Answers to Review for Unit 3: Thermochemistry
Answers to multiple choice:

| 1. c | 11. d | 21. a | 31. d | 41. c |
| :---: | :---: | :---: | :---: | :---: |
| 2. b | 12. c | 22. d | 32. c | 42. b |
| 3. d | 13. a | 23. a | 33. a | 43. a |
| 4. b | 14. d | 24. a | 34. b | 44. a |
| 5. c | 15. d | 25. c | 35. c | 45. d |
| 6. d | 16. b | 26. c | 36. a | 46. a |
| 7. c | 17. c | 27. c | 37. c | 47. a |
| 8. a | 18. a | 28. b | 38. d | 48. b |
| 9. a | 19. d | 29. c | 39. d | 49. d |
| 10. c | 20. c | 30. d | 40. b | 50. d |

Answers for Calculations. Be sure to show an equation, substitution step and your final answer. Include all units. Round your final answer to the correct number of sig digs.

1. In an experiment, 5.260 g of potassium hydroxide is mixed with a dilute solution of hydrochloric acid. A neutralization (double displacement) reaction occurs. The hydrochloric acid is in excess. The following date are obtained:

| Initial temperature of hydrochloric acid | $24.5^{\circ} \mathrm{C}$ |
| :--- | :---: |
| Volume of hydrochloric acid | 200.0 mL |
| Final temperature of solution after mixing | $31.4^{\circ} \mathrm{C}$ |

Calculate the molar heat of reaction $(\Delta H)$ per mole of potassium hydroxide.

$$
\mathrm{KOH}(\mathrm{~s})+\mathrm{HCl}(\mathrm{aq}) \rightarrow \mathrm{KCl}(\mathrm{aq})+\mathrm{H}_{2} \mathrm{O}(\mathrm{l}) \quad \Delta \mathrm{H}=?
$$

- The temperature of the water in the HCl (the system) increases after the potassium hydroxide has dissolved. This is an exothermic reaction (the reaction releases heat), so the sign for $\Delta \mathrm{H}$ will be negative.
- Calculate the amount of heat $(\mathrm{Q})$ released when the KOH reacts:

$$
\text { Given: } \begin{array}{rlrl}
\mathrm{m} & =200.0 \mathrm{~g} & \mathrm{Q} & =\mathrm{m} \cdot \mathrm{c} \cdot \Delta \mathrm{~T} \\
\mathrm{c}=4.184 \mathrm{~J} / \mathrm{g}^{\circ} \mathrm{C} & & =200.0 \mathrm{~g} \mathrm{x} 4.184 \mathrm{~J} / \mathrm{g}^{\circ} \mathrm{C} \times \mathrm{x}^{\circ} 6.9^{\circ} \mathrm{C} \\
\Delta \mathrm{~T} & =\mathrm{T}_{2}-\mathrm{T}_{1} & & =5773.92 \mathrm{~J} \\
& =31.4^{\circ} \mathrm{C}-24.5^{\circ} \mathrm{C} & & =5.774 \mathrm{~kJ} \\
& =6.9^{\circ} \mathrm{C} & &
\end{array}
$$

- The heat absorbed by the system $(5.774 \mathrm{~kJ})$ is equal to the heat released when KOH reacted; therefore, when 5.260 g of KOH is dissolved, it releases 5.774 kJ of thermal energy.
- $\mathrm{Q}=-\Delta \mathrm{H} \quad$ so $\Delta \mathrm{H}=-5.774 \mathrm{~kJ}$
- To find $\Delta \mathrm{H} / \mathrm{mol}$, divide $\Delta \mathrm{H}$ by the number of moles of KOH :

$$
\begin{aligned}
\mathrm{n}_{\text {Кон }} & =\frac{\mathrm{m}}{\mathrm{MM}_{\mathrm{KOH}}} \\
& =\frac{5.260 \mathrm{~g}}{56.11 \mathrm{~g} / \mathrm{mol}} \\
& =0.09374 \mathrm{~mol} \text { of } \mathrm{KOH}
\end{aligned}
$$

$$
\begin{aligned}
\Delta \mathrm{H} / \text { mole } & =\underline{\Delta \mathrm{H} \text { reaction }} \\
\text { moles } \mathrm{KOH} & \text { reacted } \\
& =\frac{-5.774 \mathrm{~kJ}}{0.09374 \mathrm{~mol}} \\
& =-61.6 \mathrm{~kJ} / \mathrm{mol} \mathrm{KOH}(3 \mathrm{sig} \text { digs })
\end{aligned}
$$

