1.

The equation for reaction 1 is shown.

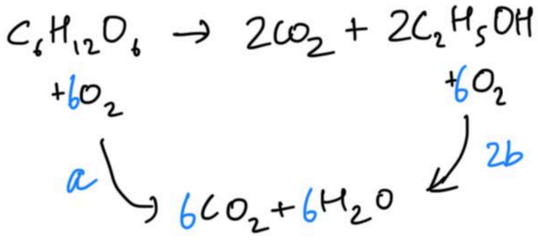
reaction 1 $C_6H_{12}O_6 \rightarrow 2CO_2 + 2C_2H_5OH$

	$\Delta H^{\ominus}_{c}$ / kJ mol^{-1}
$C_6H_{12}O_6$	a
C_2H_5OH	b

What is the correct expression for the enthalpy change of reaction 1?

A $a + b$ **B** $a - b$ **C** $a + 2b$ **D** $a - 2b$

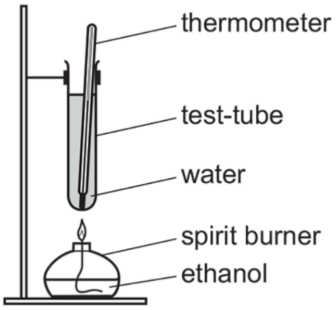
Ans: D



$\boxed{a - 2b}$

2.

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 J K^{-1} g^{-1}

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

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

Ans: A

$\Delta H = -mc\Delta T$ (ΔH is −ve ∵ combustion)

$\Delta H = -W\cancel{g} \times 4.2\,\text{J}\,\cancel{\text{K}^{-1}}\,\cancel{\text{g}^{-1}} \times Y\,\cancel{\text{K}}$ (ΔT is same in K & °C)

$= -W \times 4.2\,\text{J} \times Y$

in kJ for X g of ethanol $= \frac{-4.2WY}{1000}$

for per mol of ethanol $= \frac{\frac{-4.2WY}{1000}}{\frac{X}{Z}} = \frac{-4.2WYZ}{1000X}$

3.

$\Delta H_1^\ominus$ is the standard enthalpy of formation of methane.

$\Delta H_2^\ominus$ is the standard enthalpy of combustion of carbon.

$\Delta H_3^\ominus$ is the standard enthalpy of combustion of hydrogen.

$$CH_4(g) + 2O_2(g) \xrightarrow{\Delta H_c^\ominus} CO_2(g) + 2H_2O(l)$$

Which expression is equivalent to $\Delta H_c^\ominus$?

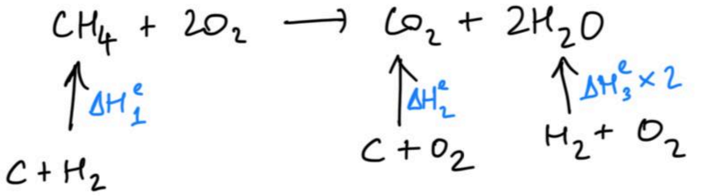
A $\Delta H_1^\ominus - \Delta H_2^\ominus + \Delta H_3^\ominus$

B $\Delta H_1^\ominus - 2\Delta H_3^\ominus - \Delta H_2^\ominus$

C $\Delta H_2^\ominus - \Delta H_3^\ominus + \Delta H_1^\ominus$

D $\Delta H_2^\ominus + 2\Delta H_3^\ominus - \Delta H_1^\ominus$

Ans: D



$\therefore \Delta H_c^e =$

$-\Delta H_1^e + \Delta H_2^e + 2\Delta H_3^e$

4.

Using the information in the table, what is the enthalpy change, q, for the reaction described?

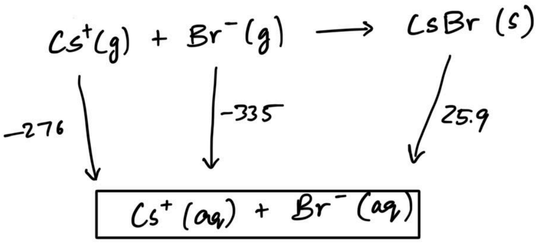
$$Cs^+(g) + Br^-(g) \rightarrow CsBr(s) \qquad \Delta H = q\,\text{kJ mol}^{-1}$$

standard enthalpy change	value / kJ mol^{-1}
$\Delta H_{sol}^\ominus$ CsBr(s)	+25.9
$\Delta H_{hyd}^\ominus$ $Cs^+(g)$	–276
$\Delta H_{hyd}^\ominus$ $Br^-(g)$	–335

A –636.9 **B** –585.1 **C** +585.1 **D** +636.9

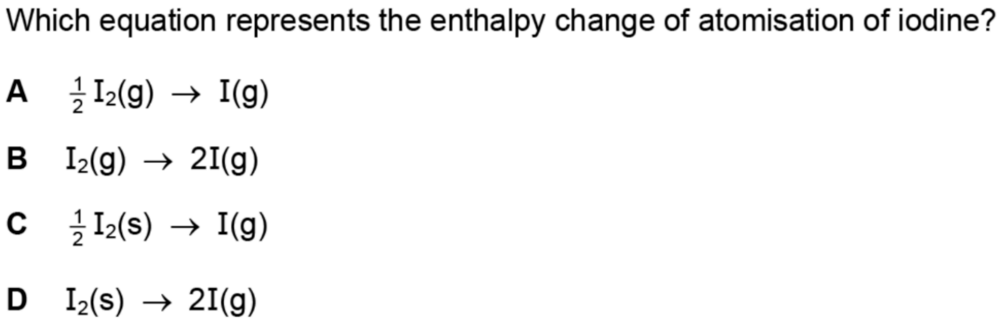
Ans: A

NOTE: dissolving gaseous ions in water = hydration enthalpy; dissolving solid in water = solution enthalpy



$-276 - 335 - 25.9 = -636.9$

5.



