta H_1^\circ$

14. June/2021/Paper_11/No.32

The diagram shows an incomplete energy profile diagram for a reaction.



Which reactions could this diagram refer to?



15. June/2021/Paper_12/No.8

Nitrogen and oxygen can react together to form nitrogen monoxide, NO.

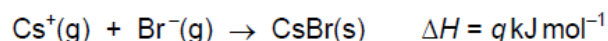


What is the bond energy of the bond between the atoms in NO?

- A 630 kJ mol⁻¹ B 810 kJ mol⁻¹ C 1260 kJ mol⁻¹ D 1620 kJ mol⁻¹

16. June/2021/Paper_13/No.7

Using the information in the table, what is the enthalpy change, q , for the reaction described?

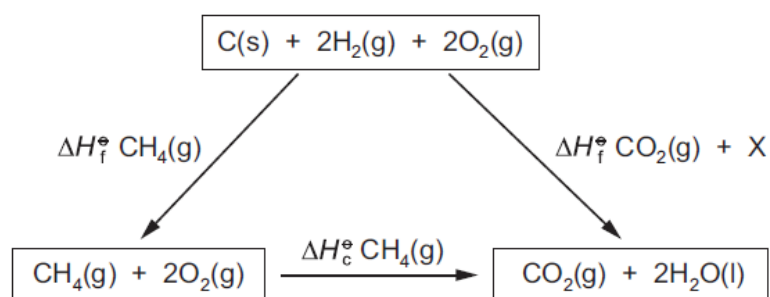


standard enthalpy change	value / kJ mol ⁻¹
$\Delta H_{\text{sol}}^\ominus \text{ CsBr}(\text{s})$	+25.9
$\Delta H_{\text{hyd}}^\ominus \text{ Cs}^+(\text{g})$	-276
$\Delta H_{\text{hyd}}^\ominus \text{ Br}^-(\text{g})$	-335

- A -636.9 B -585.1 C +585.1 D +636.9

17. June/2021/Paper_13/No.8

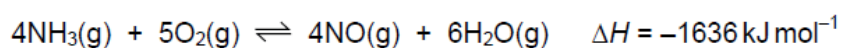
Which enthalpy change is indicated by X in the enthalpy cycle shown?



- 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

18. June/2021/Paper_13/No.11

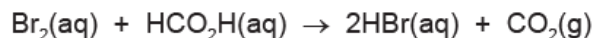
Nitric acid is produced by oxidising ammonia. The first step is to react ammonia with oxygen in the presence of a catalyst to form nitrogen monoxide.



Which set of conditions will produce the greatest yield of nitrogen monoxide at equilibrium?

	temperature	pressure
A	high	high
B	high	low
C	low	high
D	low	low

Aqueous bromine reacts with methanoic acid to form hydrogen bromide and carbon dioxide gas.



The table shows the oxidation numbers of bromine and carbon in the species involved in this reaction.

	Br in Br_2	C in HCO_2H	Br in HBr	C in CO_2
oxidation number	0	+2	-1	+4

- (a) Identify the oxidising agent in this reaction. Explain your reasoning with reference to oxidation numbers.

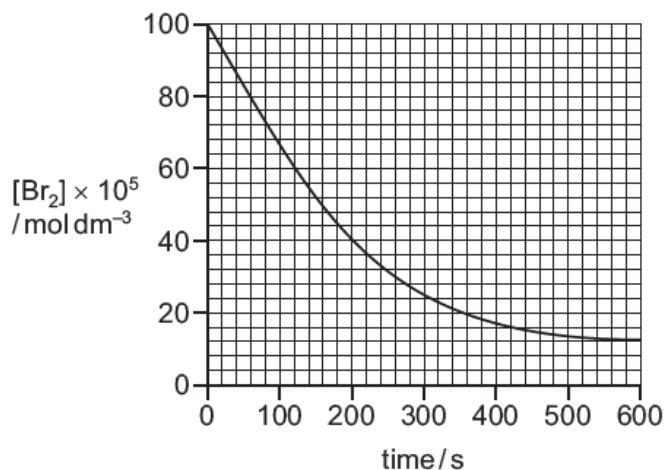
.....
 [1]

- (b) Suggest one change you would observe, ignoring temperature changes, when bromine reacts with methanoic acid.

..... [1]

- (c) This reaction can be followed by measuring the concentration of bromine present in the mixture at regular time intervals.

The graph shows the change in concentration of bromine against time in a reaction carried out at 20°C.



