

Past-paper walk-through

Enthalpy of Formation ■ 6.8

eXercise

Questions in this set

- 2026 Q7
- 2025 Q3
- 2014 Q6

Reading the mark scheme

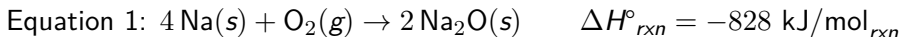
- **B1** a mark that stands on its own – the point is either made or not.
- **M1** a *method* mark: the right approach, even if the number is wrong.
- **A1** an *answer* mark, and it usually needs its M mark first.
- **C1** a working mark on the way to the answer.
- **//** separates answers the examiner accepts equally.
- **ecf** = error carried forward: a later part is marked on your own earlier answer.
- **owtte** = “or words to that effect” – the wording need not match.

Question 7

2026 ■ Q7

The following information applies to parts A and B.

Sodium metal reacts with oxygen gas according to Equation 1.



Standard enthalpies of formation are provided in Table 1.

Substance	ΔH°_f (kJ/mol)	Na(s)	0	O ₂ (g)	0	Na ₂ O(s)	?
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(a) Based on the information given, ****calculate**** the value of ΔH°_f for Na₂O(s).

Show the work that leads to your answer.

(b) An 18.4 g sample of Na(s) reacts with 12.8 g of O₂(g) according to Equation 1.

****Calculate**** the total amount of heat, in kilojoules, released during this process.

Show the work that leads to your answer.

Question 7

(c) Lattice enthalpy can be defined as the energy required to separate an ionic crystal into gaseous ions. $\text{Rb}_2\text{O}(s)$ and $\text{Na}_2\text{O}(s)$ have similar crystal structures, and their lattice enthalpies are given in Table 2.

Compound	Lattice Enthalpy (kJ/mol)
$\text{Na}_2\text{O}(s)$	2481
$\text{Rb}_2\text{O}(s)$	2163

Using Coulomb's law, **explain** why the lattice enthalpy of $\text{Rb}_2\text{O}(s)$ is smaller than that of $\text{Na}_2\text{O}(s)$.

Table 2

Compound	Lattice Enthalpy (kJ/mol)
$\text{Na}_2\text{O} (s)$	2481
$\text{Rb}_2\text{O} (s)$	2163

Table 1

Substance	ΔH_f° (kJ/mol)
Na (s)	0
O ₂ (g)	0
Na ₂ O (s)	?

Question 3

2025 ■ Q3

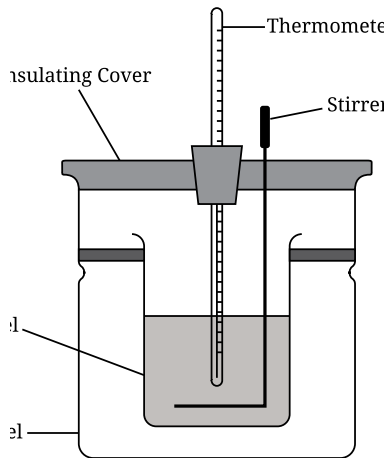
White phosphorus is composed of P_4 molecules with a tetrahedral structure, as shown in the diagram on the left. Each P atom is bonded to the other three P atoms by single bonds, as shown in the incomplete Lewis diagram on the right.

[Left: a ball-and-stick tetrahedral structure of P_4 , showing four P atoms (spheres) at the vertices of a tetrahedron connected by bonds (sticks).]

[Right: an incomplete Lewis diagram showing four P atoms arranged in a tetrahedral projection (one P at top, one P in the middle/front, two P at the bottom left and right), connected by single bonds forming the P_4 skeleton, with no lone pairs drawn yet.]

(a) In the box in part A, complete the Lewis diagram for P_4 by drawing the nonbonding electrons.

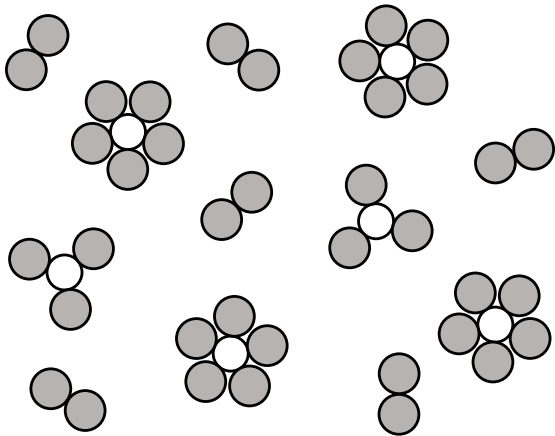
Question 3



Question 3

Mass of P_4O_{10}	0.100 g
Mass of H_2O	100.0 g
Initial temperature	22.00° C
Final temperature	22.38° C
Molar mass of P_4O_{10}	283.9 g/mol
Specific heat of H_2O	4.18 J/(g·°C)