Which equation represents the enthalpy change of atomisation of iodine?

A $\frac{1}{2}I_2(g) \rightarrow I(g)$

B $I_2(g) \rightarrow 2I(g)$

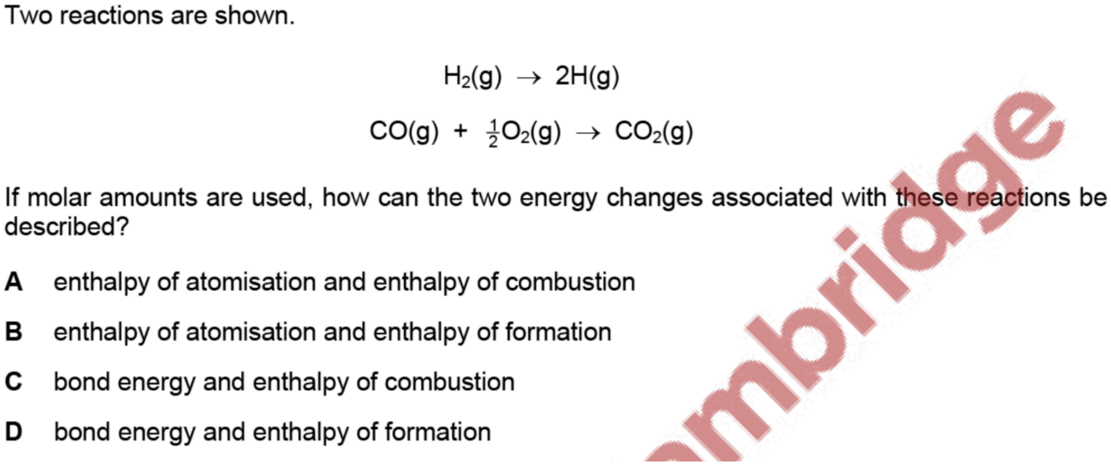
C $\frac{1}{2}I_2(s) \rightarrow I(g)$

D $I_2(s) \rightarrow 2I(g)$

Ans: C

Enthalpy of atomisation = 1 mol of element in gaseous state from element in standard state

6.



Two reactions are shown.

$$H_2(g) \rightarrow 2H(g)$$

$$CO(g) + \frac{1}{2}O_2(g) \rightarrow CO_2(g)$$

If molar amounts are used, how can the two energy changes associated with these reactions be described?

A enthalpy of atomisation and enthalpy of combustion

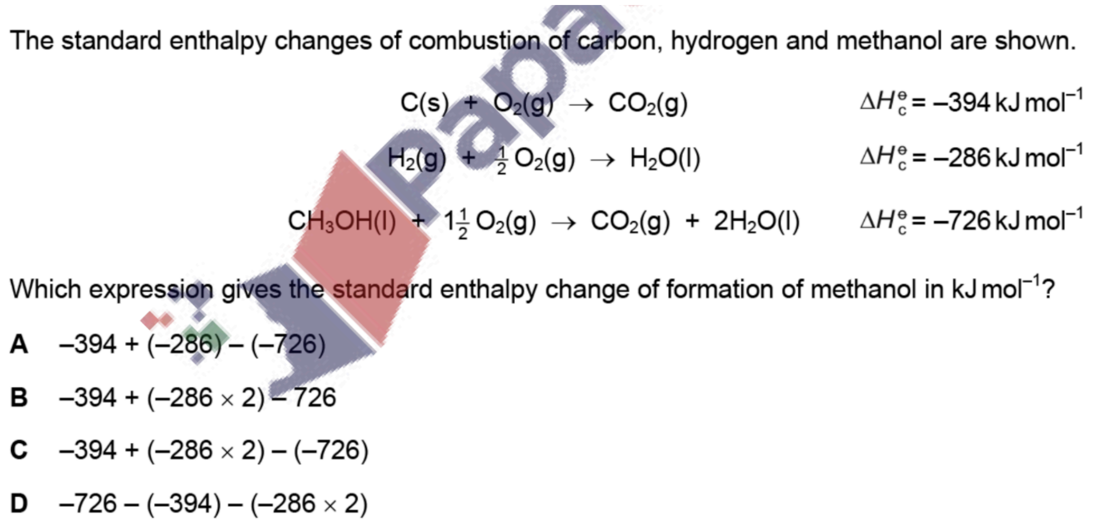
B enthalpy of atomisation and enthalpy of formation

C bond energy and enthalpy of combustion

D bond energy and enthalpy of formation

Ans: C

7.



