

Formation and Combustion

A Level

For which of the following reactions does the value of ΔH^\ominus represent **both** a standard enthalpy change of combustion and a standard enthalpy change of formation?

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

☐ 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

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Formation and Combustion Enthalpies 1



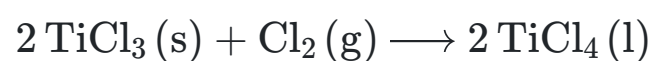
Essential Pre-Uni Chemistry F3.1

Data (all in kJ mol^{-1}):

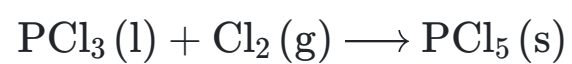
	$\Delta_f H^\ominus$		$\Delta_c H^\ominus$
$\text{CH}_4(\text{g})$	−74.8	$\text{C}_6\text{H}_6(\text{l})$	−3267.4
$\text{CCl}_4(\text{l})$	−129.6	$\text{H}_2(\text{g})$	−285.8
$\text{HCl}(\text{g})$	−92.3	$\text{C}_6\text{H}_{12}(\text{l})$	−3919.5
$\text{TiCl}_4(\text{l})$	−804.2	$\text{C}_2\text{H}_2(\text{g})$	−1300.8
$\text{TiCl}_3(\text{s})$	−720.9	$\text{C}_2\text{H}_6(\text{g})$	−1559.7
$\text{PCl}_3(\text{l})$	−319.7	$\text{C}_2\text{H}_5\text{OH}(\text{l})$	−1367.3
$\text{PCl}_5(\text{s})$	−443.5	$\text{C}_2\text{H}_4(\text{g})$	−1410.8
$\text{POCl}_3(\text{l})$	−597.1	$\text{CH}_3\text{COOH}(\text{l})$	−874.1
$\text{GeO}(\text{s})$	−212.1	$\text{C}_6\text{H}_{14}(\text{l})$	−4163.0
$\text{GeO}_2(\text{s})$	−551.0	$\text{CH}_3\text{COOC}_2\text{H}_5(\text{l})$	−2237.9
$\text{NH}_3(\text{g})$	−46.1	$\text{CO}(\text{g})$	−283.0
$\text{TiO}_2(\text{s})$	−939.7	$\text{Mg}(\text{s})$	−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)



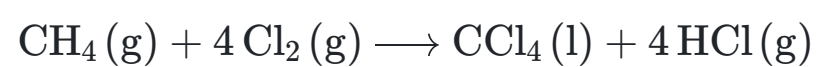
Part B (b)



Part C (c)



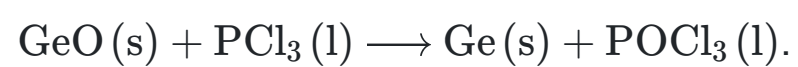
Part D (d)



Part E (e)



Part F (f)



Part G (g)



Part H (h)



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Formation and Combustion Enthalpies 2



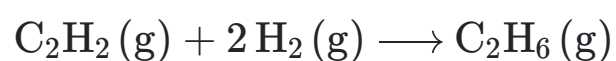
Essential Pre-Uni Chemistry F3.2

Data (all in kJ mol^{-1}):

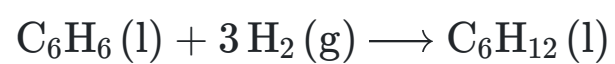
	$\Delta_f H^\ominus$		$\Delta_c H^\ominus$
$\text{CH}_4(\text{g})$	−74.8	$\text{C}_6\text{H}_6(\text{l})$	−3267.4
$\text{CCl}_4(\text{l})$	−129.6	$\text{H}_2(\text{g})$	−285.8
$\text{HCl}(\text{g})$	−92.3	$\text{C}_6\text{H}_{12}(\text{l})$	−3919.5
$\text{TiCl}_4(\text{l})$	−804.2	$\text{C}_2\text{H}_2(\text{g})$	−1300.8
$\text{TiCl}_3(\text{s})$	−720.9	$\text{C}_2\text{H}_6(\text{g})$	−1559.7
$\text{PCl}_3(\text{l})$	−319.7	$\text{C}_2\text{H}_5\text{OH}(\text{l})$	−1367.3
$\text{PCl}_5(\text{s})$	−443.5	$\text{C}_2\text{H}_4(\text{g})$	−1410.8
$\text{POCl}_3(\text{l})$	−597.1	$\text{CH}_3\text{COOH}(\text{l})$	−874.1
$\text{GeO}(\text{s})$	−212.1	$\text{C}_6\text{H}_{14}(\text{l})$	−4163.0
$\text{GeO}_2(\text{s})$	−551.0	$\text{CH}_3\text{COOC}_2\text{H}_5(\text{l})$	−2237.9
$\text{NH}_3(\text{g})$	−46.1	$\text{CO}(\text{g})$	−283.0
$\text{TiO}_2(\text{s})$	−939.7	$\text{Mg}(\text{s})$	−601.7

