

Chemical energetics: practice questions

This question set covers Topic 5 (Chemical energetics) of Cambridge O Level Chemistry 5070 and Cambridge IGCSE Chemistry 0620. It covers exothermic and endothermic reactions, temperature changes, reaction pathway diagrams, activation energy, enthalpy change, bond breaking and bond making, and calculating ΔH from bond energies. It also has questions on hydrogen as a fuel and the hydrogen–oxygen fuel cell. There are 60 marks in total. A full answer scheme with marking points follows the questions.

Notes: In IGCSE 0620, only these points are Core: the definitions of exothermic and endothermic reactions, interpreting reaction pathway diagrams, and the fact that a hydrogen–oxygen fuel cell uses hydrogen and oxygen to make electricity with water as the only chemical product. The following are Supplement (Extended): the term ΔH and its sign, the definition of activation energy, drawing and labelling pathway diagrams with ΔH and E_a , bond breaking and bond making, bond-energy calculations, and the advantages and disadvantages of fuel cells. Questions or parts marked [S] are Supplement. 0620 Core candidates may leave them out. O Level 5070 has no Core/Supplement split, so 5070 candidates should attempt everything. In the current syllabuses the hydrogen–oxygen fuel cell comes under Electrochemistry, not Chemical energetics. It is included here because it is closely linked to fuels and energy.

Key ideas

- An **exothermic** reaction transfers thermal energy to the surroundings, so the temperature of the surroundings rises. ΔH is negative.
- An **endothermic** reaction takes in thermal energy from the surroundings, so the temperature of the surroundings falls. ΔH is positive.
- **Enthalpy change (ΔH)** is the transfer of thermal energy during a reaction, usually given in kJ/mol. [S]
- **Activation energy (E_a)** is the minimum energy that colliding particles must have in order to react. [S]
- On a reaction pathway diagram, E_a is measured from the reactants up to the top of the "hump". ΔH is measured from the reactants to the products. [S]
- **Bond breaking is endothermic** (energy is taken in). **Bond making is exothermic** (energy is released). [S]
- $\Delta H = (\text{total energy needed to break bonds}) - (\text{total energy released when bonds form})$. [S]
- A catalyst lowers the activation energy but does not change ΔH .
- A hydrogen–oxygen fuel cell uses hydrogen and oxygen to produce electricity. Water is the only chemical product.

Section A: multiple choice

Choose one answer, A, B, C or D, for each question.

Question A1

Which change is endothermic? [1]

- A: burning charcoal in air

- B: adding zinc powder to copper(II) sulfate solution
- C: heating calcium carbonate strongly to form calcium oxide and carbon dioxide
- D: adding dilute nitric acid to potassium hydroxide solution

Question A2 [S]

Two colourless solutions are mixed in a beaker. The temperature of the mixture falls from 23.0 °C to 17.5 °C. Which row is correct? [1]

	type of reaction	sign of ΔH
A	exothermic	negative
B	exothermic	positive
C	endothermic	positive
D	endothermic	negative

Question A3 [S]

What is meant by the activation energy of a reaction? [1]

- A: the energy released when the products form
- B: the minimum energy that colliding particles must have in order to react
- C: the difference in energy between the reactants and the products
- D: the total energy of all the reactant particles

Question A4 [S]

The energy levels on a reaction pathway diagram are: reactants 120 kJ/mol, top of the curve 200 kJ/mol, products 50 kJ/mol. Which row gives the activation energy and the enthalpy change? [1]

	E_a / kJ/mol	ΔH / kJ/mol
A	80	-70
B	200	-70
C	80	+70
D	150	-70

Question A5

A reaction pathway diagram has energy on the vertical axis and progress of reaction on the horizontal axis. The reactant level is higher than the product level. The curve rises from the reactants to a peak and then falls to the products. Three vertical arrows are drawn on the diagram:

- arrow X goes from the reactant level up to the peak
- arrow Y goes from the product level up to the peak
- arrow Z goes from the reactant level down to the product level

Which row is correct? [1]

	type of reaction	arrow showing the overall energy change of the reaction
A	exothermic	Z
B	exothermic	X
C	endothermic	Z
D	endothermic	Y

Question A6 [S]

Use these bond energies: H–H 436 kJ/mol, F–F 158 kJ/mol, H–F 568 kJ/mol. What is ΔH for the reaction $H_2 + F_2 \rightarrow 2HF$? [1]

- A: +26 kJ/mol
- B: +542 kJ/mol
- C: –542 kJ/mol
- D: –1730 kJ/mol

Question A7

What is the only chemical product of a hydrogen–oxygen fuel cell? [1]

- A: carbon dioxide
- B: hydrogen peroxide
- C: water
- D: carbon dioxide and water

Question A8 [S]

A reaction has $\Delta H = -95$ kJ/mol. Which statement explains why ΔH is negative? [1]

- A: More energy is released making bonds than is taken in breaking bonds.
- B: More energy is taken in breaking bonds than is released making bonds.
- C: No bonds are broken during the reaction.
- D: The activation energy is greater than 95 kJ/mol.