2. An experiment was conducted using the reaction:
$\mathrm{HNO}_{3(\mathrm{aq})}+\mathrm{KOH}_{(\mathrm{aq})} \rightarrow \mathrm{H}_{2} \mathrm{O}_{(\mathrm{l})}+\mathrm{KNO}_{3(\mathrm{aq})}$
The following data were collected:

| volume of 1.3-M $\mathrm{HNO}_{3}$ | 55.0 mL |
| :--- | :--- |
| initial temperature of $\mathrm{HNO}_{3}$ | $23.5^{\circ} \mathrm{C}$ |
| volume of 1.3-M KOH | 60.0 mL |
| initial temperature of KOH | $23.5^{\circ} \mathrm{C}$ |
| final temperature after mixing | $31.8^{\circ} \mathrm{C}$ |

Calculate the heat of reaction, $\Delta \mathrm{H}$, expressed in kJ per mole of $\mathrm{HNO}_{3}$.

- The temperature of the water in the $\mathrm{HNO}_{3}$ (the system) increases after the potassium hydroxide has dissolved. This is an exothermic reaction (the reaction releases heat), so the sign for $\Delta \mathrm{H}$ will be negative.
- Calculate the amount of heat $(\mathrm{Q})$ released when the KOH and $\mathrm{HNO}_{3}$ react:


## Given:

Total volume of mixture $=115.0 \mathrm{~mL}$

$$
\begin{aligned}
\mathrm{Q} & =\mathrm{m} \cdot \mathrm{c} \cdot \Delta \mathrm{~T} \\
& =115.0 \mathrm{~g} \mathrm{x} \mathrm{4} \\
& =3993.63 \mathrm{~J} \\
& =3.994 \mathrm{~kJ}
\end{aligned}
$$

$$
\mathrm{m}=115.0 \mathrm{~g} \quad=115.0 \mathrm{~g} \times 4.184 \mathrm{~J} / \mathrm{g}^{\circ} \mathrm{C} \times 8.3^{\circ} \mathrm{C}
$$

$$
\mathrm{c}=4.184 \mathrm{~J} / \mathrm{g}^{\circ} \mathrm{C}
$$

$$
\Delta \mathrm{T}=\mathrm{T}_{2}-\mathrm{T}_{1}
$$

$$
\begin{aligned}
& =31.8^{\circ} \mathrm{C}-23.5^{\circ} \mathrm{C} \\
& =8.3^{\circ} \mathrm{C}
\end{aligned}
$$

- The heat absorbed by the system (3.994 kJ) is equal to the heat released when the KOH and $\mathrm{HNO}_{3}$ reacted
- $\mathrm{Q}=-\Delta \mathrm{H} \quad$ so $\Delta \mathrm{H}=-3.994 \mathrm{~kJ}$
- To find $\Delta \mathrm{H} / \mathrm{mol}$, divide $\Delta \mathrm{H}$ by the number of moles of $\mathrm{HNO}_{3}$ :

$$
\begin{array}{rlrl}
\mathrm{n}_{\mathrm{HNO} 3} & =\mathrm{C} \mathrm{x} \mathrm{~V} & \Delta \mathrm{H} / \mathrm{mole} & =\frac{\Delta \mathrm{H} \text { reaction }}{\text { moles } \mathrm{HNO}_{3}} \text { reacted } \\
& =1.3 \mathrm{~mol} / \mathrm{L} \times 0.0550 \mathrm{~L} & & \frac{-3.994 \mathrm{~kJ}}{0.0715 \mathrm{~mol}} \\
& =0.0715 \mathrm{~mol} \mathrm{HNO}_{3} & & =-55.9 \mathrm{~kJ} / \mathrm{mol} \mathrm{HNO}_{3} \\
& & =-56 \mathrm{~kJ} / \mathrm{mol} \mathrm{HNO}_{3}(2 \text { sig digs from } 1.3 \mathrm{M})
\end{array}
$$