The standard enthalpy changes of combustion of carbon, hydrogen and methanol are shown.

$$C(s) + O_2(g) \rightarrow CO_2(g) \qquad \Delta H^{\ominus}_c = -394\,kJ\,mol^{-1}$$

$$H_2(g) + \tfrac{1}{2}O_2(g) \rightarrow H_2O(l) \qquad \Delta H^{\ominus}_c = -286\,kJ\,mol^{-1}$$

$$CH_3OH(l) + 1\tfrac{1}{2}O_2(g) \rightarrow CO_2(g) + 2H_2O(l) \qquad \Delta H^{\ominus}_c = -726\,kJ\,mol^{-1}$$

Which expression gives the standard enthalpy change of formation of methanol in $kJ\,mol^{-1}$?

A $-394 + (-286) - (-726)$

B $-394 + (-286 \times 2) - 726$

C $-394 + (-286 \times 2) - (-726)$

D $-726 - (-394) - (-286 \times 2)$

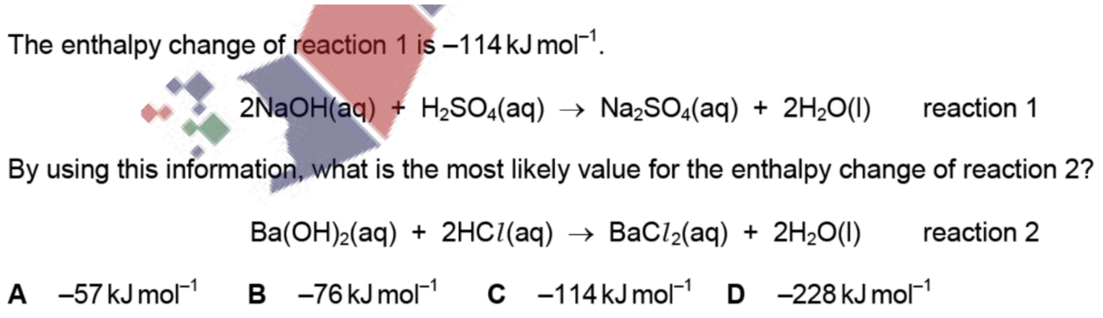
Ans: C

NOTE: when the bond between sodium and oxygen is written in this way: Na–O; it implies a covalent bond, which is incorrect.

NOTE:

Endothermic	**Exothermic**
Thermal decomposition	Combustion
Atomisation	Neutralisation

8.



The enthalpy change of reaction 1 is $-114\,kJ\,mol^{-1}$.

$$2NaOH(aq) + H_2SO_4(aq) \rightarrow Na_2SO_4(aq) + 2H_2O(l) \qquad \text{reaction 1}$$

By using this information, what is the most likely value for the enthalpy change of reaction 2?

$$Ba(OH)_2(aq) + 2HCl(aq) \rightarrow BaCl_2(aq) + 2H_2O(l) \qquad \text{reaction 2}$$

A $-57\,kJ\,mol^{-1}$ **B** $-76\,kJ\,mol^{-1}$ **C** $-114\,kJ\,mol^{-1}$ **D** $-228\,kJ\,mol^{-1}$

Ans: C

- Both reactions are neutralisation
- In both reactions 2H+ ions and 2OH– ions combine to form 2 moles of H2O
- The ionic equation is same for both, so enthalpy change is also same for both

9.

A butane burner is used to heat water. The M_r of butane is 58.

- $\Delta H^{\ominus}_{c}$ of butane is $-2877\,\text{kJ mol}^{-1}$.
- 250 g of water is heated from 12 °C to 100 °C.
- The burner transfers 47% of the heat released from the burning fuel to the water.

Assume that the butane undergoes complete combustion and none of the water evaporates.

What is the minimum mass of butane that must be burnt?

A 0.068 g **B** 1.85 g **C** 3.94 g **D** 4.48 g

Ans: C

energy needed to heat water = $250 \times 4.18 \times 88 = 91960\,J$

$\frac{47}{100}$ (energy from butane combustion) = 91960 = 91.96 kJ

⇒ energy from butane combustion = $\frac{91.96}{47/100} = 195.66$

no. of mol = $\frac{195.66}{2877} = 0.068$ ∴ mass = $0.068 \times 58 = 3.94$

10.

A student mixed $25.0\,\text{cm}^3$ of $4.00\,\text{mol dm}^{-3}$ hydrochloric acid with an equal volume of $4.00\,\text{mol dm}^{-3}$ sodium hydroxide. The initial temperature of both solutions was 15.0 °C. The maximum temperature recorded was 30.0 °C.

Using these results, what is the enthalpy change of neutralisation of hydrochloric acid?

