Part C: Thermochemical Lab - Applying Hess's Law

The enthalpy change for any reaction depends on the products and reactants and is independent of the pathway or the number of steps between the reactant and product.

In this experiment, you will measure and compare the quantity of heat involved in the reaction of sodium hydroxide solution with dilute hydrochloric acid solution, shown below:

\[
Na^+(aq) + OH^-(aq) + H^+(aq) + Cl^-(aq) \rightarrow Na^+(aq) + Cl^-(aq) + H_2O
\]

Safety:

- Hydrochloric acid and sodium hydroxide are corrosive. Avoid direct contact. If any touches your skin, wash it off immediately.
- Solid sodium hydroxide is especially dangerous because it absorbs moisture rapidly from the air, forming an extremely corrosive liquid. Avoid spilling this solid, and if a spill occurs, clean it up immediately.
- Be sure to close the lids of bottles of sodium hydroxide securely, immediately after using.

Objectives: To provide experimental verification of Hess's Law

Materials:

- 2 large styrofoam cups
- 100 mL graduated cylinder
- sodium hydroxide, NaOH
- 1.0 M sodium hydroxide solution
- 1.0 M Hydrochloric acid solution
- thermometers
- balance
- 250 mL beaker
- glass stirring rod

Dispose of solutions according to your teacher's instructions. A lab coat or apron is strongly recommended.
1. A balloon filled with 0.01 mol of hydrogen gas is kept constant at 25 degrees Celcius. If the pressure is changed from 1 atm to 1.5 atm, what is the resulting volume of the balloon?
   A) 0.27 L   B) 0.15 L   C) 0.30 L   D) 0.25 L   E) 0.12 L

2. Base your answer to the following question on the following molecules.
   (A) H₂ (B) O₂ (C) Br₂ (D) N₂ (E) F₂
   Which molecule as a gas effuses the fastest?
   A) D   B) C   C) B   D) A   E) E

3. “The pressure of a given mass of gas varies directly with the absolute, Kelvin, temperature with the volume being kept constant.” This statement best illustrates

4. The gaseous pressure in a 500 mL flask is 250 mmHg at 284 K. What is the number of moles of gas present in the flask?
   A) 0.00143 mole   B) 0.00705 mole   C) 181 moles   D) 7.05 moles   E) 143 moles

5. A gas has a density of 0.25 g/L at a pressure of 0.0821 atm and a temperature of 27.°C. What is the molar mass of the gas?
   A) 38. g/mol   B) 75. g/mol   C) 30. g/mol   D) 25. g/mol   E) 0.25 g/mol

6. The temperature of a sample of H₂O is decreased. Which of the following can be true?
   A) Volume constant, pressure constant, density constant
   B) Volume decreased, pressure increased, density decreased
   C) Volume decreased, pressure constant, density increased
   D) Volume constant, pressure decreased, density constant
   E) Volume constant, pressure increased, density constant

7. A student collected a sample of gas using water displacement. Which of the following measurements is necessary to determine the vapor pressure of the water in the sample?
   A) The water solubility of the gas   B) The temperature of the water
   C) The kinetic energy of the gas   D) The volume of the water
   E) The volume of the gas

8. Equal numbers of moles of CO₂(g), NH₃(g), SO₂(g) are placed into 3 separate identical containers. If each container has an identical pinhole leak, which of the following is true about the moles of gas remaining in each container after some time has elapsed?
   A) mol NH₃ < mol CO₂ < mol SO₂   B) mol SO₂ < mol CO₂ < mol NH₃
   C) mol NH₃ < mol SO₂ < mol CO₂   D) mol CO₂ < mol SO₂ < mol NH₃
   E) mol CO₂ < mol NH₃ < mol SO₂
9. Hydrogen gas is collected over water at 29°C. The total pressure of the system is 773 torr. If the vapor pressure of water at 29°C is 30 torr, what is the partial pressure of the hydrogen gas?

A) 743 torr  B) 803 torr  C) 753 torr  D) 30 torr  E) 773 torr

10. A gaseous mixture contains 4.50 moles hydrogen, 2.50 moles oxygen, and 3.00 moles argon. This system exerts a total pressure of 0.500 atmosphere. What is the partial pressure of the hydrogen?

A) 0.135 atm  B) 0.025 atm  C) 0.325 atm  D) 0.356 atm  E) 0.225 atm

11. Which of the following is NOT an assumption of the ideal gas law

A) There are no intermolecular forces
B) There is no effect of the kinetic energy of particles on the equation of state
C) Particles are sizeless
D) All collisions are elastic
E) All gases behave in the same manner

12. Base your answer to the following question on the elements below.

(A) Cl  
(B) At  
(C) Li  
(D) Ne  
(E) Ca

Which does not readily combine with other elements?