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

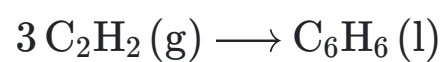
Part A (a)



Part B (b)



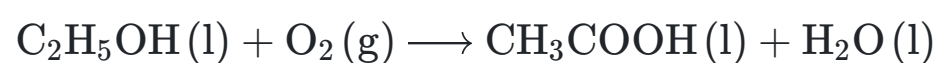
Part C (c)



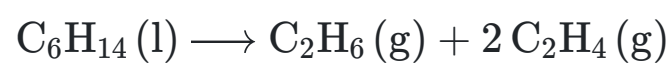
Part D (d)



Part E (e)



Part F (f)

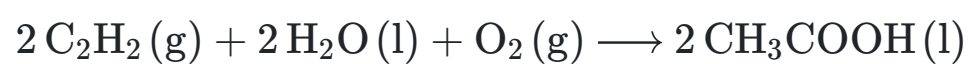


Part G (g)



Give your answer to 2 significant figures.

Part H (h)



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Formation and Combustion Enthalpies 3

A Level
P P P

Essential Pre-Uni Chemistry F3.3

Data (all in kJ mol^{-1}):

	$\Delta_f H^\ominus$		$\Delta_c H^\ominus$
$\text{CH}_4(\text{g})$	−74.8	$\text{C}_6\text{H}_6(\text{l})$	−3267.4
$\text{CCl}_4(\text{l})$	−129.6	$\text{H}_2(\text{g})$	−285.8
$\text{HCl}(\text{g})$	−92.3	$\text{C}_6\text{H}_{12}(\text{l})$	−3919.5
$\text{TiCl}_4(\text{l})$	−804.2	$\text{C}_2\text{H}_2(\text{g})$	−1300.8
$\text{TiCl}_3(\text{s})$	−720.9	$\text{C}_2\text{H}_6(\text{g})$	−1559.7
$\text{PCl}_3(\text{l})$	−319.7	$\text{C}_2\text{H}_5\text{OH}(\text{l})$	−1367.3
$\text{PCl}_5(\text{s})$	−443.5	$\text{C}_2\text{H}_4(\text{g})$	−1410.8
$\text{POCl}_3(\text{l})$	−597.1	$\text{CH}_3\text{COOH}(\text{l})$	−874.1
$\text{GeO}(\text{s})$	−212.1	$\text{C}_6\text{H}_{14}(\text{l})$	−4163.0
$\text{GeO}_2(\text{s})$	−551.0	$\text{CH}_3\text{COOC}_2\text{H}_5(\text{l})$	−2237.9
$\text{NH}_3(\text{g})$	−46.1	$\text{CO}(\text{g})$	−283.0
$\text{TiO}_2(\text{s})$	−939.7	$\text{Mg}(\text{s})$	−601.7

Use enthalpies of formation and combustion to calculate the reaction enthalpy for the reaction:

$\text{Ge}(\text{s}) + 2 \text{H}_2\text{O}(\text{l}) \longrightarrow \text{GeO}_2(\text{s}) + 2 \text{H}_2(\text{g})$ Give your answer to 3 significant figures.

