5.1 ENTHALPY CHANGE

Introduction

1. Which process has the largest enthalpy change per mole?

   A $Al^{3+}(g) \rightarrow Al^{4+}(g) + e^-$

   B $P^{5+}(g) \rightarrow P^{6+}(g) + e^-$

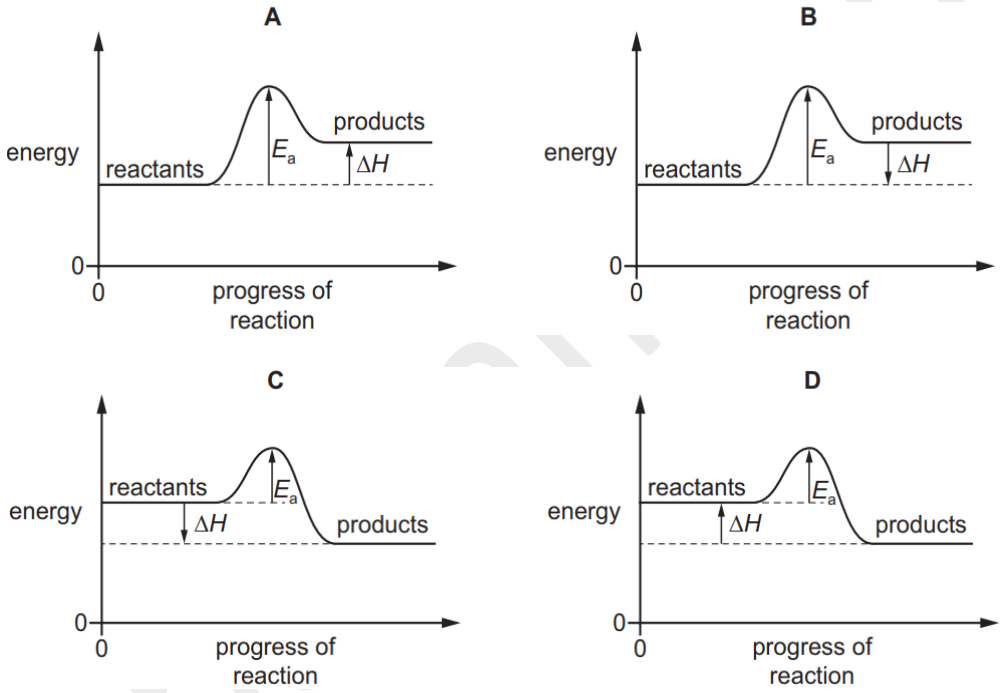
   C $S^{6+}(g) \rightarrow S^{7+}(g) + e^-$

   D $Si^{4+}(g) \rightarrow Si^{5+}(g) + e^-$

2. Nitrogen monoxide is an atmospheric pollutant that is formed inside car engines by an **endothermic** reaction between nitrogen and oxygen.

   $N_2(g) + O_2(g) \rightarrow 2NO(g)$

   Which diagram correctly represents the energy profile for this reaction?

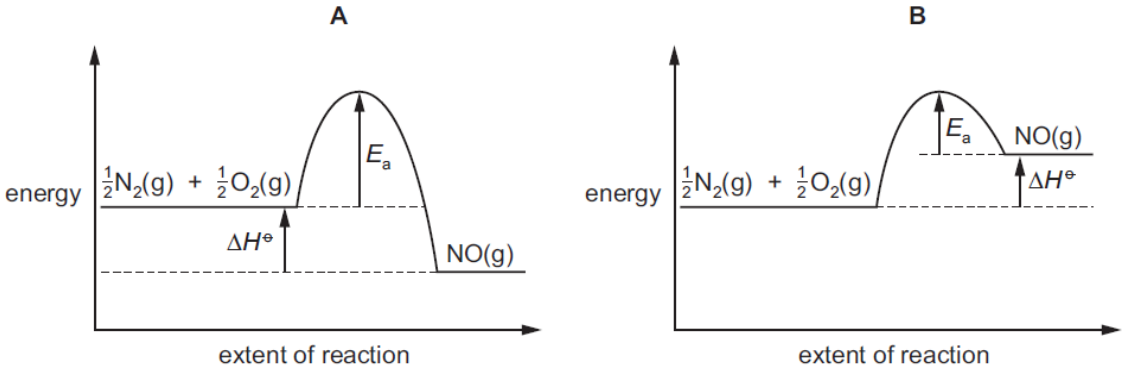


3. In the high temperatures of car engines, nitrogen reacts with oxygen to produce nitrogen monoxide.

   1/2 $N_2(g)$ + 1/2 $O_2(g)$ → NO(g) $\Delta H^{\ominus}$ = +90 kJ mol–1

   This reaction has activation energy Ea.

