Formation and Combustion

A Level

For which of the following reactions does the value of $\Delta H^{\ominus}$ represent **both** a standard enthalpy change of combustion and a standard enthalpy change of formation?

1. $\mathrm{C(s) + O_2(g) \longrightarrow CO_2(g)}$
2. $\mathrm{2\,C(s) + O_2(g) \longrightarrow 2\,CO(g)}$
3. $\mathrm{CO(g) + \frac{1}{2}\,O_2(g) \longrightarrow CO_2(g)}$

- None of the above
- **1** only
- **2** only
- **3** only
- **1** and **2** only
- **1** and **3** only
- **2** and **3** only
- All of the above

Adapted with permission from UCLES, A Level Chemistry, June 1994, Paper 4, Question 31

Formation and Combustion Enthalpies 1

A Level

Essential Pre-Uni Chemistry F3.1

Data (all in $\mathrm{kJ\,mol^{-1}}$):

	$\Delta_f H^{\ominus}$		$\Delta_c H^{\ominus}$
$\mathrm{CH_4\,(g)}$	-74.8	$\mathrm{C_6H_6\,(l)}$	-3267.4
$\mathrm{CCl_4\,(l)}$	-129.6	$\mathrm{H_2\,(g)}$	-285.8
$\mathrm{HCl\,(g)}$	-92.3	$\mathrm{C_6H_{12}\,(l)}$	-3919.5
$\mathrm{TiCl_4\,(l)}$	-804.2	$\mathrm{C_2H_2\,(g)}$	-1300.8
$\mathrm{TiCl_3\,(s)}$	-720.9	$\mathrm{C_2H_6\,(g)}$	-1559.7
$\mathrm{PCl_3\,(l)}$	-319.7	$\mathrm{C_2H_5OH\,(l)}$	-1367.3
$\mathrm{PCl_5\,(s)}$	-443.5	$\mathrm{C_2H_4\,(g)}$	-1410.8
$\mathrm{POCl_3\,(l)}$	-597.1	$\mathrm{CH_3COOH\,(l)}$	-874.1
$\mathrm{GeO\,(s)}$	-212.1	$\mathrm{C_6H_{14}\,(l)}$	-4163.0
$\mathrm{GeO_2\,(s)}$	-551.0	$\mathrm{CH_3COOC_2H_5\,(l)}$	-2237.9
$\mathrm{NH_3\,(g)}$	-46.1	$\mathrm{CO\,(g)}$	-283.0
$\mathrm{TiO_2\,(s)}$	-939.7	$\mathrm{Mg\,(s)}$	-601.7

Use standard enthalpies of formation to calculate the reaction enthalpies for the following reactions. Unless stated otherwise in the question part, give your answers to 1 decimal place.

Part A **(a)**

$$2\,\mathrm{TiCl_3\,(s)} + \mathrm{Cl_2\,(g)} \longrightarrow 2\,\mathrm{TiCl_4\,(l)}$$

Part B **(b)**

$$\mathrm{PCl_3\,(l) + Cl_2\,(g) \longrightarrow PCl_5\,(s)}$$

Part C **(c)**

$$\mathrm{2\,PCl_3\,(l) + O_2\,(g) \longrightarrow 2\,POCl_3\,(l)}$$

Part D **(d)**

$$\mathrm{CH_4\,(g) + 4\,Cl_2\,(g) \longrightarrow CCl_4\,(l) + 4\,HCl\,(g)}$$

Part E **(e)**

$$\mathrm{2\,GeO\,(s) \longrightarrow Ge\,(s) + GeO_2\,(s)}$$

Part F **(f)**

$$\mathrm{GeO\,(s) + PCl_3\,(l) \longrightarrow Ge\,(s) + POCl_3\,(l).}$$

Part G (g)

$$\mathrm{PCl_5\,(s) + 2\,TiCl_3\,(s) \longrightarrow PCl_3\,(l) + 2\,TiCl_4\,(l)}$$

Part H (h)

$\mathrm{20\,Ti\,(s) + 12\,PCl_5\,(s) \longrightarrow 20\,TiCl_3\,(s) + 3\,P_4\,(s)}$ Give your answer to 5 significant figures.

