Chemistry
Bond Enthalpy
Support Materials

[HIGHER]
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**Bond Enthalpy**

**Questions**

1. Using bond enthalpies, calculate the enthalpy change for the combustion of hydrogen to produce water shown by the equation below.

   \[ 2\text{H}_2 (g) + \text{O}_2 (g) \rightarrow 2\text{H}_2\text{O} (g) \]

2. Use bond enthalpy values from the data book to calculate the enthalpy change for the following reaction.

   \[ \text{CH}_4 (g) + \text{Br}_2 (g) \rightarrow \text{CH}_3\text{Br} (g) + \text{HBr} (g) \]

3. The data book gives the enthalpy of combustion of methane as –891kJ mol\(^{-1}\). Use bond enthalpies to calculate the enthalpy change for this reaction.

   \[ \text{CH}_4 (g) + 2\text{O}_2 (g) \rightarrow \text{CO}_2 (g) + 2\text{H}_2\text{O} (g) \]

4. Using bond enthalpy values, calculate the enthalpy change for the following addition reaction.

   \[ \text{C}_2\text{H}_4 (g) + \text{HBr} (g) \rightarrow \text{C}_2\text{H}_5\text{Br} (g) \]

5. Use the bond enthalpy values quoted in the data book to calculate the enthalpy change for the hydrogenation of but-1-ene.

   \[ \text{C}_4\text{H}_8 (g) + \text{H}_2 (g) \rightarrow \text{C}_4\text{H}_{10} (g) \]

6. Using bond enthalpy values, calculate the enthalpy change for the addition reaction between iodine and propene.

   \[ \text{C}_3\text{H}_6 (g) + \text{I}_2 (g) \rightarrow \text{C}_3\text{H}_6\text{I}_2 (g) \]
7. Hydrogen chloride can react with ethyne in a two-stage addition process to give a saturated product. Calculate the enthalpy change for this reaction using bond enthalpy values from the data book.

\[ \text{C}_2\text{H}_2 \text{ (g)} + 2\text{HCl (g)} \rightarrow \text{C}_2\text{H}_4\text{Cl}_2 \text{ (g)} \]

8. The data book gives the enthalpy of combustion of ethanol as \(-1367 \text{ kJ mol}^{-1}\). Use bond enthalpies to calculate the enthalpy change for this reaction.

\[ \text{C}_2\text{H}_5\text{OH (g)} + 3\text{O}_2 \text{ (g)} \rightarrow 2\text{CO}_2 \text{ (g)} + 3\text{H}_2\text{O (g)} \]

9. Calculate the enthalpy of formation for ethene using the enthalpy of sublimation and bond enthalpy values from the data book.

\[ 2\text{C (s)} + 2\text{H}_2 \text{ (g)} \rightarrow \text{C}_2\text{H}_4 \text{ (g)} \]

10. The data book quotes the mean bond enthalpy for a carbon-to-carbon double bond (C=C) as 602 kJ mol\(^{-1}\). Use the enthalpy of formation given and bond enthalpies from the data book to calculate the enthalpy of the C=C bond in ethene.

\[ 2\text{C (s)} + 2\text{H}_2 \rightarrow \text{C}_2\text{H}_4 \quad \Delta H_{\text{formation}} = 52 \text{ kJ mol}^{-1} \]
Solutions

1. Using bond enthalpies, calculate the enthalpy change for the combustion of hydrogen to produce water shown by the equation below.

\[ 2\text{H}_2 (\text{g}) + \text{O}_2 (\text{g}) \rightarrow 2\text{H}_2\text{O} (\text{g}) \]

Bond breaking Bond making
2 mol H–H = 2 × 432 = 864 4 mol H–O = 4 × 458 = 1832
1 mol O=O = 497

Total energy put in = +1361 kJ Total energy given out = –1832 kJ

\[ \Delta H = 1361 - 1832 = \boxed{-471 \text{ kJ mol}^{-1}} \]