- (i) Use the graph to calculate the average rate of reaction at 20 °C during the first 600 s. State the units of this rate of reaction.

average rate of reaction units [2]

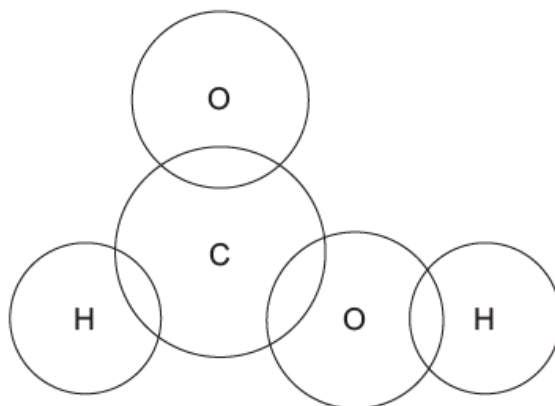
The experiment is repeated at a temperature of 40 °C. This relatively small increase in temperature produces a large increase in reaction rate.

- (ii) Sketch a graph, on the same axes, to show the expected results when repeating the experiment at 40 °C. [1]
- (iii) The rate of reaction increases when the frequency of successful collisions between reactant particles increases.

Explain why an increase in temperature produces this effect.

..... [2]

- (d) Complete the 'dot-and-cross' diagram, showing outer electrons only, to show the bonding in methanoic acid, HCO_2H .



[2]

[Total: 9]

1. June/2022/Paper_11/No.9

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

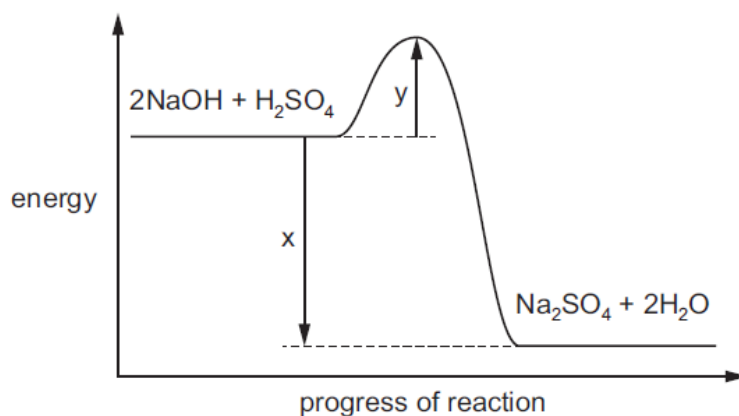


What is the correct expression to calculate Q?

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

2. June/2022/Paper_11/No.10

A reaction pathway diagram for the reaction of aqueous sodium hydroxide and dilute sulfuric acid is shown.



What is the value of the enthalpy change of neutralisation, ΔH_{neut} ?

- A** x **B** $x - y$ **C** $\frac{x}{2}$ **D** $\frac{(x - y)}{2}$

3. June/2022/Paper_12/No.9

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 $2\text{NO}_2(\text{g}) \rightarrow \text{N}_2\text{O}_4(\text{g})$?

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

4. June/2022/Paper_12/No.10

Separate samples of 25.0 cm^3 of 0.1 mol dm^{-3} $\text{NaOH}(\text{aq})$ are added to each of three different acid solutions, as described. The temperature of each of the solutions was 298 K before mixing.

sample	acid	type of acid	concentration / mol dm^{-3}	volume / cm^3
1	H_2SO_4	strong	0.05	25.0
2	HCl	strong	0.05	25.0
3	$\text{CH}_3\text{CO}_2\text{H}$	weak	0.05	25.0

Which statement describes the temperature rises that occur on mixing each of these three acids separately with NaOH ?

- A The temperature rise in all three mixtures is the same.
- B The temperature rise using H_2SO_4 and HCl is the same.
- C The temperature rise using $\text{CH}_3\text{CO}_2\text{H}$ is greater than using HCl .
- D The greatest temperature rise occurs using H_2SO_4 .

5. June/2022/Paper_13/No.9

Which equation represents an enthalpy change that is the average bond energy of the C–H bond in methane?

- A $\frac{1}{4} \text{C}(\text{g}) + \text{H}(\text{g}) \rightarrow \frac{1}{4} \text{CH}_4(\text{g})$
- B $\frac{1}{4} \text{CH}_4(\text{g}) \rightarrow \frac{1}{4} \text{C}(\text{g}) + \text{H}(\text{g})$
- C $\text{CH}_4(\text{g}) \rightarrow \text{C}(\text{g}) + 4\text{H}(\text{g})$
- D $\text{CH}_4(\text{g}) \rightarrow \text{CH}_3(\text{g}) + \text{H}(\text{g})$

6. June/2022/Paper_13/No.10

Magnesium carbonate decomposes when heated in a Bunsen burner flame.