Question 3



Question 3

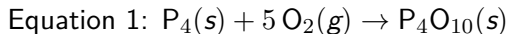
2025 ■ Q3

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[Right: an incomplete Lewis diagram showing four P atoms arranged in a tetrahedral projection (one P at top, one P in the middle/front, two P at the bottom left and right), connected by single bonds forming the P_4 skeleton, with no lone pairs drawn yet.]

(b) The reaction of white phosphorus with oxygen to form $P_4O_{10}(s)$ is thermodynamically favorable at 298 K. The reaction is represented by equation 1.



Question 3

(b)(i) The entropy change of the reaction, ΔS° , is negative. Using particle-level reasoning, explain why the entropy decreases as the reaction progresses.

(b)(ii) The enthalpy change of the reaction, ΔH° , is also negative. A student claims that the favorability of the reaction is driven by enthalpy and **not** by entropy. Is the student's claim correct? Justify your answer by using the relationship between ΔG° , ΔH° , and ΔS° .

Question 3

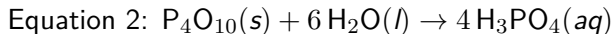
2025 ■ Q3

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(c) $P_4O_{10}(s)$ reacts exothermically with water to form phosphoric acid, as represented by equation 2.



Question 3

A chemist uses a calorimetry experiment to determine the enthalpy change for the reaction, as represented by the following diagram.

[Calorimeter diagram: a coffee-cup-style calorimeter labeled "Thermometer" (inserted through the insulating cover), "Stirrer" (inserted alongside the thermometer), "Insulating Cover" (the lid), "Inner Vessel" (the cup holding the solution, shaded), and "Outer Vessel" (the outer supporting cup).]

The chemist carries out the calorimetry experiment and records the following information.

Quantity	Value	—	—	Mass of P_4O_{10}	0.100 g	Mass of H_2O	100.0 g
Initial temperature	22.00°C	Final temperature	22.38°C	Molar mass of P_4O_{10}	283.9 g/mol	Specific heat of H_2O	4.18 J/(g · °C)

(c)(i) Calculate the amount of heat, q , released during the experiment, in kJ. Assume that the specific heat of the solution is the same as that of water.

Question 3

(c)(ii) Calculate the value of ΔH_{rxn}° for equation 2 in kJ/mol_{rxn} . Include the sign in your answer.

Question 3

2025 ■ Q3

White phosphorus is composed of P_4 molecules with a tetrahedral structure, as shown in the diagram on the left. Each P atom is bonded to the other three P atoms by single bonds, as shown in the incomplete Lewis diagram on the right.

[Left: a ball-and-stick tetrahedral structure of P_4 , showing four P atoms (spheres) at the vertices of a tetrahedron connected by bonds (sticks).]

[Right: an incomplete Lewis diagram showing four P atoms arranged in a tetrahedral projection (one P at top, one P in the middle/front, two P at the bottom left and right), connected by single bonds forming the P_4 skeleton, with no lone pairs drawn yet.]

(d) The chemist weighed out 0.100 g P_4O_{10} of and 100.0 g of H_2O to perform a second trial. In the second trial, some of the solid P_4O_{10} stuck to the weighing paper and was not transferred to the calorimeter. Given that P_4O_{10} is the limiting reactant,

Question 3

would ΔT for the second trial be greater than, less than, or equal to the value in the first trial? Justify your answer.

$\text{P}_4(\text{s})$ also reacts readily with $\text{Cl}_2(\text{g})$ to produce phosphorus trichloride, $\text{PCl}_3(\text{g})$, which in turn reacts with $\text{Cl}_2(\text{g})$ in an equilibrium process to produce $\text{PCl}_5(\text{g})$. The reactions are represented by equations 3 and 4.



Question 3

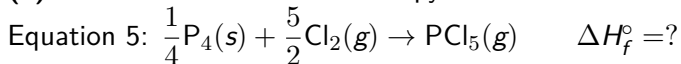
2025 ■ Q3

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[Right: an incomplete Lewis diagram showing four P atoms arranged in a tetrahedral projection (one P at top, one P in the middle/front, two P at the bottom left and right), connected by single bonds forming the P_4 skeleton, with no lone pairs drawn yet.]