Gameboard:

STEM SMART Chemistry Week 13

Formation and Combustion Enthalpies 2

A Level

P P P

Essential Pre-Uni Chemistry F3.2

Data (all in $\mathrm{kJ\,mol^{-1}}$):

	$\Delta_f H^{\ominus}$		$\Delta_c H^{\ominus}$
$\mathrm{CH_4\,(g)}$	-74.8	$\mathrm{C_6H_6\,(l)}$	-3267.4
$\mathrm{CCl_4\,(l)}$	-129.6	$\mathrm{H_2\,(g)}$	-285.8
$\mathrm{HCl\,(g)}$	-92.3	$\mathrm{C_6H_{12}\,(l)}$	-3919.5
$\mathrm{TiCl_4\,(l)}$	-804.2	$\mathrm{C_2H_2\,(g)}$	-1300.8
$\mathrm{TiCl_3\,(s)}$	-720.9	$\mathrm{C_2H_6\,(g)}$	-1559.7
$\mathrm{PCl_3\,(l)}$	-319.7	$\mathrm{C_2H_5OH\,(l)}$	-1367.3
$\mathrm{PCl_5\,(s)}$	-443.5	$\mathrm{C_2H_4\,(g)}$	-1410.8
$\mathrm{POCl_3\,(l)}$	-597.1	$\mathrm{CH_3COOH\,(l)}$	-874.1
$\mathrm{GeO\,(s)}$	-212.1	$\mathrm{C_6H_{14}\,(l)}$	-4163.0
$\mathrm{GeO_2\,(s)}$	-551.0	$\mathrm{CH_3COOC_2H_5\,(l)}$	-2237.9
$\mathrm{NH_3\,(g)}$	-46.1	$\mathrm{CO\,(g)}$	-283.0
$\mathrm{TiO_2\,(s)}$	-939.7	$\mathrm{Mg\,(s)}$	-601.7

Use standard enthalpies of combustion to calculate the reaction enthalpies for the following reactions:

Part A **(a)**

$$\mathrm{C_2H_2\,(g) + 2\,H_2\,(g) \longrightarrow C_2H_6\,(g)}$$

Part B **(b)**

$$\mathrm{C_6H_6\,(l) + 3\,H_2\,(g) \longrightarrow C_6H_{12}\,(l)}$$

Part C **(c)**

$$\mathrm{3\,C_2H_2\,(g) \longrightarrow C_6H_6\,(l)}$$

Part D **(d)**

$\mathrm{C_2H_4\,(g) + H_2O\,(l) \longrightarrow C_2H_5OH\,(l)}$ Give your answer to 3 significant figures.

Part E **(e)**

$$\mathrm{C_2H_5OH\,(l) + O_2\,(g) \longrightarrow CH_3COOH\,(l) + H_2O\,(l)}$$

Part F **(f)**

$$\mathrm{C_6H_{14}\,(l) \longrightarrow C_2H_6\,(g) + 2\,C_2H_4\,(g)}$$

Part G (g)

$$C_2H_5OH\,(l) + CH_3COOH\,(l) \longrightarrow CH_3COOC_2H_5\,(l) + H_2O\,(l)$$

Give your answer to 2 significant figures.

Part H (h)

$$2\,C_2H_2\,(g) + 2\,H_2O\,(l) + O_2\,(g) \longrightarrow 2\,CH_3COOH\,(l)$$

Gameboard:

STEM SMART Chemistry Week 13

Formation and Combustion Enthalpies 3

A Level

Essential Pre-Uni Chemistry F3.3

Data (all in $\mathrm{kJ\,mol^{-1}}$):