   Which reaction pathway diagram correctly represents this reaction?



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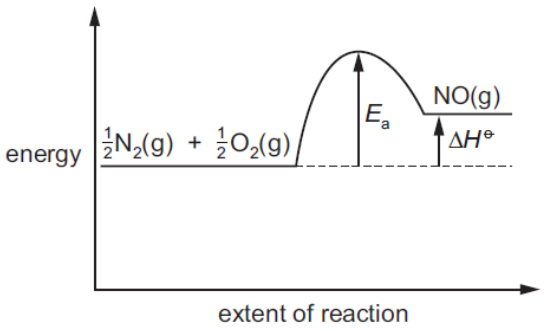

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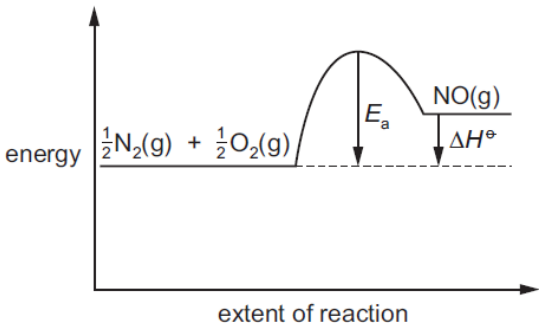
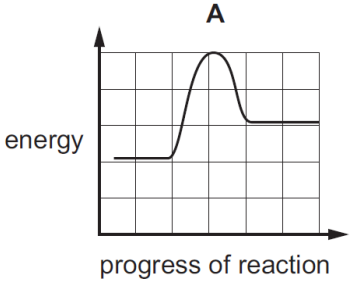


4. For a certain endothermic reaction, the activation energy is numerically equal to twice the enthalpy change of reaction. Which reaction pathway diagram is correct for this reaction?

A



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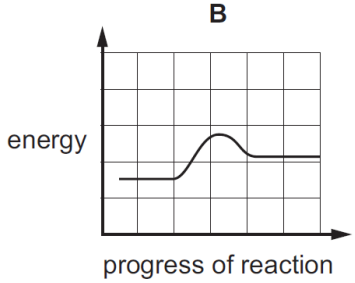

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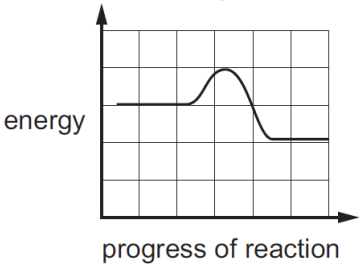

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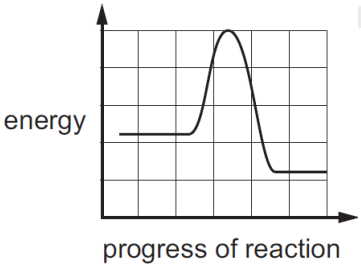
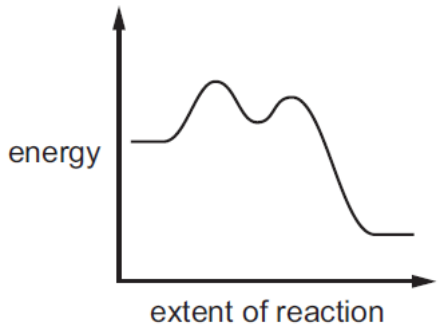


5. Which reaction pathway diagram shows an endothermic reaction that occurs in two steps and in which the second step of the reaction is likely to be faster than the first?