(e) Calculate the standard enthalpy of formation of $PCl_5(g)$ represented by equation 5.



The following particle-level diagram represents the contents of the vessel in an equilibrium mixture at 546 K involving equation 4.

Question 3

[Particle diagram: a box containing multiple particles at random positions representing an equilibrium mixture; a key indicates two-atom particles (grey-grey) = Cl_2 , four-atom tetrahedral-looking particles (grey with three white) = PCl_3 , and six-atom particles (grey with five white) = PCl_5 . The box shows several Cl_2 particles (pairs of grey circles), several PCl_3 particles (grey center with three white circles), and several PCl_5 particles (grey center with five white circles) scattered throughout.]

Question 3

2025 ■ Q3

White phosphorus is composed of P_4 molecules with a tetrahedral structure, as shown in the diagram on the left. Each P atom is bonded to the other three P atoms by single bonds, as shown in the incomplete Lewis diagram on the right.

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[Right: an incomplete Lewis diagram showing four P atoms arranged in a tetrahedral projection (one P at top, one P in the middle/front, two P at the bottom left and right), connected by single bonds forming the P_4 skeleton, with no lone pairs drawn yet.]

(f) Equation 4 for the reaction that occurs is shown.



(f)(i) If each particle in the diagram represents a partial pressure of 1.00 atm, what is the value of K_p for the equilibrium mixture at 546 K?

Question 3

(f)(ii) Does the value of K_p increase, decrease, or remain the same when the temperature is increased to 596 K? Justify your answer based on ΔH_2° .

Solution 3

(a)

Mark scheme

- Complete Lewis diagram for P_4 : the four P atoms form a tetrahedron, each bonded to the other three P atoms by single bonds, and each P atom bears one lone (nonbonding) pair of electrons — giving each P three bonding pairs plus one lone pair, satisfying the octet rule.

Solution 3

(b)

Mark scheme

- No separate response required — this is the context/stem presenting equation 1 ($\text{P}_4(\text{s}) + 5 \text{O}_2(\text{g}) \rightarrow \text{P}_4\text{O}_{10}(\text{s})$), thermodynamically favorable at 298 K, that parts (i) and (ii) below refer to.

(b)(i)

Mark scheme

- Because gas particles are more dispersed (have more accessible microstates) than solids, the entropy decreases as the reactants (which include a gas, O_2) convert into the solid product (P_4O_{10}).

Solution 3

(b)(ii)

Mark scheme

- Yes, the student's claim is correct. Given $\Delta G_{rxn}^{\circ} = \Delta H_{rxn}^{\circ} - T\Delta S_{rxn}^{\circ}$, the reaction must have $\Delta G_{rxn}^{\circ} < 0$ to be favorable. Because the reaction is exothermic, $\Delta H_{rxn}^{\circ} < 0$ and enthalpy contributes to favorability. $\Delta S_{rxn}^{\circ} < 0$, so entropy does NOT contribute to favorability — i.e., enthalpy alone drives it.

Solution 3

(c)

Mark scheme

- No separate response required — this is the context/stem describing the calorimetry experiment for the exothermic reaction of $\text{P}_4\text{O}_{10}(\text{s})$ with water (equation 2: $\text{P}_4\text{O}_{10}(\text{s}) + 6 \text{H}_2\text{O}(\text{l}) \rightarrow 4 \text{H}_3\text{PO}_4(\text{aq})$) that parts (i) and (ii) below use.

Solution 3

(c)(i)

Mark scheme

- $q = mc\Delta T = (100.1 \text{ g})(4.18 \text{ J/(g}\cdot^{\circ}\text{C)})(22.38^{\circ}\text{C} - 22.00^{\circ}\text{C}) = 160 \text{ J} = 0.16 \text{ kJ}$
(reported to the correct number of significant figures).

Solution 3

(c)(ii)

Mark scheme

$$\blacksquare \quad q_{rxn} = -q_{surr} = -0.16 \text{ kJ.}$$

$$\Delta H_{rxn}^{\circ} = \frac{-0.16 \text{ kJ}}{0.100 \text{ g P}_4\text{O}_{10}} \times \frac{283.9 \text{ g P}_4\text{O}_{10}}{1 \text{ mol P}_4\text{O}_{10}} \times \frac{1 \text{ mol P}_4\text{O}_{10}}{1 \text{ mol}_{rxn}} = -450 \text{ kJ/mol}_{rxn}.$$

The correct (negative) sign must be included.