Values for the standard enthalpies of formation, ΔH_f° , of the species involved are shown.

$$\Delta H_f^\circ \text{MgCO}_3 = -1095.8 \text{ kJ mol}^{-1}$$

$$\Delta H_f^\circ \text{MgO} = -601.7 \text{ kJ mol}^{-1}$$

$$\Delta H_f^\circ \text{CO}_2 = -393.5 \text{ kJ mol}^{-1}$$

What is the standard enthalpy change for the decomposition of magnesium carbonate?

- A +100.6 kJ mol⁻¹
- B +887.6 kJ mol⁻¹
- C +1095.8 kJ mol⁻¹
- D +2091 kJ mol⁻¹

7. June/2022/Paper_21/No.1(f)

(f) Magnesium, Mg, burns in oxygen, O₂.

The activation energy, E_a , for this reaction is +148 kJ mol⁻¹.

- (i) State **one** observation when magnesium burns in oxygen.
Do **not** refer to temperature changes in your answer.

..... [1]

(ii) On Fig. 1.1:

- sketch a reaction pathway diagram for the reaction that occurs when Mg burns in O₂
- label the diagram to show the enthalpy change, ΔH , and the activation energy, E_a , for the reaction.



Fig. 1.1

[3]

(b) When magnesium is heated in air, magnesium oxide, MgO , is the major product. Smaller amounts of magnesium nitride, Mg_3N_2 , are also made.

- (i) Calculate the oxidation number for magnesium and for the nitrogen species in Mg_3N_2 to complete Table 1.1.

Table 1.1

species	magnesium in Mg_3N_2	nitrogen in Mg_3N_2
oxidation number		

[1]

- (ii) Identify the type of reaction which takes place between magnesium and nitrogen. Explain your answer.

.....
 [1]

- (iii) Define enthalpy change of formation.

.....
 [2]

- (iv) When 3.645 g of Mg(s) burns in excess $\text{N}_2(\text{g})$ to form $\text{Mg}_3\text{N}_2(\text{s})$, 23.05 kJ of energy is released.

Calculate the enthalpy change of formation, ΔH_f , of Mg_3N_2 . Show your working.

$$\Delta H_f (\text{Mg}_3\text{N}_2) = \dots\dots\dots [3]$$

- (ii) Calculate the bond energy of $\text{C}\equiv\text{O}$ using the bond energy values in Table 3.1 and the enthalpy change, ΔH , for the thermal decomposition of **G**. Show your working.

Table 3.1

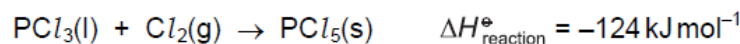
bond	bond energy / kJ mol^{-1}
C–C	350
C–O (in G)	360
C–H	410

bond energy ($\text{C}\equiv\text{O}$) = ... kJ mol^{-1}
[2]

1. Nov/2022/Paper_11/No.9

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.

2. Nov/2022/Paper_11/No.10

A student mixes 25.0 cm^3 of $0.350 \text{ mol dm}^{-3}$ sodium hydroxide solution with 25.0 cm^3 of $0.350 \text{ mol dm}^{-3}$ hydrochloric acid. The temperature increases by 2.5°C . No heat is lost to the surroundings.

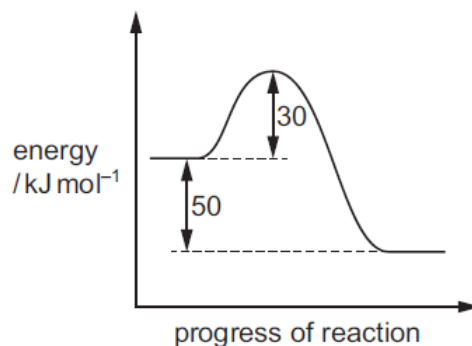
The final mixture has a specific heat capacity of $4.2 \text{ J cm}^{-3} \text{ K}^{-1}$.

What is the molar enthalpy change for the reaction?

- A -150 kJ mol^{-1}
- B -60 kJ mol^{-1}
- C -30 kJ mol^{-1}
- D $-0.15 \text{ kJ mol}^{-1}$

3. Nov/2022/Paper_12/No.9

The reaction pathway for the forward reaction of a reversible reaction is shown.

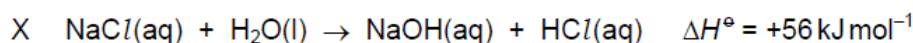
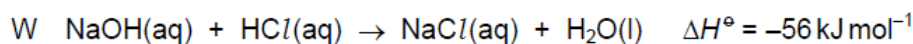


Which statement is correct?