3. $\Delta H^{\circ}=-2728 \mathrm{~kJ}$
process: equation (1) $\times 2$, equation (2) $\times 3$, equation (3) flipped
4. 

$$
\begin{array}{ll}
\Delta H^{\circ}=-699.5 \mathrm{~kJ} \quad \text { process: } & \text { equation (4) flipped } \\
& \text { equation (1) } \times 1 / 2 \\
& \text { equation (2) } \times 3 / 2 \\
& \text { equation (3) } \times 3
\end{array}
$$

alternatively: equation (4) flipped and multiplied by 2 equation (1) as is
equation (2) $\times 3$
equation (3) $\times 6$
then divide the final equation and $\Delta \mathrm{H}$ by 2
5. $\Delta H^{\circ}=+221.4 \mathrm{~kJ}$ process: equation (3) as is
equation (1) as is
equation (2) flipped
equation (4) flipped and multiplied by 2
6. For the reaction: $2 \mathrm{HNO}_{3(l)}+\mathrm{Mg}(\mathrm{OH})_{2(\mathrm{~s})} \rightarrow \mathrm{Mg}\left(\mathrm{NO}_{3}\right)_{2(\mathrm{aq})}+2 \mathrm{H}_{2} \mathrm{O}_{(l)}$

$$
\begin{aligned}
\Delta H^{\circ} \mathrm{rxn} & =\Sigma \Delta H_{\mathrm{f}}^{\circ} \text { products }-\Sigma \Delta H_{\mathrm{f}}^{\circ} \text { reactants } \\
& =\left[\Delta H_{\mathrm{f}}^{\circ} \mathrm{Mg}\left(\mathrm{NO}_{3}\right)_{2(\mathrm{aq})}+2\left(\Delta H_{\mathrm{f}}^{\circ} \mathrm{H}_{2} \mathrm{O}(\mathrm{I})\right)\right]-\left[2\left(\Delta H_{\mathrm{f}}^{\circ} \mathrm{HNO}_{3(\mathrm{l})}\right)+\Delta H_{\mathrm{f}}^{\circ} \mathrm{Mg}(\mathrm{OH})_{2(\mathrm{~s})}\right] \\
& =[-875.0 \mathrm{~kJ}+2(-285.8 \mathrm{~kJ})]-[2(-174.1 \mathrm{~kJ})+(-924.5 \mathrm{~kJ})] \\
& =[-1446.6 \mathrm{~kJ}]-[-1272.7 \mathrm{~kJ}] \\
& =-173.9 \mathrm{~kJ}
\end{aligned}
$$

7. Liquid butane, $\mathrm{C}_{4} \mathrm{H}_{10}$, burns to produce water vapour and carbon dioxide. The $\Delta \mathrm{H}$ for the reaction is $-2662.8 \mathrm{~kJ} / \mathrm{mol}$ butane burned. Use this value and $\Delta \mathrm{H}_{\mathrm{f}}^{\circ}$ values on page 597 to calculate the heat of formation $\left(\Delta \mathrm{H}^{\circ}\right)$ of butane.