2. Use bond enthalpy values from the data book to calculate the enthalpy change for the following reaction.

\[ \text{CH}_4 (\text{g}) + \text{Br}_2 (\text{g}) \rightarrow \text{CH}_3\text{Br} (\text{g}) + \text{HBr} (\text{g}) \]

Bond breaking Bond making
4 mol C–H = 4 × 414 = 1656 3 mol C–H = 3 × 414 = 1242
1 mol Br–Br = 194 1 mol C–Br = 285
1 mol H–Br = 362 1 mol H–Br = 362

Total energy put in = +1850 kJ Total energy given out = –1889 kJ

\[ \Delta H = 1850 - 1889 = \boxed{-39 \text{ kJ mol}^{-1}} \]
3. The data book gives the enthalpy of combustion of methane as $-891 \text{kJ mol}^{-1}$. Use bond enthalpies to calculate the enthalpy change for this reaction.

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

<table>
<thead>
<tr>
<th>Bond breaking</th>
<th>Bond making</th>
</tr>
</thead>
<tbody>
<tr>
<td>4 mol C–H = 4 × 414 = 1656</td>
<td>2 mol C=O = 2 × 798 = 1596</td>
</tr>
<tr>
<td>2 mol O=O = 2 × 497 = 994</td>
<td>4 mol H–O = 4 × 458 = 1832</td>
</tr>
<tr>
<td>Total energy put in = +2650 kJ</td>
<td>Total energy given out = –3428 kJ</td>
</tr>
</tbody>
</table>

$$\Delta H = 2650 - 3428 = -778 \text{ kJ mol}^{-1}$$

4. Using bond enthalpy values, calculate the enthalpy change for the following addition reaction.

$$\text{C}_2\text{H}_4 (g) + \text{HBr} (g) \rightarrow \text{C}_2\text{H}_5\text{Br} (g)$$

<table>
<thead>
<tr>
<th>Bond breaking</th>
<th>Bond making</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 mol C=C = 602</td>
<td>1 mol C–C = 346</td>
</tr>
<tr>
<td>4 mol C–H = 4 × 414 = 1656</td>
<td>5 mol C–H = 5 × 414 = 2070</td>
</tr>
<tr>
<td>1 mol H–Br = 362</td>
<td>1 mol C–Br = 285</td>
</tr>
<tr>
<td>Total energy put in = +2620 kJ</td>
<td>Total energy given out = –2701 kJ</td>
</tr>
</tbody>
</table>

$$\Delta H = 2620 - 2701 = -81 \text{ kJ mol}^{-1}$$
5. Use the bond enthalpy values quoted in the data book to calculate the enthalpy change for the hydrogenation of but-1-ene.

\[
\text{C}_4\text{H}_8 (g) + \text{H}_2 (g) \rightarrow \text{C}_4\text{H}_{10} (g)
\]

**Bond breaking**
- 1 mol C=C = 602
- 2 mol C–C = 2 × 346 = 692
- 1 mol H–H = 432
- 8 mol C–H = 8 × 414 = 3312

**Bond making**
- 3 mol C–C = 3 × 346 = 1038
- 10 mol C–H = 10 × 414 = 4140
- 2 mol C–I = 2 × 213 = 426
- 1 mol I–I = 149

Total energy put in = +5038 kJ

Total energy given out = –5178 kJ

\[\Delta H = 5038 - 5178 = -140 \text{ kJ mol}^{-1}\]

6. Using bond enthalpy values, calculate the enthalpy change for the addition reaction between iodine and propene.

\[
\text{C}_3\text{H}_6 (g) + \text{I}_2 (g) \rightarrow \text{C}_3\text{H}_6\text{I}_2 (g)
\]

**Bond breaking**
- 1 mol C=C = 602
- 1 mol C–C = 346
- 6 mol C–H = 6 × 414 = 2484
- 1 mol I–I = 149

**Bond making**
- 2 mol C–C = 2 × 346 = 692
- 6 mol C–H = 6 × 414 = 2484
- 2 mol C–I = 2 × 213 = 426

Total energy put in = +3581 kJ

Total energy given out = –3602 kJ

\[\Delta H = 3581 - 3602 = -21 \text{ kJ mol}^{-1}\]
7. Hydrogen chloride can react with ethyne in a two-stage addition process to give a saturated product. Calculate the enthalpy change for this reaction using bond enthalpy values from the data book.