	$\Delta_f H^{\ominus}$		$\Delta_c H^{\ominus}$
$\mathrm{CH_4\,(g)}$	-74.8	$\mathrm{C_6H_6\,(l)}$	-3267.4
$\mathrm{CCl_4\,(l)}$	-129.6	$\mathrm{H_2\,(g)}$	-285.8
$\mathrm{HCl\,(g)}$	-92.3	$\mathrm{C_6H_{12}\,(l)}$	-3919.5
$\mathrm{TiCl_4\,(l)}$	-804.2	$\mathrm{C_2H_2\,(g)}$	-1300.8
$\mathrm{TiCl_3\,(s)}$	-720.9	$\mathrm{C_2H_6\,(g)}$	-1559.7
$\mathrm{PCl_3\,(l)}$	-319.7	$\mathrm{C_2H_5OH\,(l)}$	-1367.3
$\mathrm{PCl_5\,(s)}$	-443.5	$\mathrm{C_2H_4\,(g)}$	-1410.8
$\mathrm{POCl_3\,(l)}$	-597.1	$\mathrm{CH_3COOH\,(l)}$	-874.1
$\mathrm{GeO\,(s)}$	-212.1	$\mathrm{C_6H_{14}\,(l)}$	-4163.0
$\mathrm{GeO_2\,(s)}$	-551.0	$\mathrm{CH_3COOC_2H_5\,(l)}$	-2237.9
$\mathrm{NH_3\,(g)}$	-46.1	$\mathrm{CO\,(g)}$	-283.0
$\mathrm{TiO_2\,(s)}$	-939.7	$\mathrm{Mg\,(s)}$	-601.7

Use enthalpies of formation and combustion to calculate the reaction enthalpy for the reaction:
$\mathrm{Ge\,(s) + 2\,H_2O\,(l) \longrightarrow GeO_2\,(s) + 2\,H_2\,(g)}$ Give your answer to 3 significant figures.

Gameboard:
STEM SMART Chemistry Week 13

Formation and Combustion Enthalpies 4

A Level

Essential Pre-Uni Chemistry F3.4

Data (all in $\mathrm{kJ\,mol^{-1}}$):

	$\Delta_f H^\ominus$		$\Delta_c H^\ominus$
$\mathrm{CH_4\,(g)}$	-74.8	$\mathrm{C_6H_6\,(l)}$	-3267.4
$\mathrm{CCl_4\,(l)}$	-129.6	$\mathrm{H_2\,(g)}$	-285.8
$\mathrm{HCl\,(g)}$	-92.3	$\mathrm{C_6H_{12}\,(l)}$	-3919.5
$\mathrm{TiCl_4\,(l)}$	-804.2	$\mathrm{C_2H_2\,(g)}$	-1300.8
$\mathrm{TiCl_3\,(s)}$	-720.9	$\mathrm{C_2H_6\,(g)}$	-1559.7
$\mathrm{PCl_3\,(l)}$	-319.7	$\mathrm{C_2H_5OH\,(l)}$	-1367.3
$\mathrm{PCl_5\,(s)}$	-443.5	$\mathrm{C_2H_4\,(g)}$	-1410.8
$\mathrm{POCl_3\,(l)}$	-597.1	$\mathrm{CH_3COOH\,(l)}$	-874.1
$\mathrm{GeO\,(s)}$	-212.1	$\mathrm{C_6H_{14}\,(l)}$	-4163.0
$\mathrm{GeO_2\,(s)}$	-551.0	$\mathrm{CH_3COOC_2H_5\,(l)}$	-2237.9
$\mathrm{NH_3\,(g)}$	-46.1	$\mathrm{CO\,(g)}$	-283.0
$\mathrm{TiO_2\,(s)}$	-939.7	$\mathrm{Mg\,(s)}$	-601.7

Use the reaction enthalpies given, and the combustion or formation enthalpies above to find the requested enthalpy change in each case:

Part A $\mathrm{NH_4Cl\,(s)}$

$\mathrm{NH_3\,(g) + HCl\,(g) \longrightarrow NH_4Cl\,(s)}$, $\Delta_r H^\ominus = -176\,\mathrm{kJ\,mol^{-1}}$ find $\Delta_f H^\ominus$ of $\mathrm{NH_4Cl\,(s)}$

Part B $\mathrm{MgCl_2\,(s)}$

$\mathrm{TiCl_4\,(l) + 2\,Mg\,(s) \longrightarrow 2\,MgCl_2\,(s) + Ti\,(s)}$ $\Delta_\mathrm{r}H^\ominus = -478.4\,\mathrm{kJ\,mol^{-1}}$, find $\Delta_\mathrm{f}H^\ominus$ of $\mathrm{MgCl_2\,(s)}$

Part C $\mathrm{CH_3COOCOCH_3\,(l)}$

$\mathrm{CH_3COOCOCH_3\,(l) + H_2O\,(l) \longrightarrow 2\,CH_3COOH\,(l)}$ $\Delta_\mathrm{r}H^\ominus = -46\,\mathrm{kJ\,mol^{-1}}$, find $\Delta_\mathrm{c}H^\ominus$ of $\mathrm{CH_3COOCOCH_3\,(l)}$ Give your answer to 4 significant figures.