- A The activation energy of the reverse reaction is $+80 \text{ kJ mol}^{-1}$.
- B The enthalpy change for the forward reaction is $+30 \text{ kJ mol}^{-1}$.
- C The enthalpy change for the forward reaction is $+50 \text{ kJ mol}^{-1}$.
- D The enthalpy change for the reverse reaction is $+30 \text{ kJ mol}^{-1}$.

4. Nov/2022/Paper_12/No.10

The enthalpy changes for the possible reactions W, X, Y and Z are given.



Which statement about the activation energies of these reactions is correct?

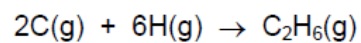
- A X is greater than W; Z is greater than Y.
- B X is greater than W; Y is greater than Z.
- C W is greater than X; Z is greater than Y.
- D W is greater than X; Y is greater than Z.

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

reaction	$\Delta H / \text{kJ mol}^{-1}$
$\text{C(s)} + 2\text{H}_2(\text{g}) \rightarrow \text{CH}_4(\text{g})$	-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

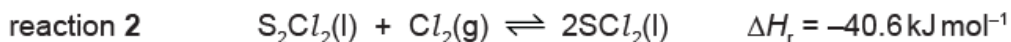
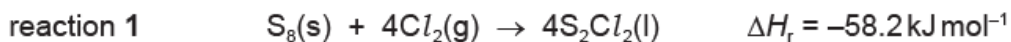
bond	bond enthalpy / kJ mol^{-1}
H-H	436
C-C	350
C=C	610
C=O	805

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}

- (d) 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.



- (i) SCl_2 is a cherry-red liquid that reacts vigorously with water to form an acidic solution.

Use this information to deduce the bonding and structure shown by SCl_2 .
Explain your answer.

.....
.....
..... [2]

- (ii) Calculate the enthalpy change of formation, ΔH_f , of $SCl_2(l)$. You may find it useful to use Hess's Law to construct an energy cycle.

enthalpy change of formation of $SCl_2(l)$, $\Delta H_f = \dots\dots\dots \text{ kJ mol}^{-1}$
[2]

- (iii) State the effect of a decrease in pressure on the position of equilibrium in reaction 2.
Explain your answer.

.....
.....
..... [1]

Fig. 3.1 shows the two structural isomers of S_2Cl_2 .

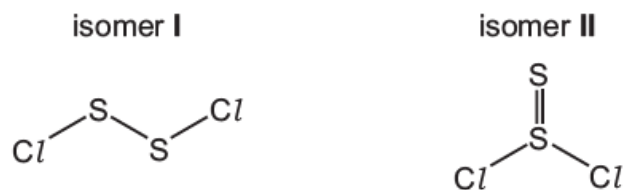


Fig. 3.1

(iv) Define the term structural isomer.

.....
..... [2]

(v) Suggest a value for the $Cl-S-S$ bond angle in isomer I. Explain your answer.

bond angle = ... °

explanation

.....

.....

..... [2]

(vi) Draw a dot-and-cross diagram to show the bonding in isomer II. Show outer shell electrons only.

[2]

1. Nov/2023/Paper_ 9701/11/No.9

Which statement about enthalpy changes is correct?

- A Enthalpy changes of reaction are always negative.
- B Enthalpy changes of combustion are always positive.
- C Enthalpy changes of formation are always positive.
- D Enthalpy changes of neutralisation are always negative.

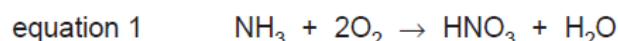
2. Nov/2023/Paper_ 9701/11/No.10

What is the definition of standard enthalpy change of neutralisation, $\Delta H_{\text{neut}}^{\ominus}$?

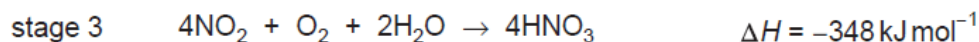
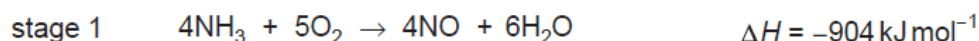
- A $\Delta H_{\text{r}}^{\ominus}$ when one mole of an aqueous acid is neutralised by an aqueous alkali
- B $\Delta H_{\text{r}}^{\ominus}$ when one mole of an aqueous alkali is neutralised by an aqueous acid
- C $\Delta H_{\text{r}}^{\ominus}$ when one mole of an aqueous acid is neutralised by one mole of an aqueous alkali
- D $\Delta H_{\text{r}}^{\ominus}$ when an aqueous acid and an aqueous alkali react together to produce one mole of water

3. Nov/2023/Paper_ 9701/12/No.11

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.