A



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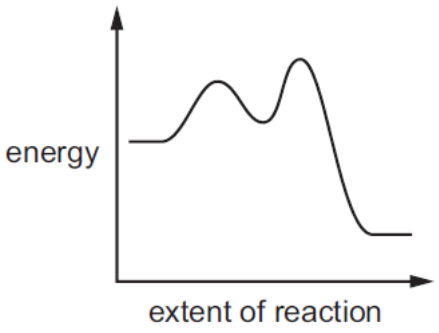

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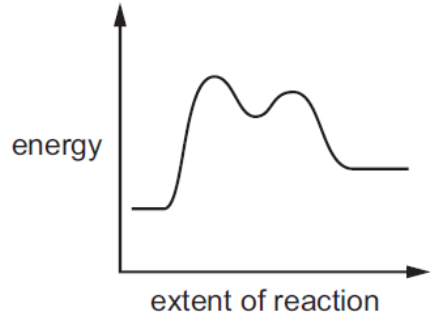

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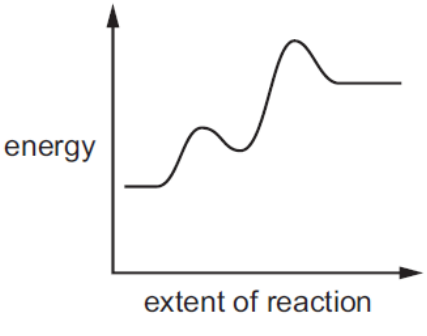


6. The enthalpy changes for the possible reactions W, X, Y and Z are given.

W NaOH(aq) + HCl (aq) → NaCl (aq) + H_2O(l) ΔH^o = –56 kJ mol^{-1}
X NaCl (aq) + H_2O(l) → NaOH(aq) + HCl (aq) ΔH^o = +56 kJ mol^{-1}
Y 2HI(g) → H_2(g) + I_2(g) ΔH^o = +11 kJ mol^{-1}
Z H_2(g) + I_2(g) → 2HI(g) ΔH^o = –11 kJ mol^{-1}

Which statement about the activation energies of these reactions is correct?

A X is greater than W; Z is greater than Y.
B X is greater than W; Y is greater than Z.
C W is greater than X; Z is greater than Y.
D W is greater than X; Y is greater than Z.

7. One commercially available 'heat pad' contains iron, activated carbon and water. The 'heat pad' is activated by air. This causes the pad to get hotter.
Which statement describes the chemical reaction occurring in the 'heat pad' when it is exposed to air?

A The reaction is endothermic and iron gains electrons.
B The reaction is endothermic and iron loses electrons.
C The reaction is exothermic and iron gains electrons.
D The reaction is exothermic and iron loses electrons.

8. All the reactants and products of an exothermic reaction are gaseous.
Which statement about this reaction is correct?

A The total bond energy of the products is less than the total bond energy of the reactants, and ΔH for the reaction is negative.
B The total bond energy of the products is less than the total bond energy of the reactants, and ΔH for the reaction is positive.
C The total bond energy of the products is more than the total bond energy of the reactants, and ΔH for the reaction is negative.
D The total bond energy of the products is more than the total bond energy of the reactants, and ΔH for the reaction is positive.

Enthalpy Change

9. The equation for a chemical reaction is shown. All substances are in their standard states.

$XeF_6 + 3H_2O \rightarrow XeO_3 + 6HF$

Which statement describes the standard enthalpy change of reaction for this reaction?

A the enthalpy change when a total of one mole of products is produced
B the enthalpy change when a total of one mole of reactants is reacted
C the enthalpy change when one mole of water reacts
D the enthalpy change when six moles of hydrogen fluoride are produced

Standard enthalpy change of formation, ΔH_f

10. Which equation has an enthalpy change equal to the standard enthalpy of formation of sodium oxide?

A Na(s) + 1/4 O_2(g) → 1/2 Na_2O(s)
B Na(s) + O_2(g) → Na_2O(s)
C 2Na(s) + 1/2 O_2(g) → Na_2O(s)
D 4Na(s) + O_2(g) → 2Na_2O(s)

11. For which equation is the enthalpy change correctly described as an enthalpy change of formation?

A $C(g) + O_2(g) \rightarrow CO_2(g)$
B $C(s) + ½ O_2(g) \rightarrow CO(g)$
C $2N(g) + 4O(g) \rightarrow N_2O_4(g)$
D $2NO(g) + O_2(g) \rightarrow 2NO_2(g)$

12. For which equation is the enthalpy change correctly described as an enthalpy change of formation?

A $2NO(g) \rightarrow N_2(g) + O_2(g)$
B $2CO(g) + O_2(g) \rightarrow 2CO_2(g)$
C $H_2O(l) + NaCl(s) \rightarrow NaCl(aq)$
D $K(s) + Mn(s) + 2O_2(g) \rightarrow KMnO_4(s)$

13. Which equation represents the reaction whose standard enthalpy change is the standard enthalpy change of formation of water?