Part D $\mathrm{C_6H_5CHCH_2}$

$\mathrm{4\,C_2H_2\,(g) \longrightarrow C_6H_5CHCH_2\,(l)}$, $\Delta_\mathrm{r}H^\ominus = -808.2\,\mathrm{kJ\,mol^{-1}}$, find $\Delta_\mathrm{c}H^\ominus$ of $\mathrm{C_6H_5CHCH_2}$ Give your answer to 4 significant figures.

Part E $\mathrm{Al_2O_3\,(s)}$

$\mathrm{4\,Al\,(s) + 3\,GeO_2\,(s) \longrightarrow 2\,Al_2O_3\,(s) + 3\,Ge\,(s)}$ $\Delta_\mathrm{r}H^\ominus = -1698.4\,\mathrm{kJ\,mol^{-1}}$, find $\Delta_\mathrm{f}H^\ominus$ of $\mathrm{Al_2O_3\,(s)}$ Give your answer to 4 significant figures.

Part F $\mathrm{Fe_2O_3}$

$\mathrm{Fe_2O_3\,(s) + 3\,CO\,(g) \longrightarrow 2\,Fe\,(s) + 3\,CO_2\,(g)}$, $\Delta_\mathrm{r}H^\ominus = -24.8\,\mathrm{kJ\,mol^{-1}}$, find $\Delta_\mathrm{f}H^\ominus$ of $\mathrm{Fe_2O_3}$

Part G $\mathrm{CuO(s)}$

$\mathrm{3\,CuO\,(s) + 2\,NH_3\,(g) \longrightarrow 3\,Cu\,(s) + N_2\,(g) + 3\,H_2O\,(l)}$, $\Delta_r H^\ominus = -293.3\,\mathrm{kJ\,mol^{-1}}$, find $\Delta_f H^\ominus$ of $\mathrm{CuO\,(s)}$ Give your answer to 3 significant figures.

Part H $\mathrm{H_3PO_4\,(s)}$

$\mathrm{2\,PCl_5\,(s) + 8\,H_2O\,(l) \longrightarrow 2\,H_3PO_4\,(s) + 10\,HCl\,(g)}$, $\Delta_r H^\ominus = -307.6\,\mathrm{kJ\,mol^{-1}}$, find $\Delta_f H^\ominus$ of $\mathrm{H_3PO_4\,(s)}$ Give your answer to 3 significant figures.

Part I Ga

$\mathrm{Ga_2O_3\,(s) + 3\,Mg\,(s) \longrightarrow 2\,Ga\,(s) + 3\,MgO\,(s)}$, $\Delta_r H^\ominus = -716.1\,\mathrm{kJ\,mol^{-1}}$, find $\Delta_c H^\ominus$ of Ga.

Part J $\mathrm{HCl\,(g)}$

$\mathrm{TiCl_4\,(l) + 2\,H_2O\,(l) \longrightarrow TiO_2\,(s) + 4\,HCl\,(aq)}$, $\Delta_r H^\ominus = -232.3\,\mathrm{kJ\,mol^{-1}}$, find $\Delta_{sol} H^\ominus$ of $\mathrm{HCl\,(g)}$ Give your answer to 3 significant figures.

Gameboard:

STEM SMART Chemistry Week 13

Reducing Carbon Dioxide

A Level

The standard enthalpy changes of formation of carbon monoxide and carbon dioxide are $-110\,\mathrm{kJ\,mol^{-1}}$ and $-393\,\mathrm{kJ\,mol^{-1}}$, respectively.