$$
\begin{aligned}
& \mathrm{C}_{4} \mathrm{H}_{10}(\mathrm{l})+13 / 2 \mathrm{O}_{2}(\mathrm{~g}) \rightarrow 4 \mathrm{CO}_{2}(\mathrm{~g})+5 \mathrm{H}_{2} \mathrm{O}(\mathrm{~g}) \quad \Delta \mathrm{H}=-2662.8 \mathrm{~kJ} / \mathrm{mol} \text { butane } \\
& \Delta H^{\circ} \mathrm{rxn}=\Sigma \Delta H_{\mathrm{f}}^{\circ} \text { products }-\Sigma \Delta H_{\mathrm{f}}^{\circ} \text { reactants } \\
&-2662.8 \mathrm{~kJ}=\left[4\left(\Delta H_{\mathrm{f}}^{\circ} \mathrm{CO}_{2(\mathrm{~g})}\right)+5\left(\Delta H_{\mathrm{f}}^{\circ} \mathrm{H}_{2} \mathrm{O}_{(\mathrm{g})}\right)\right]-\left[\Delta H_{\mathrm{f}}^{\circ} \mathrm{C}_{4} \mathrm{H}_{10}(\mathrm{l})\right] \\
&-2662.8 \mathrm{~kJ}=[4(-393.5 \mathrm{~kJ})+5(-241.8 \mathrm{~kJ})]-\left[\Delta H_{\mathrm{f}}^{\circ} \mathrm{C}_{4} \mathrm{H}_{10}(\mathrm{l})\right] \\
&-2662.8 \mathrm{~kJ}=[-2783 \mathrm{~kJ}]-\left[\Delta H_{\mathrm{f}}^{\circ} \mathrm{C}_{4} \mathrm{H}_{10}(\mathrm{l})\right] \\
& 120.2 \mathrm{~kJ}=-\left[\Delta H_{\mathrm{f}}^{\circ} \mathrm{C}_{4} \mathrm{H}_{10}(\mathrm{l})\right] \\
& \Delta H_{\mathrm{f}}^{\circ} \mathrm{C}_{4} \mathrm{H}_{10}(\mathrm{l})=-120.2 \mathrm{~kJ}
\end{aligned}
$$

8. Use bond energies to estimate the enthalpy change $(\Delta \mathrm{H})$ for the reaction when solid nitrogen triiodide ( $\mathrm{NI}_{3}$, a contact explosive) decomposes to produce nitrogen gas and pure iodine vapour:

$$
2 \mathrm{NI}_{3(\mathrm{~s})} \rightarrow \mathrm{N}_{2(\mathrm{~g})}+3 \mathrm{I}_{2(\mathrm{v})}
$$

Express your answer in $\mathrm{kJ} / \mathrm{mol}$ of $\mathrm{NI}_{3}$.
$\Delta H^{\circ}$ rxn $=\Sigma$ bond energy reactants $-\Sigma$ bond energy products

$$
=\Sigma[6(\mathrm{~N}-\mathrm{I})]-[1(\mathrm{~N} \equiv \mathrm{~N})+3(\mathrm{I}-\mathrm{I})]
$$

$$
=\Sigma[6(159 \mathrm{~kJ})]-[1(945 \mathrm{~kJ})+3(151 \mathrm{~kJ})]
$$

$$
=954 \mathrm{~kJ}-1398 \mathrm{~kJ}
$$

$$
=-444 \mathrm{~kJ} \text { for } 2 \text { moles of } \mathrm{NI}_{3} \text { or }-222 \mathrm{~kJ} \text { per mole of } \mathrm{NI}_{3}
$$

9. Use bond energies to estimate $\Delta \mathrm{H}$ for the reaction:

$$
\mathrm{C}_{2} \mathrm{H}_{4}+\mathrm{Cl}_{2} \rightarrow \mathrm{C}_{2} \mathrm{H}_{4} \mathrm{Cl}_{2}
$$

Express your answer in $\mathrm{kJ} / \mathrm{mol}$ of $\mathrm{C}_{2} \mathrm{H}_{4}$.

$\Delta H^{\circ} \mathrm{rxn}=\Sigma$ bond energy reactants $-\Sigma$ bond energy products

$$
\begin{aligned}
& =\Sigma[4(\mathrm{C}-\mathrm{H})+1(\mathrm{C}=\mathrm{C})+1(\mathrm{Cl}-\mathrm{Cl})]-[1(\mathrm{C}-\mathrm{C})+4(\mathrm{C}-\mathrm{H})+2(\mathrm{C}-\mathrm{Cl})] \\
& =\Sigma[4(338 \mathrm{~kJ})+1(607 \mathrm{~kJ})+1(243 \mathrm{~kJ})]-[1(347 \mathrm{~kJ})+4(338 \mathrm{~kJ})+2(397 \mathrm{~kJ})] \\
& =2202 \mathrm{~kJ}-2493 \mathrm{~kJ} \\
& =-291 \mathrm{~kJ} \text { for } 1 \text { mole of } \mathrm{C}_{2} \mathrm{H}_{4}
\end{aligned}
$$

