

Chemical energetics

Mark scheme and worked solutions for 30 questions: 15 multiple choice, 15 structured.

1 Core Exothermic and endothermic reactions [1]

Answer: A

Worked solution

Burning is a combustion reaction. The surrounding air warms up, which means thermal energy has moved from the reacting magnesium and oxygen out into the surroundings (the air). A reaction that transfers thermal energy to the surroundings is exothermic, so the answer is A.

2 Core Exothermic and endothermic reactions [1]

Answer: B

Worked solution

As potassium nitrate dissolves, the temperature drops from 20°C to 12°C. A temperature drop in the surroundings means the process has absorbed thermal energy from those surroundings (the water). Taking in thermal energy from the surroundings, causing a temperature decrease, is the definition of endothermic, so the answer is B.

3 Core Exothermic and endothermic reactions [1]

Answer: A

Worked solution

When the adhesive hardens, chemical bonds form between the two components. The mixture becoming warm shows that thermal energy is being released into the surroundings during this process. A reaction that releases thermal energy to the surroundings, raising its temperature, is exothermic, so the answer is A.

4**Core**

Exothermic and endothermic reactions

[1]

Answer: C

Worked solution

ΔH is defined as the energy of the products minus the energy of the reactants. Here, $\Delta H = (-394) - (0) = -394 \text{ kJ/mol}$. The negative sign shows the products have less energy than the reactants, confirming this is an exothermic reaction (as expected for combustion), so the answer is C.

5**Supplement**

Exothermic and endothermic reactions

[1]

Answer: D

Worked solution

Burning petrol releases thermal energy as heat (and does useful work in the engine), so it is exothermic. By definition, ΔH is negative for exothermic reactions, so the answer is D.

6**Supplement**

Exothermic and endothermic reactions

[1]

Answer: B

Worked solution

Because the limestone only decomposes while it is being heated, thermal energy must constantly be absorbed from the Bunsen burner (or kiln burners) for the reaction to continue. This makes it endothermic, and endothermic reactions have ΔH positive, so the answer is B.

7**Supplement**

Exothermic and endothermic reactions

[1]

Answer: B

Worked solution

Activation energy, E_a , is defined as the minimum energy that colliding particles must have in order to react. Statement B matches this definition exactly, so the answer is B. The other options describe different energy quantities: overall energy released (A), total bond energy of reactants (C), and enthalpy change (D).

8**Supplement**

Exothermic and endothermic reactions

[1]

Answer: A

Worked solution

A catalyst speeds up a reaction by lowering the activation energy needed for particles to react — here, from 165 kJ/mol down to 55 kJ/mol. However, a catalyst does not change the energy of the reactants or the products, so the overall enthalpy change, ΔH , stays exactly the same. The answer is A.

9**Supplement**

Exothermic and endothermic reactions

[1]

Answer: C

Worked solution

Breaking the O=O double bond in oxygen requires an input of energy, since energy must be supplied to pull bonded atoms apart — this is always an endothermic process. Forming the new S=O bonds in sulfur dioxide releases energy, since forming bonds is always exothermic. This matches option C.

10**Supplement**

Exothermic and endothermic reactions

[1]

Answer: A

Worked solution

The Cl–Cl bond must be broken for one chlorine molecule to form two chlorine atoms. Breaking any bond requires energy to be absorbed, making this an endothermic process (the energy comes from the absorbed ultraviolet light). The answer is A.

11**Supplement**

Exothermic and endothermic reactions

[1]

Answer: C

Worked solution

For any reaction, ΔH = energy to break bonds in reactants – energy released forming bonds in products. If the reaction is exothermic overall, this value must be negative, meaning less energy was used breaking bonds than was released forming new ones. This matches option C.

12**Supplement**

Exothermic and endothermic reactions

[1]

Answer: C

Worked solution

First find the energy needed to break the bonds in the reactants: one H–H bond (436) plus one Cl–Cl bond (242), giving 678 kJ/mol. Next find the energy released forming the bonds in the products: two H–Cl bonds are formed (since there are 2 mol of HCl), so $2 \times 431 = 862$ kJ/mol. Then $\Delta H = \text{energy to break bonds} - \text{energy released forming bonds} = 678 - 862 = -184$ kJ/mol. Checking by working backwards: $-184 = 678 - 862 \checkmark$. The negative sign confirms this matches option C.