A $-62.7\,\text{kJ mol}^{-1}$

B $-31.4\,\text{kJ mol}^{-1}$

C $-15.7\,\text{kJ mol}^{-1}$

D $-3.14\,\text{kJ mol}^{-1}$

Ans: B

$HCl + NaOH \longrightarrow NaCl + H_2O$

mol of HCl = $\frac{25}{1000} \times 4 = 0.1$

mol of NaOH = 0.1

$\Delta T = 15$

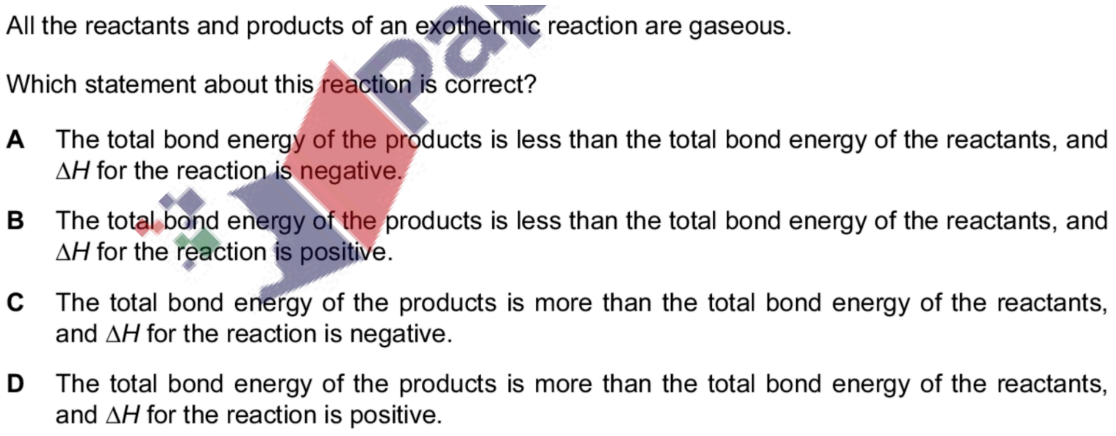
volume of solution = mass of solution

total volume = $25 + 25 = 50\,cm^3 = 50\,g$

$\Delta Q = 50 \times 4.18 \times 15 = 3135$

For 1 mol HCl, $\Delta Q = \frac{1}{0.1} \times 3135 = 31350 = -31.4\,kJ$

11.



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.

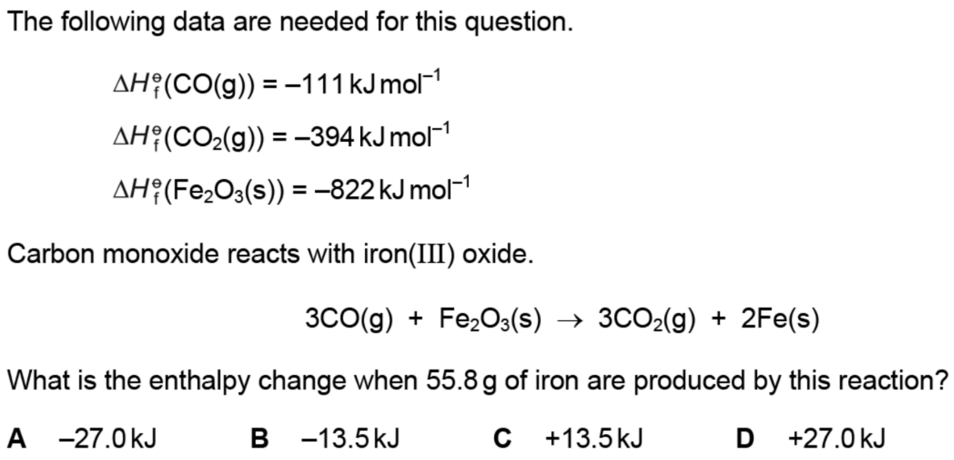
Ans: C

- Exothermic, so energy released in bond making > energy absorbed in bond breaking
- Bond energy of products = energy released in bond making
- Bond energy of reactants = energy absorbed in bond breaking
- Thus bond energy of products > bond energy of reactants

NOTE:

- In exothermic reactions, energy of products < energy of reactants HOWEVER, total bond energy of products > total bond energy of reactants
- In endothermic reactions, energy of products > energy of reactants HOWEVER, total bond energy of products < total bond energy of reactants

12.



The following data are needed for this question.

$\Delta H_f^\ominus(CO(g)) = -111\,kJ\,mol^{-1}$

$\Delta H_f^\ominus(CO_2(g)) = -394\,kJ\,mol^{-1}$

$\Delta H_f^\ominus(Fe_2O_3(s)) = -822\,kJ\,mol^{-1}$

Carbon monoxide reacts with iron(III) oxide.

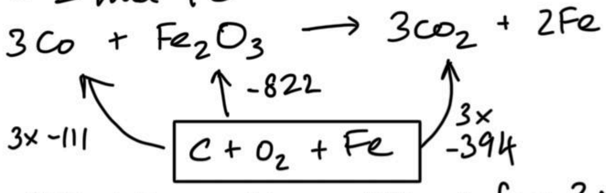
$$3CO(g) + Fe_2O_3(s) \rightarrow 3CO_2(g) + 2Fe(s)$$

What is the enthalpy change when 55.8 g of iron are produced by this reaction?