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Formation and Combustion Enthalpies 4



Essential Pre-Uni Chemistry F3.4

Data (all in kJ mol^{-1}):

	$\Delta_f H^\ominus$		$\Delta_c H^\ominus$
$\text{CH}_4(\text{g})$	-74.8	$\text{C}_6\text{H}_6(\text{l})$	-3267.4
$\text{CCl}_4(\text{l})$	-129.6	$\text{H}_2(\text{g})$	-285.8
$\text{HCl}(\text{g})$	-92.3	$\text{C}_6\text{H}_{12}(\text{l})$	-3919.5
$\text{TiCl}_4(\text{l})$	-804.2	$\text{C}_2\text{H}_2(\text{g})$	-1300.8
$\text{TiCl}_3(\text{s})$	-720.9	$\text{C}_2\text{H}_6(\text{g})$	-1559.7
$\text{PCl}_3(\text{l})$	-319.7	$\text{C}_2\text{H}_5\text{OH}(\text{l})$	-1367.3
$\text{PCl}_5(\text{s})$	-443.5	$\text{C}_2\text{H}_4(\text{g})$	-1410.8
$\text{POCl}_3(\text{l})$	-597.1	$\text{CH}_3\text{COOH}(\text{l})$	-874.1
$\text{GeO}(\text{s})$	-212.1	$\text{C}_6\text{H}_{14}(\text{l})$	-4163.0
$\text{GeO}_2(\text{s})$	-551.0	$\text{CH}_3\text{COOC}_2\text{H}_5(\text{l})$	-2237.9
$\text{NH}_3(\text{g})$	-46.1	$\text{CO}(\text{g})$	-283.0
$\text{TiO}_2(\text{s})$	-939.7	$\text{Mg}(\text{s})$	-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 $\text{NH}_4\text{Cl}(\text{s})$

$\text{NH}_3(\text{g}) + \text{HCl}(\text{g}) \longrightarrow \text{NH}_4\text{Cl}(\text{s})$, $\Delta_r H^\ominus = -176 \text{ kJ mol}^{-1}$ find $\Delta_f H^\ominus$ of $\text{NH}_4\text{Cl}(\text{s})$

Part B $\text{MgCl}_2(\text{s})$

$\text{TiCl}_4(\text{l}) + 2 \text{Mg}(\text{s}) \longrightarrow 2 \text{MgCl}_2(\text{s}) + \text{Ti}(\text{s})$ $\Delta_r H^\ominus = -478.4 \text{ kJ mol}^{-1}$, find $\Delta_f H^\ominus$ of $\text{MgCl}_2(\text{s})$

Part C $\text{CH}_3\text{COOCOCH}_3(\text{l})$

$\text{CH}_3\text{COOCOCH}_3(\text{l}) + \text{H}_2\text{O}(\text{l}) \longrightarrow 2 \text{CH}_3\text{COOH}(\text{l})$ $\Delta_r H^\ominus = -46 \text{ kJ mol}^{-1}$, find $\Delta_c H^\ominus$ of $\text{CH}_3\text{COOCOCH}_3(\text{l})$ Give your answer to 4 significant figures.

Part D $\text{C}_6\text{H}_5\text{CHCH}_2$

$4 \text{C}_2\text{H}_2(\text{g}) \longrightarrow \text{C}_6\text{H}_5\text{CHCH}_2(\text{l})$, $\Delta_r H^\ominus = -808.2 \text{ kJ mol}^{-1}$, find $\Delta_c H^\ominus$ of $\text{C}_6\text{H}_5\text{CHCH}_2$ Give your answer to 4 significant figures.

Part E $\text{Al}_2\text{O}_3(\text{s})$

$4 \text{Al}(\text{s}) + 3 \text{GeO}_2(\text{s}) \longrightarrow 2 \text{Al}_2\text{O}_3(\text{s}) + 3 \text{Ge}(\text{s})$ $\Delta_r H^\ominus = -1698.4 \text{ kJ mol}^{-1}$, find $\Delta_f H^\ominus$ of $\text{Al}_2\text{O}_3(\text{s})$ Give your answer to 4 significant figures.