Section B: short answer

Bond energy data for Sections B and C (mean values, kJ/mol)

bond	bond energy / kJ/mol
H–H	436
H–Br	366
Br–Br	193
O=O	498
O–H	464

C–H	413
C=O	805

Question B1

State what is meant by an **exothermic** reaction, in terms of energy transfer and temperature. [2]

Question B2 [S]

- (a) State what the symbol ΔH represents.
 (b) State the sign of ΔH for an endothermic reaction. [2]

Question B3

A student adds 2.0 g of each of four different solids, P, Q, R and S, to a separate 50 cm³ portion of water. The starting temperature is 20.0 °C each time.

solid	final temperature / °C
P	27.5
Q	14.0
R	31.0
S	18.5

- (i) Identify the two solids that dissolve endothermically.
 (ii) Identify the solid that gives the largest temperature rise and state the size of the rise.
 (iii) Suggest why the student used the same mass of solid and the same volume of water each time. [3]

Question B4 [S]

Methane burns in air. Explain, in terms of bond breaking and bond making, why this reaction is exothermic. [2]

Question B5 [S]

Hydrogen bromide decomposes: $2\text{HBr} \rightarrow \text{H}_2 + \text{Br}_2$. Use the bond energy data to calculate ΔH for this reaction and state whether it is exothermic or endothermic. [3]

Question B6

- (a) Write the balanced equation for the overall reaction in a hydrogen–oxygen fuel cell.
 (b) State the form of energy that a fuel cell produces directly. [2]

Question B7 [S]

Sketch, on paper, a labelled reaction pathway diagram for an **endothermic** reaction. Then describe your diagram in words: state what is on each axis and how E_a and ΔH are shown. [3]

Question B8 [S]

Methane in the gas supply burns in an exothermic reaction. However, when a student turns on the gas tap of a Bunsen burner, the gas does not start to burn until a lit splint is held at the top of the tube. Explain why. [3]

Section C: structured questions

Question C1

A student puts 25.0 cm^3 of dilute hydrochloric acid into a polystyrene cup and records its temperature. She then adds dilute sodium hydroxide solution 5.0 cm^3 at a time. After each addition she stirs and records the highest temperature. Both solutions start at room temperature.

total volume of NaOH added / cm^3	temperature / $^{\circ}\text{C}$
0.0	21.0
5.0	23.4
10.0	25.8
15.0	28.2
20.0	30.6
25.0	31.4
30.0	30.6
35.0	29.8
40.0	29.0

- (a) Suggest why a polystyrene cup is used instead of a glass beaker. [1]
- (b) The student plots a graph of temperature against volume of NaOH added. Describe how she should use the graph to find the volume of NaOH that exactly neutralises the acid. Use the data to find this volume and the maximum temperature shown where your two lines cross. [3]
- (c) Explain why the temperature falls once more NaOH has been added than the volume you found in (b). [2]
- (d) The experiment is repeated using the same volumes, but both solutions are twice as concentrated. Predict the maximum temperature **rise** and explain your answer. [2]

Question C2 [S]

The table gives energy values from the reaction pathway diagram for a reaction, both without and with a catalyst.

point on the diagram	energy / kJ/mol
reactants	40
highest point, no catalyst	250
highest point, with catalyst	160
products	130

- (a) State whether the reaction is exothermic or endothermic. Give a reason. [2]

- (b) Calculate the activation energy without a catalyst and the enthalpy change, ΔH . [2]
- (c) Calculate the activation energy with the catalyst, and state the effect of the catalyst on ΔH . [2]
- (d) Describe how both activation energies and ΔH would be shown by arrows on the diagram. [2]

Question C3 [S]

Methane is the main compound in natural gas. Use the bond energy data before Section B.