Part A Carbon monoxide formation

Write an equation, including state symbols, for the first of these enthalpy changes (formation of carbon monoxide).

Part B Carbon dioxide formation

Write an equation, including state symbols, for the second of these enthalpy changes (formation of carbon dioxide).

Part C Standard enthalpy change

Use the two standard enthalpy of formation values to calculate, in $\mathrm{kJ\,mol^{-1}}$, the standard enthalpy change of the reaction

$$\mathrm{C + CO_2 \longrightarrow 2\,CO}$$

Part D Condition

In light of the result obtained in the previous part, suggest what condition is necessary to obtain a reasonable yield of carbon monoxide by this reaction.

- Low temperature
- High temperature
- Low pressure
- Presence of O_2

Adapted with permission from UCLES, A Level Chemistry, June 1990, Paper 2, Question 1

Gameboard:
STEM SMART Chemistry Week 13

C_3H_6 Combustion

A Level

A and **B** are two isomers with the molecular formula C_3H_6. The standard enthalpies of formation, $\Delta_f H^\ominus$, of both **A** and **B** have been found by first measuring the standard enthalpies of combustion, $\Delta_c H^\ominus$, of each. These values are given in the table below, together with the standard enthalpies of combustion of carbon and hydrogen.

	A	**B**	**carbon**	**hydrogen**
$\Delta_c H^\ominus / \mathrm{kJ\,mol^{-1}}$	-2058	-2091	-393.5	-241.8

Part A Combustion equation

Give the equation for the complete combustion of C_3H_6. (Balance it for one mole of the hydrocarbon.)

Part B $\Delta_f H^\ominus$ of A

Calculate the standard enthalpy of formation of **A**.

Part C $\Delta_f H^\ominus$ of B

Calculate the standard enthalpy of formation of **B**.

Part D Isomerisation

Gaseous **B** needs to be stored carefully since it can convert explosively to the elements, to isomer **A**, or to other hydrocarbons. Calculate the standard enthalpy change for the reaction **B** $\longrightarrow$ **A**.

Adapted with permission from the Cambridge Chemistry Challenge 2011, Question 1

Gameboard:
STEM SMART Chemistry Week 13

Ethene Combustion

A Level

C C C

The standard enthalpy change of combustion of but-1-ene, $\mathrm{C_4H_8\,(g)}$, is $x\,\mathrm{kJ\,mol^{-1}}$.

The standard enthalpy change of the reaction $2\,\mathrm{C_2H_4\,(g)} \longrightarrow \mathrm{C_4H_8\,(g)}$ is $y\,\mathrm{kJ\,mol^{-1}}$.

Write down an expression, in terms of x and y, for the standard enthalpy change of combustion of ethene, $\mathrm{C_2H_4\,(g)}$ when expressed in $\mathrm{kJ\,mol^{-1}}$ (your answer should not feature any units).

The following symbols may be useful: `x, y`

Adapted with permission from UCLES, A Level Chemistry, November 1993, Paper 4, Question 8

Gameboard:

STEM SMART Chemistry Week 13

Dinitrogen Pentoxide Formation

A Level

In the gas phase, $\mathrm{N_2O_5}$ decomposes to oxygen and nitrogen dioxide. Use the data below (determined at $298\,\mathrm{K}$) to calculate the standard enthalpy change at $298\,\mathrm{K}$ for the reaction:

$$2\,\mathrm{N_2O_5\,(g)} \longrightarrow 4\,\mathrm{NO_2\,(g)} + \mathrm{O_2\,(g)}$$

	value/$\mathrm{kJ\,mol^{-1}}$
$\Delta_\mathrm{f}H^\ominus$ of $\mathrm{N_2O_5\,(g)}$	11.3
$\Delta_\mathrm{r}H^\ominus$ for $\mathrm{NO\,(g)} + \frac{1}{2}\,\mathrm{O_2\,(g)} \longrightarrow \mathrm{NO_2\,(g)}$	−58.1
bond strength in $\mathrm{N_2\,(g)}$	945
bond strength in $\mathrm{O_2\,(g)}$	498
bond strength in $\mathrm{NO\,(g)}$	631

Adapted with permission from the Cambridge Chemistry Challenge, Question 1, 2019