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

(e) The structure of glucose, $C_6H_{12}O_6$, is shown in Fig. 3.2.

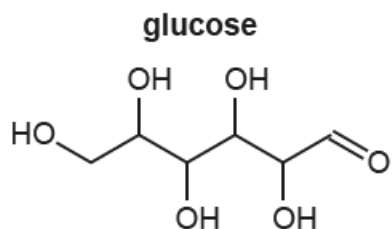


Fig. 3.2

- (i) Complete Table 3.1 to identify the number of primary, secondary and tertiary alcohol groups present in the structure shown in Fig. 3.2.

Table 3.1

type of alcohol group	primary	secondary	tertiary
number of groups			

[1]

- (ii) Separate samples of aqueous glucose are tested with the reagents shown in Table 3.2.

Complete Table 3.2 with the observation for each reaction.

Write “no reaction” if applicable.

Table 3.2

reagent and conditions	observation with glucose
acidified $KMnO_4(aq)$ and warm	
Fehling’s reagent and warm	
alkaline $I_2(aq)$ and warm	

[3]

- (iii) There are many structural isomers of $C_6H_{12}O_6$.

Define structural isomers.

.....

..... [1]

5. Nov/2023/Paper_9701/21/No.3(b)

Compounds **C** and **D** are alkenes with the same molecular formula, C_5H_{10} .



Fig. 4.1

- (b) The mass spectrum of **C** shows a molecular ion peak at $m/e = 70$. This peak has a relative intensity of 48.7.

The relative intensity of the $[M+1]$ peak is 2.7.

Show that this information is consistent with the molecular formula of **C**.

[2]

Phosphoric(V) acid, H_3PO_4 , is used in both inorganic and organic reactions.

(b) H_3PO_4 is also formed in the process shown in reaction 1.

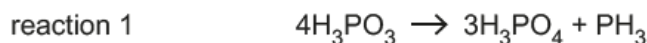


Table 3.1 shows some relevant thermodynamic data.

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.

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

(iii) Explain why reaction 1 is a disproportionation reaction.

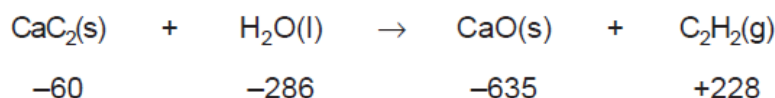
Explain your reasoning with reference to relevant oxidation numbers.

.....

 [2]

7. June/2023/Paper_9701/11/No.5

Calcium carbide, CaC_2 , reacts with water, as shown. The data below the equation show, 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 $+753 \text{ kJ mol}^{-1}$

8. June/2023/Paper_9701/12/No.9

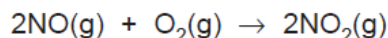
A student mixed 25.0 cm^3 of 4.00 mol dm^{-3} hydrochloric acid with an equal volume of 4.00 mol dm^{-3} sodium hydroxide. The initial temperature of both solutions was 15.0°C . The maximum temperature recorded was 30.0°C . The heat capacity of the final solution can be assumed to be $4.18 \text{ J K}^{-1} \text{ g}^{-1}$ and the density of this solution can be assumed to be 1.00 g cm^{-3} .

Using these results, what is the enthalpy change of neutralisation of hydrochloric acid?

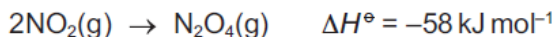
- A $-62.7 \text{ kJ mol}^{-1}$
- B $-31.4 \text{ kJ mol}^{-1}$
- C $-15.7 \text{ kJ mol}^{-1}$
- D $-3.14 \text{ kJ mol}^{-1}$

9. June/2023/Paper_9701/12/No.10

Nitrogen monoxide is rapidly oxidised to nitrogen dioxide.

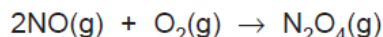


Nitrogen dioxide can then dimerise to form dinitrogen tetroxide.



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

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}

10. June/2023/Paper_9701/13/No.10

Which equation represents the reaction whose standard enthalpy change is the standard enthalpy change of formation of water?