A $2H_2(g) + O_2(g) \rightarrow 2H_2O(l)$
B $H_2(g) + ½ O_2(g) \rightarrow H_2O(l)$
C $H^+(aq) + OH^-(aq) \rightarrow H_2O(l)$
D $2H(g) + O(g) \rightarrow H_2O(l)$

14. Which reaction has an enthalpy change equal to the standard enthalpy change of formation of propane?

A $3C(g) + 4H_2(g) \rightarrow C_3H_8(g)$
B $3C(g) + 8H(g) \rightarrow C_3H_8(g)$
C $3C(s) + 4H_2(g) \rightarrow C_3H_8(g)$
D $3C(s) + 4H_2(g) \rightarrow C_3H_8(l)$

15. The equation for the reaction of nitrogen with hydrogen is shown.
$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$ $\Delta H_r^\ominus = -92.2$ kJ mol^{-1}
Which statement is correct?

A $\Delta H_r^\ominus$ is measured at 298 °C.
B $\Delta H_r^\ominus$ is measured at 101 kPa.
C $\Delta H_r^\ominus$ represents the standard enthalpy change for the formation of ammonia gas.
D $\Delta H_r^\ominus$ represents the enthalpy change when 1.0 mol of $N_2(g)$ reacts with 1.0 mol of $H_2(g)$.

16. Skiers trapped by snowstorms use heat packs to keep warm. The heat may be generated by the reaction below.

$4Fe(s) + 3O_2(g) \rightarrow 2Fe_2O_3(s)$; $\Delta H = -1648$ kJ

What is the standard enthalpy change of formation of iron(III) oxide?

A 0 kJ mol^{-1} **B** –824 kJ mol^{-1} **C** –1648 kJ mol^{-1} **D** –3296 kJ mol^{-1}

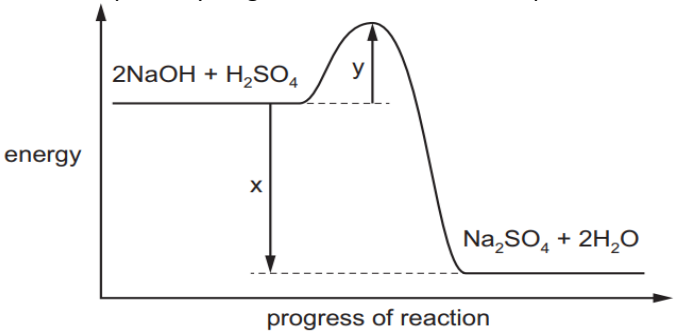
17. The equation for a reaction is shown.
$H_2(g) + ½ O_2(g) \rightarrow H_2O(l)$; $\Delta H = x$ kJ mol^{-1}
Which pair of descriptions is fully correct for this reaction?

	type(s) of enthalpy change	value of *x*
A	formation only	positive
B	formation only	negative
C	combustion, formation	positive
D	combustion, formation	negative

18. What is the definition of enthalpy change of neutralization $\Delta H^{\ominus}_{neut}$?

A $\Delta H^{\ominus}_{r}$ when one mole of an aqueous acid is neutralised by an aqueous alkali.
B $\Delta H^{\ominus}_{r}$ when one mole of an aqueous alkali is neutralised by an aqueous acid.
C $\Delta H^{\ominus}_{r}$ when one mole of an aqueous acid is neutralised by one mole of an aqueous alkali.
D $\Delta H^{\ominus}_{r}$ when an aqueous acid and an aqueous alkali react together to produce one mole of water.

19. A reaction pathway diagram for the reaction of aqueous sodium hydroxide and dilute sulfuric acid is shown.



What is the value of the enthalpy change of neutralisation, ΔH_{neut}?

A x B **x – y** C **x/2** D **(x-y)/2**

20. Which statement about enthalpy changes is correct?

A Enthalpy changes of reaction are always negative.
B Enthalpy changes of combustion are always positive.
C Enthalpy changes of formation are always positive.
D Enthalpy changes of neutralisation are always negative.

21. Three processes are described.
1 H+(aq) + OH–(aq) ⟶ H2O(l)
2 CH4(g) + 2O2(g) ⟶ CO2(g) + 2H2O(l)
3 NH3(g) ⟶ NH3(l)
Which statement is correct?