13**Supplement**

Exothermic and endothermic reactions

[1]

Answer: D

Worked solution

The enzymes in yeast act as a biological catalyst, providing an alternative pathway with a lower activation energy so that more particles can react successfully, which speeds up the decomposition. Since the reactants and products themselves are unchanged, the enthalpy change, ΔH , of the reaction is not affected by the catalyst. This matches option D.

14**Core**

Exothermic and endothermic reactions

[1]

Answer: B

Worked solution

The temperature of the solution rises from 22°C to 34°C, showing that thermal energy is being transferred from the reacting mixture into the surroundings (the solution and the cup). A reaction that releases thermal energy to its surroundings, raising their temperature, is exothermic, so the answer is B.

15**Supplement**

Exothermic and endothermic reactions

[1]

Answer: D

Worked solution

The enthalpy change of the reverse reaction always has the same size but the opposite sign to the forward reaction, because the same amount of energy is involved, just transferred in the opposite direction. Since the forward reaction has $\Delta H = -92$ kJ/mol, the reverse reaction (decomposition of ammonia) has $\Delta H = +92$ kJ/mol. The answer is D.

Mark scheme

(a)

[2]

- a reaction that transfers thermal energy to the surroundings (1)
- causing an increase in the temperature of the surroundings (1)

(b)

[2]

- the temperature of the sachet (the surroundings) rises / increases (1)
- this shows that thermal energy is being released from the reacting iron and oxygen into the surroundings (1)

ALLOW converse phrasing, e.g. "energy is given out, so the temperature goes up"

Worked solution

An exothermic reaction is one that transfers thermal energy to the surroundings, causing the temperature of the surroundings to rise. In the hand warmer, iron reacts slowly with oxygen from the air to form iron(III) oxide. You can tell this reaction is exothermic because the sachet itself gets warm and stays warm for hours — this warmth is thermal energy that has been released by the chemical reaction into the surroundings (the sachet and the air around it, including the person holding it).

Mark scheme

(a) [2]

- a reaction that takes in thermal energy from the surroundings (1)
- causing a decrease in the temperature of the surroundings (1)

(b) [2]

- positive / +ve (1)
- because the process is endothermic — thermal energy is taken in from the surroundings, shown by the fall in temperature (1)

ALLOW ECF from (a) if the reasoning is internally consistent

(c) [2]

- above / higher than the reactants (1)
- because in an endothermic process the products end up with more energy than the reactants — energy has been absorbed into the products (1)

Worked solution

An endothermic reaction takes in thermal energy from the surroundings, cooling them down. Here, the temperature of the water falls from 21°C to 9°C, showing that dissolving ammonium nitrate absorbs thermal energy from the water. Since the process is endothermic, ΔH is positive. On a reaction pathway diagram, this means the products (the dissolved ions) are drawn above the reactants (the solid and water), because energy has flowed into the system to form them — the gap between the reactant and product energy levels represents the ΔH value, which is positive here.

Mark scheme

(a) [1]

- $E_a = 160 - 100 = 60 \text{ kJ}$

ALLOW kJ/mol as the unit throughout this question

(b) [2]

- $\Delta H = \text{energy of products} - \text{energy of reactants}$ (1)
- $\Delta H = 20 - 100 = -80 \text{ kJ}$ (1)

(c) [2]

- exothermic (1)
- because the products are at a lower energy than the reactants, so energy has been released to the surroundings (1)

ECF from (b)

(d) [1]

- $E_a(\text{reverse}) = 160 - 20 = 140 \text{ kJ}$

Worked solution

The activation energy is the difference between the energy of the reactants and the highest point on the pathway: $160 - 100 = 60 \text{ kJ}$ for the forward reaction. The enthalpy change is the difference between the energy of the products and the energy of the reactants: $20 - 100 = -80 \text{ kJ}$. Because this is negative, the products end up with less energy than the reactants, so the reaction is exothermic — the "extra" 80 kJ has been released to the surroundings. For the reverse reaction, the activation energy is measured from the products up to the same highest point: $160 - 20 = 140 \text{ kJ}$. Notice the reverse activation energy (140 kJ) is larger than the forward one (60 kJ) by exactly 80 kJ, which is the size of ΔH — this is always true for a reversible reaction.