- A $2\text{H}_2(\text{g}) + \text{O}_2(\text{g}) \rightarrow 2\text{H}_2\text{O}(\text{l})$
B $\text{H}_2(\text{g}) + \frac{1}{2}\text{O}_2(\text{g}) \rightarrow \text{H}_2\text{O}(\text{l})$
C $\text{H}^+(\text{aq}) + \text{OH}^-(\text{aq}) \rightarrow \text{H}_2\text{O}(\text{l})$
D $2\text{H}(\text{g}) + \text{O}(\text{g}) \rightarrow \text{H}_2\text{O}(\text{l})$

11. June/2023/Paper_9701/13/No.12

The enthalpy change for neutralisation of $\text{HNO}_3(\text{aq})$ with $\text{NaOH}(\text{aq})$ is $-57.0 \text{ kJ mol}^{-1}$.

In an experiment, 20.0 cm^3 of 4.00 mol dm^{-3} HNO_3 is mixed with 30.0 cm^3 of 2.00 mol dm^{-3} NaOH in an insulated container. The initial temperature of both solutions is 25.0°C .

It can be assumed that the heat capacity of the product mixture is $4.2 \text{ J cm}^{-3}^\circ\text{C}^{-1}$ and that there are no heat losses.

What is the maximum final temperature of the mixture?

- A 41.3°C B 44.0°C C 46.7°C D 52.1°C

Some bond energies are listed.

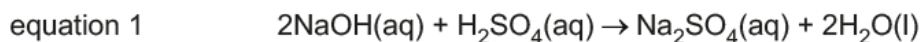
bond	bond energy / kJ mol^{-1}
H-H	436
O-H	463
O-O	146
O=O	496

One mole of hydrogen reacts with oxygen to give water vapour.

Using the bond energy data, what is the value for the enthalpy change of this reaction?

- A +221 kJ mol^{-1}
- B +6 kJ mol^{-1}
- C -242 kJ mol^{-1}
- D -417 kJ mol^{-1}

A neutralisation reaction occurs when NaOH(aq) is added to $\text{H}_2\text{SO}_4\text{(aq)}$.



(a) Define enthalpy change of neutralisation, ΔH_{neut} .

.....

 [2]

(b) An experiment is carried out to calculate ΔH_{neut} for the reaction between NaOH(aq) and $\text{H}_2\text{SO}_4\text{(aq)}$.

100cm^3 of 1.00mol dm^{-3} NaOH(aq) is added to 75cm^3 of 1.00mol dm^{-3} $\text{H}_2\text{SO}_4\text{(aq)}$ in a polystyrene cup and stirred. Results from the experiment are shown in Table 2.1.

Table 2.1

initial temperature of NaOH(aq) / $^{\circ}\text{C}$	20.0
initial temperature of $\text{H}_2\text{SO}_4\text{(aq)}$ / $^{\circ}\text{C}$	20.0
maximum temperature of mixture / $^{\circ}\text{C}$	27.8

(i) Use equation 1 to calculate the amount, in mol, of $\text{H}_2\text{SO}_4\text{(aq)}$ that is neutralised in the experiment.

amount of $\text{H}_2\text{SO}_4\text{(aq)}$ neutralised = ... mol [1]

(ii) Calculate ΔH_{neut} using the results in Table 2.1. Include units in your answer.

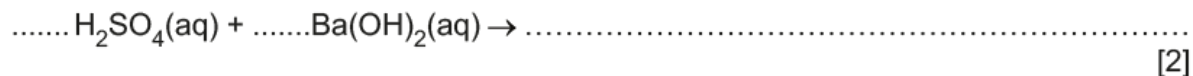
Assume that:

- the specific heat capacity of the final solution is $4.18\text{J g}^{-1}\text{K}^{-1}$
- 1.00cm^3 of the final solution has a mass of 1.00g
- there is no heat loss to the surroundings
- full dissociation of $\text{H}_2\text{SO}_4\text{(aq)}$ occurs
- the experiment takes place at constant pressure.

Show your working.

$\Delta H_{\text{neut}} = \dots\dots\dots$ units [3]

- (c) (i) Complete the equation for the reaction that occurs when a solution of $\text{Ba}(\text{OH})_2$ is added to aqueous sulfuric acid. Include state symbols.

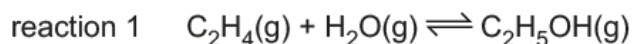


- (ii) Suggest why the enthalpy change of neutralisation cannot be determined using the addition of dilute sulfuric acid to aqueous barium hydroxide.

.....
..... [1]

[Total: 9]

In industry, ethanol is made by reacting ethene with steam in the presence of H_3PO_4 .



- (a) Use the bond energy values in Table 4.1 to calculate the enthalpy change, ΔH_r , for reaction 1.