A None of the processes have a positive enthalpy change.
B Only process 1 has a positive enthalpy change.
C Only process 2 has a positive enthalpy change.
D Only process 3 has a positive enthalpy change.

22. The reaction of hydrogen with oxygen is shown.
$2H_2(g) + O_2(g) \longrightarrow 2H_2O(l)$
Which expression corresponds to the standard enthalpy change of this reaction?

A $2 \times \Delta H^{\ominus}_{f}(H_2O)$
B $\Delta H^{\ominus}_{c}(H_2O) - \Delta H^{\ominus}_{c}(H_2)$
C $\Delta H^{\ominus}_{c}(H_2)$
D $2 \times \Delta H^{\ominus}_{f}(H_2O) + 2 \times \Delta H^{\ominus}_{c}(H_2)$

23. The equation for the reaction of nitrogen with hydrogen is shown.
$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$ $\Delta H_r^{\ominus} = -92.2$ kJ mol^{-1}
Which statement is correct?

A $\Delta H_r^{\ominus}$ is measured at 298 °C.
B $\Delta H_r^{\ominus}$is measured at 101 kPa.
C $\Delta H_r^{\ominus}$ represents the standard enthalpy change for the formation of ammonia gas.
D $\Delta H_r^{\ominus}$ represents the enthalpy change when 1.0 mol of $N_2(g)$ reacts with 1.0 mol of $H_2(g)$.

24. The table shows bond energies for some diatomic molecules. Deuterium, D, is an isotope of hydrogen.

Energy, / kJ mol–1	bond
158	F–F
242	Cl–Cl
193	Br–Br
151	*I–I*
436	H–H
442	D–D

Which statements are correct?
1. Diatomic molecules have exact values for their bond energies, which are always positive.
2. The trend in Group 7 bond energies can be explained by the variation in instantaneous dipole–induced dipole (id–id) forces.
3. A value for the enthalpy change for the reaction between deuterium and chlorine can be calculated using these data alone.

A 1 only **B** 1 and 2 only **C** 1 and 3 only **D** 2 and 3 only

25. Some bond energies are listed.

bond energy / kJ mol^{-1}	bond
436	H–H
463	O–H
146	O–O
496	O=O

One mole of hydrogen reacts with oxygen to give water vapour.
Using the bond energy data, what is the value for the enthalpy change of this reaction?

A +221 kJ mol^{-1} **B** +6 kJ mol^{-1} **C** –242 kJ mol^{-1} **D** –417 kJ mol^{-1}

26. Ethane can react with fluorine to produce 1,2-difluoroethane, $C_2H_4F_2$.

$C_2H_6 + 2F_2 \rightarrow C_2H_4F_2 + 2HF \quad \Delta H = -960$ kJ mol^{-1}

	bond energy/ kJ mol^{-1}
C–H	410
C–C	350
F–F	158
H–F	562

What is the bond energy of the C–F bond in 1,2-difluoroethane?

A 407 kJ mol^{-1} **B** 474 kJ mol^{-1} **C** 486 kJ mol^{-1} **D** 972 kJ mol^{-1}

27. Nitrogen and oxygen can react together to form nitrogen monoxide, NO.
$N_2 + O_2 \rightarrow 2NO \quad \Delta H = +180 \text{ kJ mol}^{-1}$
What is the bond energy of the bond between the atoms in NO?

A 630 kJ mol^{-1} **B** 810 kJ mol^{-1} **C** 1260 kJ mol^{-1} **D** 1620 kJ mol^{-1}

28. When 1.0 mol of ethanoic acid, CH_3COOH, in aqueous solution is neutralised by an excess of aqueous sodium hydroxide, 55 kJ mol–1 of energy is released.
Which statement about this reaction is correct?

A The reaction is exothermic because only bond breaking takes place.
B The reaction is exothermic because only bond forming takes place.
C The reaction is exothermic because more energy is given out in breaking bonds than is taken in to form bonds.
D The reaction is exothermic because more energy is given out in forming bonds than is taken in to break bonds.

Measuring enthalpy changes

29. In an experiment, 1.60 g of a fuel is burnt. 45.0% of the energy released is absorbed by 200 g of water. The temperature of the water rises from 18.0 °C to 66.0 °C.
What is the total energy released per gram of fuel burnt?