Solution 3

(d)

Mark scheme

- Less than. If less P_4O_{10} is present (some stuck to the weighing paper), less thermal energy will be transferred to the water during the reaction, causing the temperature increase (ΔT) to be less than it was with the full 0.100 g of P_4O_{10} .

Solution 3

(e)

Mark scheme

- Using Hess's law:

$$\Delta H_{f,\text{PCl}_5(g)}^\circ = \frac{1}{4}\Delta H_1^\circ + \Delta H_2^\circ = \frac{1}{4}(-1148) + (-88) = -375 \text{ kJ/mol.}$$

Solution 3

(f)

Mark scheme

- No separate response required — this is the context/stem presenting equation 4 ($\text{PCl}_3(g) + \text{Cl}_2(g) \rightleftharpoons \text{PCl}_5(g)$, $\Delta H_2^\circ = -88 \text{ kJ/mol}_{\text{rxn}}$) that parts (i) and (ii) below refer to.

Solution 3

(f)(i)

Mark scheme

- Reading partial pressures of 1.00 atm per particle from the diagram (4 PCl_5 , 2 PCl_3 , 6 Cl_2 particles): $K_p = \frac{P_{\text{PCl}_5}}{(P_{\text{PCl}_3})(P_{\text{Cl}_2})} = \frac{4.00}{(2.00)(6.00)} = \frac{1}{3} = 0.333$.

Solution 3

(f)(ii)

Mark scheme

- Decrease. The negative value of ΔH_2° indicates the reaction is exothermic. Because exothermic reactions favor reactant formation at higher temperature (the equilibrium shifts toward reactants as heat is added), the value of K_p decreases.

Question 6

2014 ■ Q6

A student places a mixture of plastic beads consisting of polypropylene (PP) and polyvinyl chloride (PVC) in a 1.0 L beaker containing distilled water. After stirring the contents of the beaker vigorously, the student observes that the beads of one type of plastic sink to the bottom of the beaker and the beads of the other type of plastic float on the water. The chemical structures of PP and PVC are represented by the diagrams below, which show segments of each polymer.

[Structural diagram of PP: a repeating polymer backbone $\text{—C(H)(CH}_3\text{)—C(H)(H)—}$ shown as three repeat units, the middle one in brackets with subscript n , labeled "PP".]

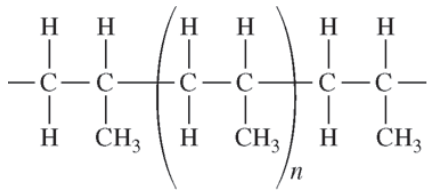
[Structural diagram of PVC: a repeating polymer backbone $\text{—C(H)(Cl)—C(H)(H)—}$ shown as three repeat units, the middle one in brackets with subscript n , labeled "PVC".]

Question 6

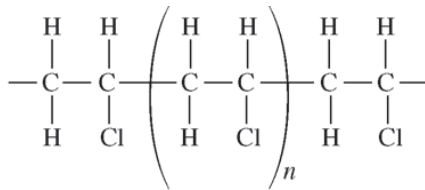
(a) Given that the spacing between polymer chains in PP and PVC is similar, the beads that sink are made of which polymer? Explain.

Question 6

heat on the water. The chemical structures of PP and PVC are represented by the diagrams below, segments of each polymer.



PP

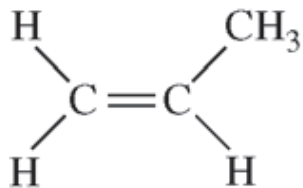


PVC

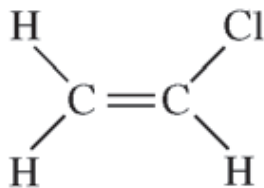
Question 6

Substance	$\text{C}_2\text{H}_3\text{Cl}(g)$	$\text{C}_3\text{H}_6(g)$	$\text{CO}_2(g)$	$\text{H}_2\text{O}(g)$	$\text{HCl}(g)$	$\text{O}_2(g)$
Standard Enthalpy of Formation (kJ/mol)	37	21	-394	-242	-92	0

Question 6



Propene



Vinyl Chloride (chloroethene)

Question 6

2014 ■ Q6

A student places a mixture of plastic beads consisting of polypropylene (PP) and polyvinyl chloride (PVC) in a 1.0 L beaker containing distilled water. After stirring the contents of the beaker vigorously, the student observes that the beads of one type of plastic sink to the bottom of the beaker and the beads of the other type of plastic float on the water. The chemical structures of PP and PVC are represented by the diagrams below, which show segments of each polymer.