Mark scheme

(a) [2]

- exothermic (1)
- because energy (thermal energy) is released, transferred to the surroundings, during the reaction (1)

(b) [2]

- endothermic (1)
- because energy (thermal energy) must be absorbed, taken in from sunlight, for the reaction to occur (1)

(c) [1]

- they are the reverse of each other / the reactants and products of one are the products and reactants of the other

ALLOW respiration releases the energy that photosynthesis originally stored in glucose**Worked solution**

Respiration breaks down glucose using oxygen and releases energy that the cell can use for its life processes, so it is exothermic. Photosynthesis does the opposite: it uses energy absorbed from sunlight to build glucose from carbon dioxide and water, so it is endothermic. The two equations are exact reverses of one another, and the energy released by respiration is ultimately the same energy that was stored in the glucose during photosynthesis — energy is being passed from sunlight, into glucose, and then released again for the cell to use.

Mark scheme

(a) [2]

- endothermic (1)
- because thermal energy must continually be taken in (from the Bunsen burner) for the reaction to continue — shown by the need for constant heating (1)

(b) [2]

- the minimum energy (1)
- that colliding particles must have in order to react (1)

(c) [2]

- (i) the activation energy would decrease / be lowered, because the catalyst provides an alternative reaction pathway (1)
- (ii) the enthalpy change, ΔH , would stay the same / be unaffected (1)

Worked solution

Copper(II) carbonate only breaks down while it is being heated, showing that thermal energy must be continuously supplied for the reaction to keep going — this makes it endothermic. Activation energy is the minimum energy that colliding particles need in order to react. A catalyst works by offering an alternative reaction pathway with a lower activation energy, so more particles can react successfully at a given temperature. However, adding a catalyst never changes the energy of the reactants or products themselves, so it has no effect on the overall enthalpy change, ΔH , of the reaction.

Mark scheme

(a)

[2]

- one C=C bond and one H-H bond are broken (1)
- $612 + 436 = 1048$ kJ (1)

ALLOW counting every bond in the reactants, $(4 \times 413) + 612 + 436 = 2700$ kJ (2)

(b)

[2]

- one C-C bond and two (new) C-H bonds are formed (1)
- $347 + (2 \times 413) = 347 + 826 = 1173$ kJ (1)

ALLOW counting every bond in the product, $(6 \times 413) + 347 = 2825$ kJ (2), only if every reactant bond was also counted in (a)

(c)

[3]

- $\Delta H = \text{energy to break bonds} - \text{energy released forming bonds}$ (1)
- $\Delta H = 1048 - 1173 = -125$ kJ/mol (1)
- exothermic (1)

ECF from (a) and (b)

ALLOW $2700 - 2825 = -125$ kJ/mol from the count-every-bond method

REJECT mixing the two methods, e.g. $1048 - 2825 = -1777$ kJ/mol; award the method mark only

Worked solution

In this reaction, the C=C double bond in ethene and the H-H bond in hydrogen are broken, while a new C-C single bond and two new C-H bonds are formed (the four C-H bonds already present in ethene are unchanged, so they are not counted). Breaking bonds needs $612 + 436 = 1048$ kJ. Forming the new bonds releases $347 + (2 \times 413) = 1173$ kJ. So $\Delta H = 1048 - 1173 = -125$ kJ/mol. Since more energy is released forming bonds than is needed to break them, the reaction is exothermic, which fits with hydrogenation reactions being used industrially without needing to add much extra energy.

Mark scheme

(a) [2]

- $(2 \times 436) + 496$ (1)
- $= 1368$ kJ (1)

(b) [2]

- 2 mol of H_2O contain 4 O–H bonds in total; 4×463 (1)
- $= 1852$ kJ (1)

(c) [2]

- $\Delta H = 1368 - 1852 = -484$ kJ/mol (1)
- exothermic (1)

ECF from (a) and (b)**Worked solution**

The reactants contain two H–H bonds and one O=O bond, so the energy needed to break them all is $(2 \times 436) + 496 = 1368$ kJ. The products are 2 mol of H_2O , and each water molecule has two O–H bonds, so 4 O–H bonds form in total, releasing $4 \times 463 = 1852$ kJ. The enthalpy change is $\Delta H = 1368 - 1852 = -484$ kJ/mol. This is negative, so the reaction is exothermic, which is why hydrogen fuel cells can be used to generate useful energy.