- (a) Write the balanced equation, with state symbols, for the complete combustion of methane to form carbon dioxide and water vapour. [1]
- (b) Calculate the total energy needed to break all the bonds in the reactants. [2]
- (c) Calculate the total energy released when all the bonds in the products form. [2]
- (d) Calculate ΔH for the reaction and explain what its sign shows. [3]

Question C4

Hydrogen is being developed as a fuel for vehicles.

- (a) [S] Use the bond energy data to calculate ΔH for $2\text{H}_2 + \text{O}_2 \rightarrow 2\text{H}_2\text{O}$ (all gases). Then give the energy released per mole of hydrogen burned. [3]
- (b) [S] Using your answers to (a) and C3(d), show which fuel releases more energy per gram: hydrogen or methane. [A_r : H = 1, C = 12] [2]
- (c) State one environmental advantage of using hydrogen in a fuel cell instead of burning methane. [1]
- (d) [S] Give two disadvantages of using hydrogen–oxygen fuel cells in cars compared with petrol engines. [2]

Total: Section A 8 marks, Section B 20 marks, Section C 32 marks. Total 60 marks.

Answers

Section A

A1: C. Thermal decomposition needs a continuous supply of heat, so it is endothermic. Combustion, displacement and neutralisation are all exothermic.

A2: C. The temperature falls, so thermal energy is taken in from the surroundings. The reaction is endothermic and ΔH is positive.

A3: B. Option C describes ΔH , not E_a .

A4: A. $E_a = 200 - 120 = 80 \text{ kJ/mol}$. $\Delta H = 50 - 120 = -70 \text{ kJ/mol}$ (the products are lower than the reactants, so the reaction is exothermic).

A5: A. The products are at a lower energy than the reactants, so energy is given out and the reaction is exothermic. The overall energy change runs from the reactant level to the product level (arrow Z). Arrow X is the activation energy. Arrow Y runs from the products to the peak, so it does

not describe this reaction.

A6: C. Bonds broken: $436 + 158 = 594$ kJ. Bonds made: $2 \times 568 = 1136$ kJ. $\Delta H = 594 - 1136 = -542$ kJ/mol. (A comes from forgetting that there are two H-F bonds. B has the sign reversed. D comes from adding the two totals.)

A7: C. $2\text{H}_2 + \text{O}_2 \rightarrow 2\text{H}_2\text{O}$. There is no carbon in the fuel, so no CO_2 forms.

A8: A. ΔH = energy in (breaking) – energy out (making). It is negative when making bonds releases more energy than breaking bonds takes in.

Section B

B1 [2]

- thermal energy is transferred (given out) from the reaction to the surroundings (1)
- so the temperature of the surroundings / mixture increases (1)

B2 [2]

- (a) the enthalpy change: the thermal energy transferred during the reaction (accept: heat energy change, in kJ/mol) (1)
- (b) positive / + (1)

B3 [3]

- (i) Q and S (both needed) (1)
- (ii) R; rise = $31.0 - 20.0 = 11.0$ °C (1)
- (iii) so that the test is fair / the temperature changes can be compared; a different mass or volume would change the size of the temperature change (1)

B4 [2]

- energy is taken in to break the C-H and O=O bonds, and energy is released when the C=O and O-H bonds form (1)
- more energy is released making bonds than is taken in breaking bonds (1)

B5 [3]

- bonds broken: $2 \times \text{H-Br} = 2 \times 366 = 732$ kJ and bonds made: $\text{H-H} + \text{Br-Br} = 436 + 193 = 629$ kJ (1)
- $\Delta H = 732 - 629 = +103$ kJ/mol (sign needed) (1)
- endothermic (ΔH positive) (1)

Allow error carried forward for the conclusion if it matches the sign of the candidate's ΔH value.

B6 [2]

- (a) $2\text{H}_2 + \text{O}_2 \rightarrow 2\text{H}_2\text{O}$ (correct formulae and balanced) (1)
- (b) electrical energy / electricity (1)

B7 [3]

- y-axis energy, x-axis progress of reaction; product level drawn **higher** than reactant level (1)
- curve rises from reactants to a peak then falls to products; E_a shown by an arrow from the reactant level up to the peak (1)
- ΔH shown by an upward arrow from the reactant level to the product level (positive) (1)

Arrow rule: the ΔH arrow always starts at the reactant level. It points up for an endothermic reaction and down for an exothermic reaction. The E_a arrow always points up, from the reactant level to the peak.