\[ \text{C}_2\text{H}_2 (g) + 2\text{HCl} (g) \rightarrow \text{C}_2\text{H}_4\text{Cl}_2 (g) \]

**Bond breaking**
- 1 mol C\(\equiv\)C = 835
- 2 mol C–H = 2 \times 414 = 828
- 2 mol H–Cl = 2 \times 428 = 856

Total energy put in = +2519 kJ

**Bond making**
- 1 mol C–C = 346
- 4 mol C–H = 4 \times 414 = 1656
- 2 mol C–Cl = 2 \times 326 = 652

Total energy given out = −2654 kJ

\[ \Delta H = 2519 - 2654 = -135 \text{ kJ mol}^{-1} \]
8. The data book gives the enthalpy of combustion of ethanol as $-1367 \text{ kJ mol}^{-1}$. Use bond enthalpies to calculate the enthalpy change for this reaction.

$$\text{C}_2\text{H}_5\text{OH} (\text{g}) + 3\text{O}_2 (\text{g}) \rightarrow 2\text{CO}_2 (\text{g}) + 3\text{H}_2\text{O} (\text{g})$$

**Bond breaking**

- $1 \text{ mol C} - \text{C} = 346$
- $5 \text{ mol C} - \text{H} = 5 \times 414 = 2070$
- $1 \text{ mol C} - \text{O} = 358$
- $1 \text{ mol H} - \text{O} = 458$
- $3 \text{ mol O} = \text{O} = 3 \times 497 = 1491$

**Total energy put in** $= +4723 \text{ kJ}$

**Bond making**

- $4 \text{ mol C} = \text{O} = 4 \times 798 = 3192$
- $6 \text{ mol H} - \text{O} = 6 \times 458 = 2748$

**Total energy given out** $= -5940 \text{ kJ}$

$$\Delta H = 4723 - 5940 = -1217 \text{ kJ mol}^{-1}$$
9. Calculate the enthalpy of formation for ethene using the enthalpy of sublimation and bond enthalpy values from the data book.

\[ 2\text{C (s)} + 2\text{H}_2 (g) \rightarrow \text{C}_2\text{H}_4 (g) \]

**Bond breaking**
- 2 mol C (s) → C (g) = 2 × 715 = 1430
- 2 mol H–H = 2 × 432 = 864

**Total energy put in** = +2294 kJ

**Bond making**
- 1 mol C=\text{C} = 602
- 4 mol C–\text{H} = 4 × 414 = 1656

**Total energy given out** = −2258 kJ

\[ \Delta H = +36 \text{ kJ mol}^{-1} \]

10. The data book quotes the mean bond enthalpy for a carbon-to-carbon double bond (C=\text{C}) as 602 kJ mol\(^{-1}\). Use the enthalpy of formation given and bond enthalpies from the data book to calculate the enthalpy of the C=\text{C} bond in ethene.

\[ 2\text{C (s)} + 2\text{H}_2 (g) \rightarrow \text{C}_2\text{H}_4 (g) \]

\[ \Delta H_{\text{formation}} = 52 \text{ kJ mol}^{-1} \]

**Bond breaking**
- 2 mol C (s) → C (g) = 2 × 715 = 1430
- 2 mol H–H = 2 × 432 = 864

**Total energy put in** = +2294 kJ

**Bond making**
- 1 mol C=\text{C} = x
- 4 mol C–\text{H} = 4 × 414 = 1656

**Total energy given out** = −(1656 + x) kJ

\[ \Delta H_{\text{formation}} = 52 = 2294 – (1656 + x) \]

\[ x = 52 = 2294 – 1656 = 586 \text{ kJ mol}^{-1} \]