Mark scheme

(a) [2]

- it is the activation energy (1)
- the minimum energy that colliding particles (hydrogen peroxide molecules) must have in order to react (1)

(b) [2]

- the catalyst provides an alternative reaction pathway with a lower activation energy (1)
- so a greater proportion of particles have enough energy to react when they collide, which increases the rate of reaction (1)

(c) [2]

- -98 kJ/mol (1)
- because a catalyst only provides an alternative pathway (changes the activation energy) — it does not change the energy of the reactants or products, so ΔH is unaffected (1)

Worked solution

The 75 kJ/mol figure is the activation energy without a catalyst — the minimum energy that colliding hydrogen peroxide molecules need in order to react. Manganese(IV) oxide works as a catalyst by providing a different reaction pathway that needs only 25 kJ/mol of activation energy. Since more particles will have this lower amount of energy at a given temperature, more successful collisions happen per second, so the reaction goes faster. However, the catalyst does not alter the reactants or products, so the enthalpy change stays at -98 kJ/mol whether or not the catalyst is used.

Mark scheme

(a)

[1]

- $27.5 - 19.5 = 8.0\text{ }^{\circ}\text{C}$

(b)

[2]

- a reaction that transfers thermal energy to the surroundings (1)
- causing an increase in the temperature of the surroundings (1)

(c)

[3]

- the temperature of the mixture (the surroundings) increases, from 19.5°C to a maximum of 27.5°C (1)
- this shows that thermal energy is being released by the reaction (1)
- into the surroundings (the solution/cup), which matches the definition of an exothermic reaction (1)

ALLOW ECF from (a)**Worked solution**

The highest recorded temperature is 27.5°C , so the temperature rise is $27.5 - 19.5 = 8.0^{\circ}\text{C}$. An exothermic reaction is one that transfers thermal energy to the surroundings, causing their temperature to rise. Because the temperature of the acid-alkali mixture rises as the two solutions react, thermal energy must be flowing out of the reacting particles and into the surroundings (the solution itself, which is being measured). This matches the definition of an exothermic reaction, confirming that neutralisation is exothermic.

Mark scheme

(a)

[2]

- the heat pack (the iron reacting with air) (1)
- because thermal energy is transferred to the surroundings, shown by the temperature rise / it becoming warm (1)

(b)

[3]

- the cold spray (the chemical dissolving in water) (1)
- because thermal energy is taken in from the surroundings (1)
- shown by the temperature falling / it becoming cold (1)

Worked solution

The heat pack becomes warm because the reaction between iron and oxygen releases thermal energy into its surroundings — this release of energy, shown by the rise in temperature, is what makes a reaction exothermic. The cold spray becomes cold because the chemical dissolving inside it absorbs thermal energy from its surroundings (including your skin) rather than releasing it — this absorption of energy, shown by the fall in temperature, is what makes a process endothermic.

Mark scheme

(a) [2]

- $944 + (3 \times 436)$ (1)
- $= 2252$ kJ (1)

(b) [2]

- 2 mol NH_3 contain 6 N–H bonds in total; 6×391 (1)
- $= 2346$ kJ (1)

(c) [2]

- $\Delta H = 2252 - 2346 = -94$ kJ/mol (1)
- exothermic (1)

ECF from (a) and (b)

(d) [1]

- endothermic; $\Delta H = +94$ kJ/mol

ALLOW ECF from (c), with the sign reversed and the same size**Worked solution**

Breaking the reactant bonds needs 944 ($\text{N} \equiv \text{N}$) + (3×436) ($\text{H}-\text{H}$) = 2252 kJ. Each ammonia molecule has 3 N–H bonds, so 2 mol of NH_3 contain 6 N–H bonds, releasing $6 \times 391 = 2346$ kJ when they form. So $\Delta H = 2252 - 2346 = -94$ kJ/mol, showing the forward reaction is exothermic. Because the reaction is reversible, the reverse reaction (ammonia decomposing back into nitrogen and hydrogen) must have exactly the opposite enthalpy change: $+94$ kJ/mol, making it endothermic.