A 25 100 J B 55 700 J C 89 200 J D 143 000 J

30. A student mixes 25.0 cm^3 of 0.350 mol dm^{-3} sodium hydroxide solution with 25.0 cm^3 of 0.350 mol dm^{-3} hydrochloric acid. The temperature increases by 2.5 °C. No heat is lost to the surroundings.
The final mixture has a specific heat capacity of 4.2 J cm^{-3} K^{-1}.
What is the molar enthalpy change for the reaction?

A –150 kJ mol^{-1} **B** –60 kJ mol^{-1} C –30 kJ mol^{-1} D –0.15 kJ mol^{-1}

31. A student mixed 25.0 cm^3 of 4.00 mol dm^{-3} hydrochloric acid with an equal volume of 4.00 mol dm^{-3} sodium hydroxide. The initial temperature of both solutions was 15.0°C. The maximum temperature recorded was 30.0°C. The heat capacity of the final solution can be assumed to be 4.18 J $K^{-1}g^{-1}$ and the density of this solution can be assumed to be 1.00 g cm^{-3}.
Using these results, what is the enthalpy change of neutralisation of hydrochloric acid?

A –62.7 kJ mol^{-1} **B** –31.4 kJ mol^{-1} **C** –15.7 kJ mol^{-1} **D** –3.14 kJ mol^{-1}

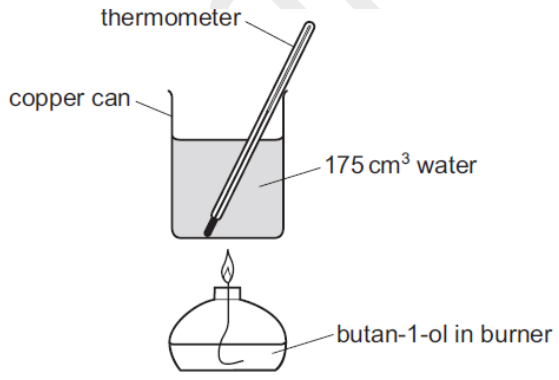
32. The enthalpy change for neutralisation of $HNO_3(aq)$ with NaOH(aq) is –57.0 kJ mol^{-1}.
In an experiment, 20.0 cm^3 of 4.00 mol dm^{-3} HNO_3 is mixed with 30.0 cm^3 of 2.00 mol dm^{-3} NaOH in an insulated container. The initial temperature of both solutions is 25.0 °C.
It can be assumed that the heat capacity of the product mixture is 4.2 J $cm^{-3}°C^{-1}$ and that there are no heat losses.
What is the maximum final temperature of the mixture?

A **41.3°C** B 44.0°C C 46.7°C D 52.1°C

33. In an experiment to calculate the enthalpy change of combustion of a fuel, 1.5 g (0.0326 mol) of the fuel was used to heat 200 g of water. The temperature of the water rose from 25 °C to 55 °C. The specific heat capacity of water is 4.18 J $g^{-1}K^{-1}$.
There is significant heat loss in this experiment. Therefore, the experimental value for theenthalpy change of combustion, ΔH_c, of the fuel will be different from the theoretical value.
Using the information above, what is the experimental value for the enthalpy change of combustion, ΔH_c, of the fuel?

A –1410 kJ mol^{-1} **B** –769 kJ mol^{-1} **C** –30.7 kJ mol^{-1} **D** –16.7 kJ mol^{-1}

34. The apparatus used to determine a value for the enthalpy of combustion of butan-1-ol is shown.
The mass of 1.00 cm^3 of water is 1.00 g. (butan-1-ol Mr = 74)

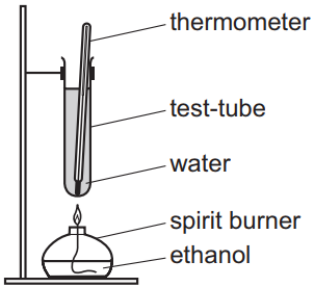


initial mass of burner + butan-1-ol	58.34 g
initial temperature of water	17.6 °C
final mass of burner + butan-1-ol	57.85 g
final temperature of water	41.1 °C

Which value, to three significant figures, for the enthalpy of combustion of butan-1-ol can be calculated from these data?