Table 4.1

bond	bond energy / kJ mol^{-1}
C—C	350
C=C	610
C≡C	840
C—H	410
C—O	360
C=O	740
O—H	460

$$\Delta H_r = \dots\dots\dots \text{kJ mol}^{-1} \quad [2]$$

- (b) Reaction 1 reaches equilibrium at constant temperature and pressure.

Deduce what effect increasing the pressure will have on the amount of ethanol in the new equilibrium mixture. Use Le Chatelier's principle to explain your answer.

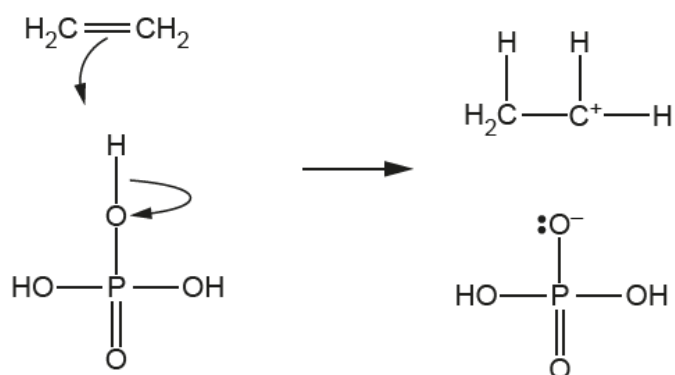
effect of increasing pressure

explanation

..... [2]

- (c) The mechanism for reaction 1 can be described in three steps. Steps 1 and 2 for reaction 1 are shown in Fig. 4.1.

step 1



step 2

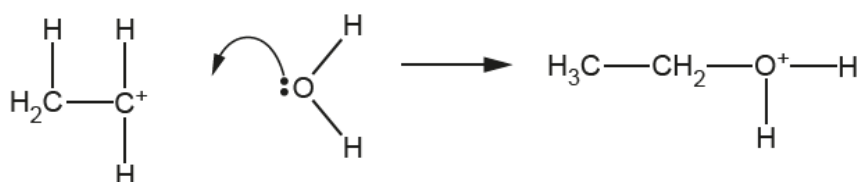


Fig. 4.1

- (i) Describe the behaviour of H_3PO_4 in step 1 in Fig. 4.1. Explain your answer.

.....
 [1]

- (ii) Identify the species that behaves as an electrophile in step 2 in Fig. 4.1. Explain your answer.

.....
 [1]

- (iii) Complete Fig. 4.2 to show the mechanism for step 3 of reaction 1. Include charges, dipoles, lone pairs of electrons and curly arrows, as appropriate.

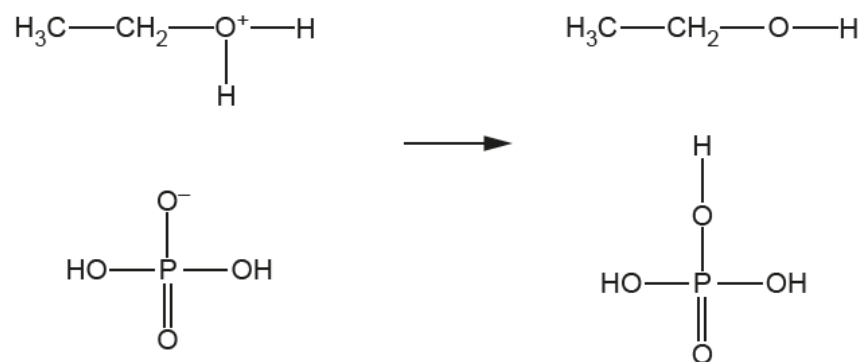


Fig. 4.2

[2]

- (iv) Describe how a catalyst affects a reaction. Explain your answer.

.....
 [2]

- (v) Use Fig. 4.1 and Fig. 4.2 to justify why H_3PO_4 is described as a catalyst in reaction 1.

.....
 [1]

- (vi) Propene also reacts with steam. A mixture of organic products is produced.

Explain why propan-2-ol is produced in the higher yield.

.....

 [2]

- (d) Describe the covalent bonds present between the carbon atoms in an ethene molecule by completing Table 4.2.

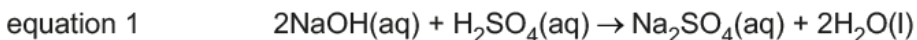
Table 4.2

	sigma (σ)	pi (π)
type of orbitals involved in bond		
how the orbitals overlap		

[2]

[Total: 15]

A neutralisation reaction occurs when NaOH(aq) is added to H₂SO₄(aq).



(a) Define enthalpy change of neutralisation, ΔH_{neut} .

.....