A –27.0 kJ **B** –13.5 kJ **C** +13.5 kJ **D** +27.0 kJ

Ans: B

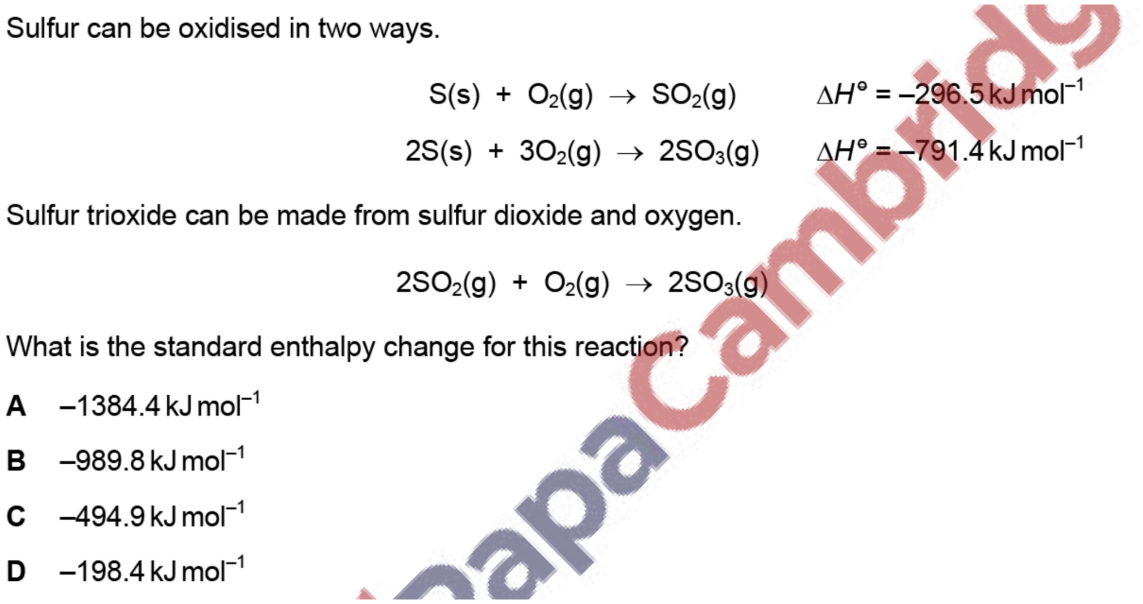
55·8g = 1 mol Fe



$-3 \times -111 + 822 + 3 \times -394 = -27 \rightarrow$ for 2mol

$\therefore$ for 1mol of Fe = $-13{\cdot}5$

13.


Sulfur can be oxidised in two ways.

$$S(s) + O_2(g) \rightarrow SO_2(g) \qquad \Delta H^\circ = -296.5\,kJ\,mol^{-1}$$

$$2S(s) + 3O_2(g) \rightarrow 2SO_3(g) \qquad \Delta H^\circ = -791.4\,kJ\,mol^{-1}$$

Sulfur trioxide can be made from sulfur dioxide and oxygen.

$$2SO_2(g) + O_2(g) \rightarrow 2SO_3(g)$$

What is the standard enthalpy change for this reaction?

A $-1384.4\,kJ\,mol^{-1}$

B $-989.8\,kJ\,mol^{-1}$

C $-494.9\,kJ\,mol^{-1}$

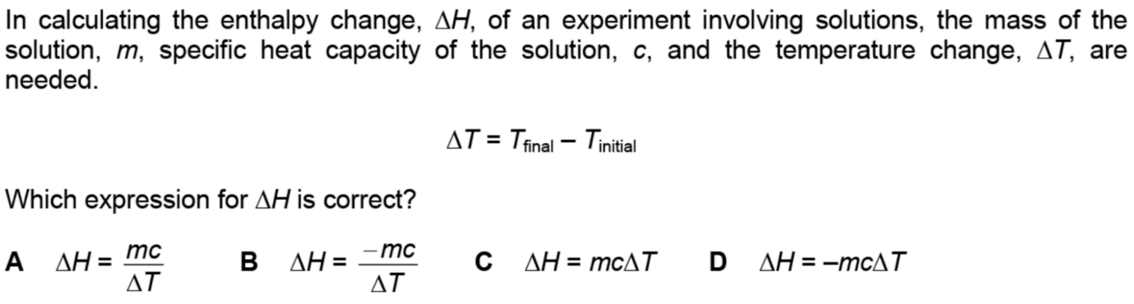
D $-198.4\,kJ\,mol^{-1}$

Ans: D

PAY ATTENTION to the COEFFICIENTS!!

The first equation is for formation of 1 mole of SO2, while the second equation is for formation of 2 moles of SO3!

14.


In calculating the enthalpy change, ΔH, of an experiment involving solutions, the mass of the solution, m, specific heat capacity of the solution, c, and the temperature change, ΔT, are needed.

$$\Delta T = T_{final} - T_{initial}$$

Which expression for ΔH is correct?

A $\Delta H = \frac{mc}{\Delta T}$ **B** $\Delta H = \frac{-mc}{\Delta T}$ **C** $\Delta H = mc\Delta T$ **D** $\Delta H = -mc\Delta T$

Ans: D

15.