A –114 J mol^{-1} **B** –17.2 kJ mol^{-1} **C** –2600 kJ mol^{-1} **D** –4540 kJ mol^{-1}

35. An experiment was performed to determine the enthalpy of combustion of ethanol.

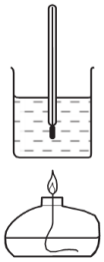


The data collected are shown.
mass of water = W g
mass of ethanol burned = X g
temperature rise = Y°C
molar mass of ethanol = Z g mol^{-1}
specific heat capacity of water = 4.2 $JK^{-1}g^{-1}$

Which expression can be used to calculate the enthalpy of combustion of ethanol in $kJmol^{-1}$?

A $\frac{-4.2WYZ}{1000X}$ **B** $\frac{-4.2WYX}{1000Z}$ **C** $\frac{-4.2XYZ}{1000W}$ **D** $\frac{-4.2X(Y+273)Z}{1000W}$

36. Use of the Data Booklet is relevant to this question.
A student carried out an experiment to determine the enthalpy change for the combustion of methanol. The following results were obtained by the student.



start temperature of the water	20°C
final temperature of the water	53°C
mass of alcohol burner before burning	259.65g
mass of alcohol burner after	259.15g
mass of glass beaker plus water	150.00g
mass of glass beaker	50.00g

How much of the heat energy produced by the burning of methanol went into the water?

A 209J **B 13 794J** **C** 20 691J **D** 22 154J

37. In order to determine the enthalpy of neutralisation of a strong acid and a strong alkali, 25.0 cm^3 of 2.00 mol dm^{-3} sodium hydroxide is added to 25.0 cm^3 of 2.00 mol dm^{-3} hydrochloric acid. The increase in temperature is 12 °C. In a second experiment, the same method is used, but 50.0 cm^3 of 2.00 mol dm^{-3} sodium hydroxide is added to 50.0 cm^3 of 2.00 mol dm^{-3} hydrochloric acid. What is the increase in temperature in the second experiment?

A 6 °C **B** 12 °C **C** 24 °C **D** 48 °C

38. In an experiment to measure the enthalpy change of neutralisation of hydrochloric acid, 20 cm^3 of solution containing 0.04 mol of HCl is placed in a plastic cup of negligible heat capacity.
A 20 cm^3 sample of aqueous sodium hydroxide containing 0.04 mol of NaOH, at the same initial temperature, is added and the temperature rises by 15 K.
If the heat capacity per unit volume of the final solution is 4.2 J $K^{-1}cm^{-3}$, what is the enthalpy change of neutralisation of hydrochloric acid?

A $\frac{20 \times 4.2 \times 15}{0.04}$ J mol^{-1}

B $40 \times 4.2 \times 15 \times 0.08$ J mol^{-1}

C $\frac{40 \times 4.2 \times 15}{0.04}$ J mol^{-1}

D $\frac{20 \times 4.2 \times 15}{0.08}$ J mol^{-1}

39. A student mixes 25.0 cm^3 of 0.100 mol dm^{-3} sodium hydroxide solution with 25.0 cm^3 of 0.100 mol dm^{-3} hydrochloric acid and the student records a temperature rise of 2.50 °C.
What is the enthalpy change of the reaction per mole of NaOH?

A –209 kJ mol^{-1}
B –104.5 kJ mol^{-1}
C –209 J mol^{-1}
D –522.5 J mol^{-1}

40. 50 cm^3 of 1.0 mol dm^{-3} H_2SO_4 is added to 100 cm^3 of 1.0 mol dm^{-3} NaOH in an insulated vessel.
Both solutions are at a temperature of 20 °C before mixing. After mixing, the temperature rises and the highest temperature reached is 29 °C.
Assume that:
- all the energy released in the reaction goes into raising the temperature of the aqueous reaction mixture
- the specific heat capacity of the mixture is 4.2 J cm^{-3} K^{-1}.

What is the value of the enthalpy of neutralisation determined from this experiment?

A –113.4 kJ mol^{-1}
B –56.7 kJ mol^{-1}
C –37.8 kJ mol^{-1}
D –18.9 kJ mol^{-1}

41. When 0.47 g of a hydrocarbon is completely burnt in air, the energy released heats 200 g of water from 23.7 °C to 41.0 °C.
What is the amount of energy absorbed, in Joules, by the water?

A 0.47 x 4.18 x 17.3
B 0.47 x 4.18 x (273 + 17.3)
C 200 x 4.18 x 17.3
D 200 x 4.18 x (273 + 17.3)

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