B8 [3]

- colliding particles need at least the activation energy to react (1)
- at room temperature too few collisions between methane and oxygen molecules have this much energy (1)
- the lit splint supplies the energy needed to overcome E_a . Once the reaction starts, the energy released by the exothermic reaction gives more molecules the activation energy, so burning continues (1)

Section C

C1 [8]

(a) polystyrene is a (thermal) insulator, so less heat is lost to the surroundings (1)

(b)

- draw a straight line of best fit through the rising points and another through the falling points; the volume is where the two lines cross (1)
- volume = 22.5 cm^3 (accept $22.0\text{--}23.0 \text{ cm}^3$) (1)
- maximum temperature = 31.8°C (accept $31.6\text{--}32.0^\circ\text{C}$) (1)

31.4°C (the highest reading in the table) does not score the third mark, because the question asks for the value where the lines cross. Working: rising line $T = 21.0 + 0.48V$; falling line $T = 35.4 - 0.16V$. Setting them equal gives $0.64V = 14.4$, so $V = 22.5 \text{ cm}^3$ and $T = 21.0 + 0.48 \times 22.5 = 31.8^\circ\text{C}$. Students reading a graph do not need to write these equations.

(c)

- all the acid has reacted, so no more energy is released by neutralisation (1)
- the extra NaOH is at room temperature and cools the mixture / heat is lost to the surroundings (1)

(d)

- the rise roughly doubles, to about 21.6°C (original rise $31.8 - 21.0 = 10.8^\circ\text{C}$) (1)
- twice as many moles of acid and alkali react and release twice the energy, but into the

same volume (mass) of solution (1)

Allow error carried forward from (b): award the first mark for twice the candidate's own temperature rise.

C2 [8]

(a) endothermic (1); the products (130 kJ/mol) have more energy than the reactants (40 kJ/mol) / ΔH is positive (1)

(b) $E_a = 250 - 40 = 210$ kJ/mol (1); $\Delta H = 130 - 40 = +90$ kJ/mol (sign needed) (1)

(c) E_a with catalyst = $160 - 40 = 120$ kJ/mol (1); ΔH is unchanged / still +90 kJ/mol (1)

(d)

- each E_a : an arrow from the reactant level up to the top of its own curve; the catalysed curve has the lower peak (1)
- ΔH : a single upward arrow from the reactant level to the product level, the same for both pathways (1)

C3 [8]

(a) $\text{CH}_4(\text{g}) + 2\text{O}_2(\text{g}) \rightarrow \text{CO}_2(\text{g}) + 2\text{H}_2\text{O}(\text{g})$ (1)

(b)

- bonds broken: 4 C–H and 2 O=O (1)
- $(4 \times 413) + (2 \times 498) = 1652 + 996 = 2648$ kJ (1)

(c)

- bonds made: 2 C=O and 4 O–H (1)
- $(2 \times 805) + (4 \times 464) = 1610 + 1856 = 3466$ kJ (1)

(d)

- $\Delta H = 2648 - 3466$ (1)
- $= -818$ kJ/mol (1)
- the negative sign shows the reaction is exothermic: more energy is released making bonds than is taken in breaking bonds (1)

Bond energies are average values, so this answer is slightly different from a value measured by experiment.

C4 [8]

(a)

- bonds broken: $(2 \times 436) + 498 = 1370$ kJ; bonds made: $4 \times 464 = 1856$ kJ (1)
- $\Delta H = 1370 - 1856 = -486$ kJ/mol (for the equation as written) (1)
- energy per mole of $\text{H}_2 = 486 \div 2 = 243$ kJ (1)

(b)

- either correct value per gram: hydrogen $M_r = 2$, so $243 \div 2 = 121.5$ kJ/g; **or** methane $M_r = 16$, so $818 \div 16 = 51.1$ kJ/g (1)

- both values, with the conclusion that hydrogen releases more energy per gram (about 2.4 times as much) (1)

Allow error carried forward from C3(d) and C4(a).

(c) the only product is water / no carbon dioxide (greenhouse gas) or carbon monoxide is produced (1). Also accept: no oxides of nitrogen are formed, because there is no high-temperature combustion.

(d) any two (1 each):

- hydrogen is a gas that is difficult / bulky to store; it needs high-pressure tanks
- hydrogen is flammable / forms explosive mixtures with air
- few hydrogen filling stations
- most hydrogen is made from fossil fuels (or by electrolysis using electricity that may come from fossil fuels), so CO_2 may still be produced
- fuel cells are expensive (e.g. they use costly catalysts)