 [2]

(b) In an experiment, 50.0 cm³ of 2.00 mol dm⁻³ NaOH(aq) is added to 60.0 cm³ of 1.00 mol dm⁻³ H₂SO₄(aq) in a polystyrene cup and stirred. Both solutions have a temperature of 21.4 °C before mixing. The maximum temperature of the mixture is measured.

(i) Use equation 1 to calculate the amount, in mol, of H₂SO₄(aq) that is neutralised in the experiment.

amount of H₂SO₄ neutralised = ... mol [1]

(ii) Calculate the theoretical maximum temperature of the mixture in this experiment.

Assume that:

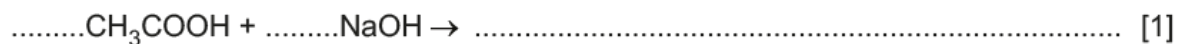
- enthalpy change of neutralisation, ΔH_{neut} , of NaOH(aq) and H₂SO₄(aq) is -57.1 kJ mol⁻¹
- full dissociation of H₂SO₄(aq) occurs
- the specific heat capacity of the final solution is 4.18 J g⁻¹ K⁻¹
- 1.00 cm³ of the final solution has a mass of 1.00 g
- there is no heat loss to the surroundings
- the experiment takes place at constant pressure.

Show your working.

theoretical maximum temperature = ... °C [3]

(c) The enthalpy change of neutralisation of $\text{CH}_3\text{COOH}(\text{aq})$ and $\text{NaOH}(\text{aq})$ is $-55.2 \text{ kJ mol}^{-1}$.

(i) Complete the equation for the reaction.



(ii) Values for the enthalpy change of neutralisation, ΔH_{neut} , are shown in Table 3.1.

Table 3.1

reagents	$\Delta H_{\text{neut}}/\text{kJ mol}^{-1}$
$\text{NaOH} + \text{HCl}$	-57.1
$\text{NaOH} + \text{CH}_3\text{COOH}$	-55.2

Suggest why the value for ΔH_{neut} of the weak acid, CH_3COOH , reacting with NaOH is different to the value obtained using the strong acid, HCl . Assume that the values are determined under the same conditions.

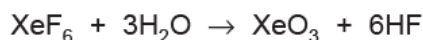
.....

..... [1]

[Total: 8]

16. March/2023/Paper_9701/12/No.10

The equation for a chemical reaction is shown. All substances are in their standard states.



Which statement describes the standard enthalpy change of reaction for this reaction?

- A the enthalpy change when a total of one mole of products is produced
- B the enthalpy change when a total of one mole of reactants is reacted
- C the enthalpy change when one mole of water reacts
- D the enthalpy change when six moles of hydrogen fluoride are produced

17. March/2023/Paper_9701/12/No.16

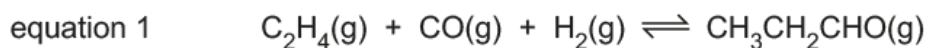
The table shows bond energies for some diatomic molecules. Deuterium, D, is an isotope of hydrogen.

bond	energy / kJ mol^{-1}
F–F	158
Cl–Cl	242
Br–Br	193
I–I	151
H–H	436
D–D	442

Which statements are correct?

- 1 Diatomic molecules have exact values for their bond energies, which are always positive.
 - 2 The trend in Group 7 bond energies can be explained by the variation in instantaneous dipole–induced dipole (id–id) forces.
 - 3 A value for the enthalpy change for the reaction between deuterium and chlorine can be calculated using these data alone.
- A 1 only B 1 and 2 only C 1 and 3 only D 2 and 3 only

- (d) The reaction of ethene, C_2H_4 , with a 1:1 mixture of CO and H_2 is shown in equation 1.



At atmospheric pressure a cobalt-based catalyst is used in this reaction.

- (i) State and explain the effect of using a catalyst on this reaction.

.....

.....

.....

..... [2]

- (ii) Explain why the yield of $\text{CH}_3\text{CH}_2\text{CHO}(\text{g})$ increases when the overall pressure of the reaction mixture is increased.

.....
 [1]

- (iii) Use the information in Table 3.2 to calculate the enthalpy change, ΔH_r , of the reaction in equation 1.

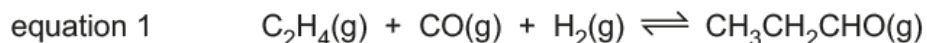


Table 3.2

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

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

- (iv) The reaction mixture is cooled to collect $\text{CH}_3\text{CH}_2\text{CHO}$ as a liquid.

Identify all types of van der Waals' forces that are present between molecules of $\text{CH}_3\text{CH}_2\text{CHO}$.

.....
 [1]