[Structural diagram of PP: a repeating polymer backbone $\text{—C(H)(CH}_3\text{)—C(H)(H)—}$ shown as three repeat units, the middle one in brackets with subscript n , labeled "PP".]

[Structural diagram of PVC: a repeating polymer backbone $\text{—C(H)(Cl)—C(H)(H)—}$ shown as three repeat units, the middle one in brackets with subscript n , labeled "PVC".]

(b) PP is synthesized from propene, C_3H_6 , and PVC is synthesized from vinyl chloride, $\text{C}_2\text{H}_3\text{Cl}$. The structures of the molecules are shown below.

Question 6

[Structural diagram of Propene: $\text{H}_2\text{C} = \text{CH}(\text{CH}_3)$, drawn with H and CH_3 on one carbon and two H atoms on the other.]

[Structural diagram of Vinyl Chloride (chloroethene): $\text{H}_2\text{C} = \text{CHCl}$, drawn with H and Cl on one carbon and two H atoms on the other.]

The boiling point of liquid propene (226 K) is lower than the boiling point of liquid vinyl chloride (260 K). Account for this difference in terms of the types and strengths of intermolecular forces present in each liquid.

Question 6

2014 ■ Q6

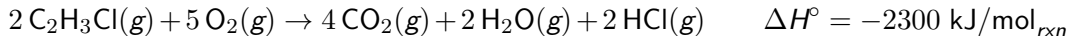
A student places a mixture of plastic beads consisting of polypropylene (PP) and polyvinyl chloride (PVC) in a 1.0 L beaker containing distilled water. After stirring the contents of the beaker vigorously, the student observes that the beads of one type of plastic sink to the bottom of the beaker and the beads of the other type of plastic float on the water. The chemical structures of PP and PVC are represented by the diagrams below, which show segments of each polymer.

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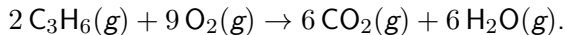
[Structural diagram of PVC: a repeating polymer backbone $\text{—C(H)(Cl)—C(H)(H)—}$ shown as three repeat units, the middle one in brackets with subscript n , labeled "PVC".]

(c) In a separate experiment, the student measures the enthalpies of combustion of propene and vinyl chloride. The student determines that the combustion of 2.00 mol of vinyl chloride releases 2300 kJ of energy, according to the equation below.

Question 6



Using the table of standard enthalpies of formation below, determine whether the combustion of 2.00 mol of propene releases more, less, or the same amount of energy that 2.00 mol of vinyl chloride releases. Justify your answer with a calculation. The balanced equation for the combustion of 2.00 mol of propene is



Substance	$\text{C}_2\text{H}_3\text{Cl}(g)$	$\text{C}_3\text{H}_6(g)$	$\text{CO}_2(g)$	$\text{H}_2\text{O}(g)$	$\text{HCl}(g)$	$\text{O}_2(g)$
Standard Enthalpy of Formation (kJ/mol)	37	21	-394	-242	-92	0

Solution 6

(a)

Mark scheme

- The PVC beads sink. Since the spacing between polymer chains in PP and PVC is similar, density is set by mass: a Cl atom (in PVC's repeat unit) has a greater mass than the CH₃ group (in PP's repeat unit), making PVC denser than water while PP is less dense, so PVC sinks and PP floats.

Solution 6

(b)

Mark scheme

- Both substances experience London dispersion forces, but vinyl chloride is polar (has a C–Cl bond) and so also has dipole-dipole interactions, whereas propene is essentially nonpolar with only LDFs. Vinyl chloride's Cl atom also gives it a larger, more polarizable electron cloud. As a result, intermolecular attractions are stronger overall in vinyl chloride, giving it the higher boiling point (260 K vs. 226 K for propene).

Solution 6

(c)

Mark scheme

- Balanced combustion of propene:

$2 \text{C}_3\text{H}_6(g) + 9 \text{O}_2(g) \rightarrow 6 \text{CO}_2(g) + 6 \text{H}_2\text{O}(g)$. Using standard enthalpies of formation (kJ/mol: $\text{C}_3\text{H}_6=21$, $\text{CO}_2=-394$, $\text{H}_2\text{O}=-242$, $\text{O}_2=0$):

$\Delta H^\circ = [6(-394) + 6(-242)] - 2(21) = -3858 \text{ kJ/mol}_{\text{rxn}}$ (1 point for this calculation). Since 2.00 mol vinyl chloride releases 2300 kJ but 2.00 mol propene releases 3858 kJ, the combustion of propene releases more energy (1 point for the correct comparison consistent with the calculated value).