Gaseous phosphorus pentachloride can be decomposed into gaseous phosphorus trichloride and chlorine by heating. The table gives the bond energies.

bond	bond energy / kJ mol^{-1}
P–Cl (in both chlorides)	330
Cl–Cl	242

What is the enthalpy change for the decomposition of PCl_5 to PCl_3 and Cl_2?

A –418 kJ mol^{-1}

B –88 kJ mol^{-1}

C +88 kJ mol^{-1}

D +418 kJ mol^{-1}

Ans: D

NOTE: for Cl2, bond is Cl–Cl. Don't accidentally multiply the bond energy by 2!!

16.

Metaldehyde, $(CH_3CHO)_4$, is used as a solid fuel for camping stoves. The equation for the complete combustion of metaldehyde is shown.

$$(CH_3CHO)_4(s) + 10O_2(g) \rightarrow 8CO_2(g) + 8H_2O(l)$$

$\Delta H^{\ominus}_{c}$ = standard enthalpy change of combustion.

Which expression will give a correct value for the enthalpy change of formation of metaldehyde?

A $\Delta H^{\ominus}_{c}$metaldehyde – (8$\Delta H^{\ominus}_{c}$carbon + 8$\Delta H^{\ominus}_{c}$hydrogen)

B $\Delta H^{\ominus}_{c}$metaldehyde – (8$\Delta H^{\ominus}_{c}$carbon + 16$\Delta H^{\ominus}_{c}$hydrogen)

C (8$\Delta H^{\ominus}_{c}$carbon + 8$\Delta H^{\ominus}_{c}$hydrogen) – $\Delta H^{\ominus}_{c}$metaldehyde

D (8$\Delta H^{\ominus}_{c}$carbon + 16$\Delta H^{\ominus}_{c}$hydrogen) – $\Delta H^{\ominus}_{c}$metaldehyde

Ans: C

17.

Solid sulfur consists of molecules made up of eight atoms covalently bonded together.

The bonding in sulfur dioxide is O=S=O.

enthalpy change of combustion of S_8, $\Delta H^{\ominus}_{c}S_8(s)$= –2376 kJ mol^{-1}

energy required to break 1 mole $S_8(s)$ into gaseous atoms = 2232 kJ mol^{-1}

O=O bond enthalpy = 496 kJ mol^{-1}

Using these data, what is the value of the S=O bond enthalpy?

A 239 kJ mol^{-1} **B** 257 kJ mol^{-1} **C** 319 kJ mol^{-1} **D** 536 kJ mol^{-1}

Ans: D

$$\underset{\underset{2232}{\downarrow}}{S_8} + \underset{\underset{8\times 496}{\downarrow}}{8O_2} \longrightarrow 8SO_2$$

$$2232 + 8\times 496 - x = -2376$$

$$\Rightarrow x = 8576$$

$$O=S=O \quad \therefore 8SO_2 = 16\ S=O$$

$$\therefore S=O \text{ enthalpy} = \frac{8576}{16} = 536$$

18.

The following data are needed for this question.

$$NaHCO_3(s) + HCl(aq) \rightarrow NaCl(aq) + H_2O(l) + CO_2(g) \qquad \Delta H = -38.97\,kJ\,mol^{-1}$$

$$Na_2CO_3(s) + 2HCl(aq) \rightarrow 2NaCl(aq) + H_2O(l) + CO_2(g) \qquad \Delta H = -96.59\,kJ\,mol^{-1}$$

On heating, sodium hydrogencarbonate decomposes as shown.

$$2NaHCO_3(s) \rightarrow Na_2CO_3(s) + H_2O(l) + CO_2(g)$$

What is the enthalpy change for this decomposition?

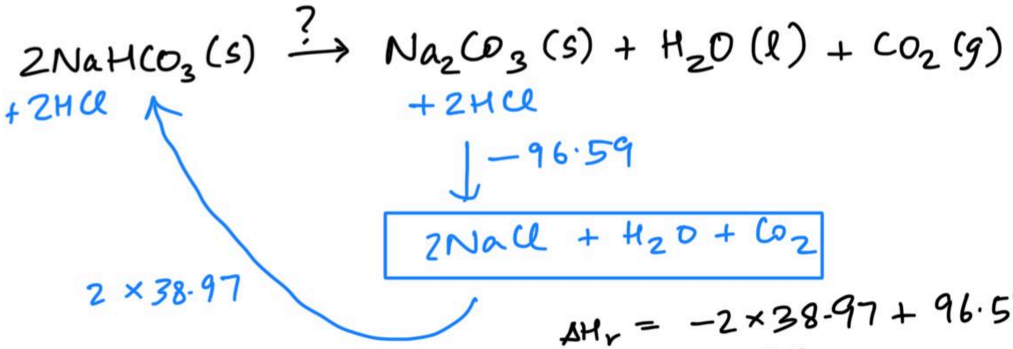
A –57.62 kJ mol^{-1}

B –18.65 kJ mol^{-1}

C 18.65 kJ mol^{-1}

D 57.62 kJ mol^{-1}

Ans: C

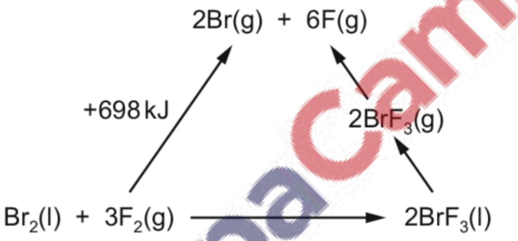


$$\Delta H_r = -2\times 38.97 + 96.59$$
$$= 18.65$$

19.