Mark scheme

(a)

[2]

- +196 kJ/mol (1)
- because the reverse of an exothermic reaction is endothermic, with the same size of enthalpy change but the opposite sign (1)

(b)

[2]

- $E_a(\text{reverse}) = E_a(\text{forward}) - \Delta H(\text{forward}) = 250 - (-196)$ (1)
- = 446 kJ/mol (1)

ALLOW ECF from (a)

(c)

[2]

- the reverse reaction (1)
- because the products (SO_3) are at a lower energy than the reactants (the forward reaction is exothermic), so the reverse reaction must climb from this lower level to the same peak, i.e.
 $E_a(\text{reverse}) = E_a(\text{forward}) + 196$ (1)

ALLOW the reverse reaction is endothermic, so its activation energy includes the energy needed to raise the products up to the reactant level**Worked solution**

Since the forward reaction is exothermic with $\Delta H = -196$ kJ/mol, the reverse reaction must be endothermic with $\Delta H = +196$ kJ/mol — the same size, opposite sign. On a reaction pathway diagram, the activation energy for the reverse reaction is measured from the (lower) product energy level up to the same peak that the forward reaction is measured from, so $E_a(\text{reverse}) = E_a(\text{forward}) + 196 = 250 + 196 = 446$ kJ/mol. Because the products are much lower in energy than the reactants (a large exothermic ΔH), the reverse reaction has to climb a much bigger energy hill, which is why its activation energy is so much higher than the forward reaction's.

Mark scheme

(a) [2]

- sodium hydroxide: $+12.5^{\circ}\text{C}$ (an increase) (1)
- ammonium chloride: -5.5°C (a decrease) (1)

ALLOW a fall / decrease of 5.5°C without a minus sign

(b) [2]

- exothermic (1)
- because the temperature of the surroundings (the water) increases, showing thermal energy is being released to the surroundings (1)

(c) [2]

- endothermic (1)
- because the temperature of the surroundings (the water) decreases, showing thermal energy is being taken in from the surroundings (1)

Worked solution

Sodium hydroxide's temperature rises by $32.5 - 20.0 = 12.5^{\circ}\text{C}$, while ammonium chloride's temperature falls by $20.0 - 14.5 = 5.5^{\circ}\text{C}$. A temperature rise means thermal energy has been released into the water, so dissolving sodium hydroxide is exothermic. A temperature fall means thermal energy has been absorbed from the water, so dissolving ammonium chloride is endothermic. This shows that dissolving is not always the same type of process — it depends on the particular substance being dissolved.

Mark scheme

(a)

[2]

- breaking bonds is endothermic (1)
- making bonds is exothermic (1)

(b)

[3]

- energy must be absorbed to break the bonds in the reactants (ethanol and oxygen) (1)
- energy is released when the new bonds in the products (carbon dioxide and water) form (1)
- because more energy is released forming the new bonds than is absorbed breaking the old ones, the overall reaction releases energy / is exothermic (1)

Worked solution

Breaking any chemical bond always requires an input of energy (endothermic), while forming any new bond always releases energy (exothermic). When ethanol burns, energy must first be absorbed to break the C–C, C–H, C–O, O–H and O=O bonds in the reactants. Then energy is released as new C=O and O–H bonds form in the carbon dioxide and water produced. Combustion reactions like this are exothermic overall because the amount of energy released forming the new, more stable bonds in the products is greater than the amount of energy absorbed breaking the bonds in the reactants — the surplus energy is released to the surroundings as heat.

Mark scheme

(a) [2]

- $(4 \times 413) + (2 \times 496)$ (1)
- $= 1652 + 992 = 2644$ kJ (1)

(b) [2]

- CO_2 contains 2 C=O bonds; $2\text{H}_2\text{O}$ contains 4 O–H bonds; $(2 \times 805) + (4 \times 463)$ (1)
- $= 1610 + 1852 = 3462$ kJ (1)

(c) [3]

- $\Delta H = \text{energy to break bonds} - \text{energy released forming bonds}$ (1)
- $\Delta H = 2644 - 3462 = -818$ kJ/mol (1)
- exothermic (1)

| ECF from (a) and (b)

(d) [1]

- lower; because the reaction is exothermic, the products have less energy than the reactants

| ECF from (c)

Worked solution

Breaking the four C–H bonds in methane and the two O=O bonds in oxygen needs $(4 \times 413) + (2 \times 496) = 2644$ kJ. The products are one CO_2 molecule (with 2 C=O bonds) and two H_2O molecules (with 4 O–H bonds in total), so forming these releases $(2 \times 805) + (4 \times 463) = 3462$ kJ. This gives $\Delta H = 2644 - 3462 = -818$ kJ/mol, confirming that methane combustion is strongly exothermic, as expected for a fuel used for heating. On a reaction pathway diagram, this means the products would be drawn at a lower energy level than the reactants, with the large drop in energy between them representing the ΔH value released to the surroundings.