Part F Fe_2O_3

$\text{Fe}_2\text{O}_3(\text{s}) + 3 \text{CO}(\text{g}) \longrightarrow 2 \text{Fe}(\text{s}) + 3 \text{CO}_2(\text{g})$, $\Delta_r H^\ominus = -24.8 \text{ kJ mol}^{-1}$, find $\Delta_f H^\ominus$ of Fe_2O_3

Part G CuO (s)

$3 \text{ CuO (s)} + 2 \text{ NH}_3 \text{ (g)} \longrightarrow 3 \text{ Cu (s)} + \text{ N}_2 \text{ (g)} + 3 \text{ H}_2\text{O (l)}$, $\Delta_r H^\ominus = -293.3 \text{ kJ mol}^{-1}$, find $\Delta_f H^\ominus$ of CuO (s) Give your answer to 3 significant figures.

Part H H₃PO₄ (s)

$2 \text{ PCl}_5 \text{ (s)} + 8 \text{ H}_2\text{O (l)} \longrightarrow 2 \text{ H}_3\text{PO}_4 \text{ (s)} + 10 \text{ HCl (g)}$, $\Delta_r H^\ominus = -307.6 \text{ kJ mol}^{-1}$, find $\Delta_f H^\ominus$ of H₃PO₄ (s) Give your answer to 3 significant figures.

Part I Ga

$\text{Ga}_2\text{O}_3 \text{ (s)} + 3 \text{ Mg (s)} \longrightarrow 2 \text{ Ga (s)} + 3 \text{ MgO (s)}$, $\Delta_r H^\ominus = -716.1 \text{ kJ mol}^{-1}$, find $\Delta_c H^\ominus$ of Ga.

Part J HCl(g)

$\text{TiCl}_4 \text{ (l)} + 2 \text{ H}_2\text{O (l)} \longrightarrow \text{TiO}_2 \text{ (s)} + 4 \text{ HCl (aq)}$, $\Delta_r H^\ominus = -232.3 \text{ kJ mol}^{-1}$, find $\Delta_{\text{sol}} H^\ominus$ of HCl(g) Give your answer to 3 significant figures.

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Reducing Carbon Dioxide

A Level

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

Part A Carbon monoxide formation

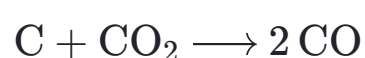
Write an equation, including state symbols, for the first of these enthalpy changes (formation of carbon monoxide).

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 kJ mol^{-1} , the standard enthalpy change of the reaction



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 O₂
-

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C₃H₆ Combustion

A Level



A and **B** are two isomers with the molecular formula C₃H₆. 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
$\Delta_c H^\ominus / \text{kJ mol}^{-1}$	−2058	−2091	−393.5	−241.8

Part A Combustion equation

Give the equation for the complete combustion of C₃H₆. (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**.

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Ethene Combustion

A Level

The standard enthalpy change of combustion of but-1-ene, $\text{C}_4\text{H}_8(\text{g})$, is $x \text{ kJ mol}^{-1}$.

The standard enthalpy change of the reaction $2 \text{C}_2\text{H}_4(\text{g}) \longrightarrow \text{C}_4\text{H}_8(\text{g})$ is $y \text{ kJ mol}^{-1}$.

Write down an expression, in terms of x and y , for the standard enthalpy change of combustion of ethene, $\text{C}_2\text{H}_4(\text{g})$ when expressed in kJ mol^{-1} (your answer should not feature any units).

The following symbols may be useful: x , y

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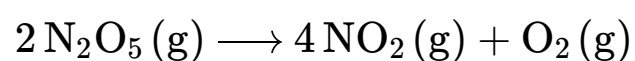
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Dinitrogen Pentoxide Formation

A Level



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



	value/ kJ mol^{-1}
$\Delta_f H^\ominus$ of $\text{N}_2\text{O}_5(\text{g})$	11.3
$\Delta_r H^\ominus$ for $\text{NO}(\text{g}) + \frac{1}{2}\text{O}_2(\text{g}) \longrightarrow \text{NO}_2(\text{g})$	−58.1
bond strength in $\text{N}_2(\text{g})$	945
bond strength in $\text{O}_2(\text{g})$	498
bond strength in $\text{NO}(\text{g})$	631

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