An energy cycle is drawn for the following reaction.

$$Br_2(l) + 3F_2(g) \rightarrow 2BrF_3(l)$$



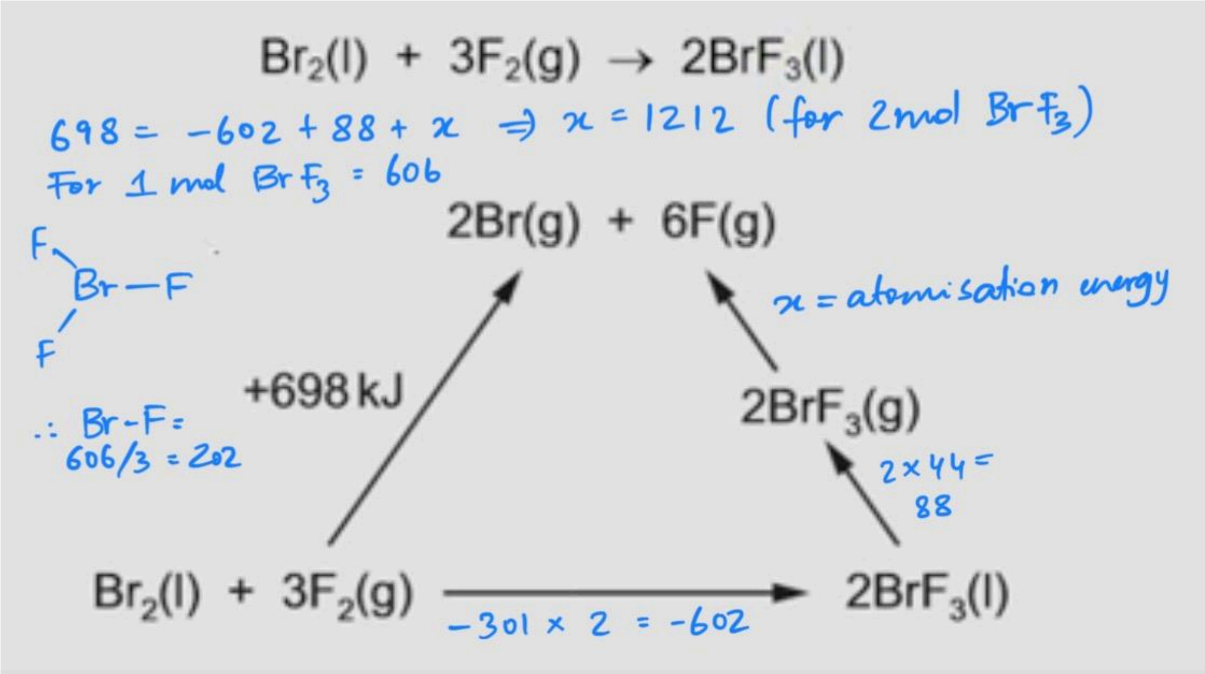
The standard enthalpy of formation of $BrF_3(l)$ = –301 kJ mol^{-1}.

The enthalpy change of $BrF_3(l)$ to $BrF_3(g)$ is +44 kJ mol^{-1}.

What is the average bond energy of the Br–F bond in BrF_3?

A 152 kJ mol^{-1} **B** 202 kJ mol^{-1} **C** 304 kJ mol^{-1} **D** 404 kJ mol^{-1}

Ans: B



$Br_2(l) + 3F_2(g) \rightarrow 2BrF_3(l)$

$698 = -602 + 88 + x \Rightarrow x = 1212$ (for 2mol BrF_3)

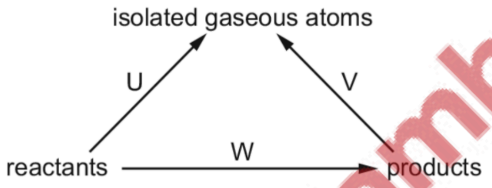
For 1 mol BrF_3 = 606

x = atomisation energy

$\therefore$ Br-F = $606/3 = 202$

20.

Hess' law may be used to determine enthalpy changes using average bond energies, as shown in the diagram.



U is the sum of the average bond energies of the reactants, and V is the sum of the average bond energies of the products.

For the reaction shown below, which expression will give a value for W, the enthalpy change of combustion of methane?

$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$$

A U – V **B** U + V **C** 2(U – V) **D** V – U

Ans: A

21.

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

Ans: A

22.

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}

Ans: B

$HCl + NaOH \rightarrow NaCl + H_2O$

mol of HCl $= \frac{25}{1000} \times 4 = 0{\cdot}1$

$Q = -mc\Delta T$ $\quad 1.00\,g\,cm^{-3} \Rightarrow 1\,cm^3 = 1g$

$\therefore m = 25 + 25 = 50g$

$\Delta T = 15°C = 15K$

$Q = -50 \times 4{\cdot}18 \times 15 = -3135\,J$ for $0{\cdot}1$ mol H_2O

$\therefore$ for 1 mol H_2O, $Q = \frac{-3135 \times 10}{1000} = -31{\cdot}4\,kJ\,mol^{-1}$

23.

Nitrogen monoxide is rapidly oxidised to nitrogen dioxide.

$$2NO(g) + O_2(g) \rightarrow 2NO_2(g)$$

Nitrogen dioxide can then dimerise to form dinitrogen tetroxide.

$$2NO_2(g) \rightarrow N_2O_4(g) \qquad \Delta H^{\ominus} = -58\,kJ\,mol^{-1}$$

$$\Delta H^{\ominus}_{f}NO = +91\,kJ\,mol^{-1} \text{ and } \Delta H^{\ominus}_{f}NO_2 = +34\,kJ\,mol^{-1}$$

What is the value of the standard enthalpy change for the reaction shown?

$$2NO(g) + O_2(g) \rightarrow N_2O_4(g)$$

A $+56\,kJ\,mol^{-1}$ **B** $-1\,kJ\,mol^{-1}$ **C** $-115\,kJ\,mol^{-1}$ **D** $-172\,kJ\,mol^{-1}$

Ans: D

24.

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.

Ans: D

25.

Nitric acid is made industrially by the oxidation of ammonia. The overall equation for the process is shown.

equation 1 $NH_3 + 2O_2 \rightarrow HNO_3 + H_2O$

The process happens in three stages. The equations and enthalpy changes for these stages are given.

stage 1	$4NH_3 + 5O_2 \rightarrow 4NO + 6H_2O$	$\Delta H = -904\,kJ\,mol^{-1}$
stage 2	$2NO + O_2 \rightarrow 2NO_2$	$\Delta H = -114\,kJ\,mol^{-1}$
stage 3	$4NO_2 + O_2 + 2H_2O \rightarrow 4HNO_3$	$\Delta H = -348\,kJ\,mol^{-1}$

What is the enthalpy change of the process shown in equation 1?

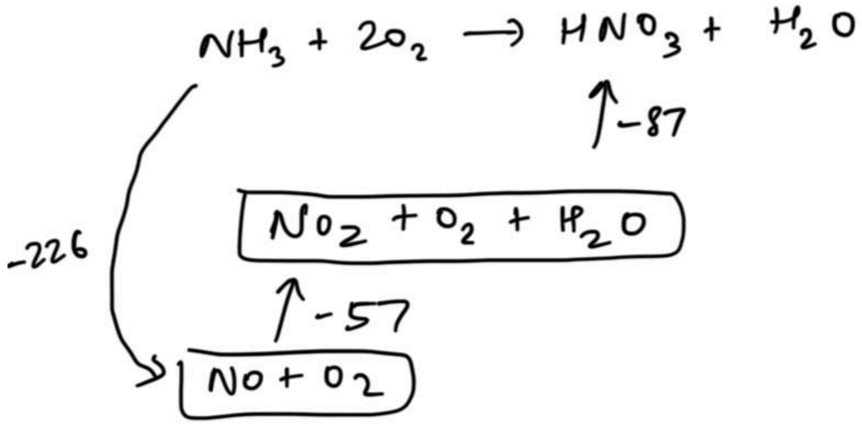
A $-1480\,kJ\,mol^{-1}$

B $-370\,kJ\,mol^{-1}$

C $-341.5\,kJ\,mol^{-1}$

D $+82\,kJ\,mol^{-1}$

Ans: B



26.

The enthalpy change for a reaction can be calculated from values of:

- enthalpies of formation, $\Delta H_f^{\ominus}$
- enthalpies of combustion, $\Delta H_c^{\ominus}$
- bond energies, *E*.

The enthalpy change of the reaction given = $\Delta H_r^{\ominus}$.

$$2C_2H_6(g) + 3O_2(g) \rightarrow 2CH_4(g) + 2CO_2(g) + 2H_2O(l)$$

Which expression could be used to calculate $\Delta H_r^{\ominus}$?

A $\Delta H_c^{\ominus}(C_2H_6(g))$

B $2\Delta H_c^{\ominus}(C_2H_6(g)) - 2\Delta H_c^{\ominus}(CH_4(g))$

C $E(C–C) + 2E(C–H) - 4E(C{=}O) - 4E(H–O)$

D $\Delta H_f^{\ominus}(CH_4(g)) + \Delta H_f^{\ominus}(CO_2(g)) + \Delta H_f^{\ominus}(H_2O(l)) - \Delta H_f^{\ominus}(C_2H_6(g))$

Ans: B

27.

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

Ans: D

28.

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

bond	energy / kJ mol^{-1}
F–F	158
C*l*–C*l*	242
Br–Br	193
I–I	151
H–H	436
D–D	442

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

Ans: A

- You will need the bond energy of D−Cl as well

29.

Three processes are described.

1 $H^+(aq) + OH^-(aq) \rightarrow H_2O(l)$

2 $CH_4(g) + 2O_2(g) \rightarrow CO_2(g) + 2H_2O(l)$

3 $NH_3(g) \rightarrow NH_3(l)$

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.

Ans: A