A) A  B) B  C) C  D) D  E) E

13. The pressure of a real gas is sometimes less than that predicted by the ideal gas law because the ideal gas law does not include the factor of

A) mass of molecules  B) shape of molecules
C) size of molecules  D) energy of molecules
E) intermolecular forces

14. A 320. mL sample of a dry gas is collected at 47°C and 740 mm Hg. What is its volume at 7°C and 560 mm Hg?

A) 277 mL  B) 370 mL  C) 483 mL  D) 320 mL  E) 212 mL

15. A sample of a gas would have the same volume if

<table>
<thead>
<tr>
<th>Kelvin Temperature</th>
<th>Pressure</th>
</tr>
</thead>
<tbody>
<tr>
<td>(A) doubled</td>
<td>doubled</td>
</tr>
<tr>
<td>(B) halved</td>
<td>doubled</td>
</tr>
<tr>
<td>(C) doubled</td>
<td>halved</td>
</tr>
<tr>
<td>(D) unchanged</td>
<td>doubled</td>
</tr>
</tbody>
</table>

A) A  B) B  C) C  D) D  E) None of the above
16. A sample of an ideal gas has a volume of 3800. mL at 100. mmHg and 127°C. What would be its volume at STP?
   A) 1,970 mL  B) 341 mL  C) 17,200 mL  D) 733 mL  E) 4,230 mL

17. How much heat is absorbed when 50.0 grams of water is heated from 22.0°C to 36.0°C?
   \[ \text{Specific heat of water} = 4.184 \text{ J \cdot g}^{-1} \text{ \cdot ^oC}^{-1} \]
   A) 4,520 J  B) 7,530 J  C) 15,060 J  D) 2,930 J  E) 1,510 J

18. \[ \text{C(s) + O}_2(g) \rightarrow \text{CO}_2(g) \Delta H = -394 \text{kJ mol}^{-1} \]
   \[ \text{CO(g) + \frac{1}{2} O}_2(g) \rightarrow \text{CO}_2(g) \Delta H = -283 \text{kJ mol}^{-1} \]
   From this information, calculate \( \Delta H \) of the equation
   \[ \text{C(s) + \frac{1}{2} O}_2(g) \rightarrow \text{CO(g)} \]
   A) \(-577 \text{ kJ mol}^{-1}\)  B) \(-111 \text{ kJ mol}^{-1}\)
   C) \(-394 \text{ kJ mol}^{-1}\)  D) \(-222 \text{ kJ mol}^{-1}\)
   E) \(-283 \text{ kJ mol}^{-1}\)

19. Gas 1 and gas 2 are in containers of equal volume \( (V_1=V_2) \). If \( T_1 = T_2 \), \( m_1 < m_2 \), and \( n_1 = n_2 \), then what is true about the pressure, \( P \), in the two containers?
   \[ \text{Note: } T \text{ is the temperature in Kelvins, } m \text{ is the molecular mass of the gas, } n \text{ is the quantity of matter in moles.} \]
   A) \( P_1 < P_2 \)  B) Not enough data to tell.
   C) \( P_1 = P_2 \), always  D) \( P_1 > P_2 \)
   E) \( P_1 = P_2 \), at low temperatures only

20. Which of the following is not considered standard pressure?
   A) 101.3 kPa
   B) 760 mmHg
   C) 760 torr
   D) 1 atm
   E) all of the above are standard pressure

Version 2
21. Which curve represents the relationship between the volume of an ideal gas and its pressure for a certain number of molecules at a constant temperature?

A) ![Graph A]

B) ![Graph B]

C) ![Graph C]

D) ![Graph D]

22. If the temperature remains constant while the volume of a given amount of gas is tripled, the pressure will be

A) 9 times the original pressure

B) the same as the original pressure

C) 2/3 of the original pressure

D) 3 times the original pressure

E) 1/3 of the original pressure

23. Base your answer to the following question on the information below:

<table>
<thead>
<tr>
<th>Sample</th>
<th>Mass</th>
<th>Pressure</th>
<th>Temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gas A</td>
<td>2 moles</td>
<td>760 mm.</td>
<td>273° K.</td>
</tr>
<tr>
<td>Gas B</td>
<td>1 mole</td>
<td>380 mm.</td>
<td>273° K.</td>
</tr>
<tr>
<td>Gas C</td>
<td>1 mole</td>
<td>760 mm.</td>
<td>273° K.</td>
</tr>
<tr>
<td>Gas D</td>
<td>2 moles</td>
<td>760 mm.</td>
<td>546° K.</td>
</tr>
</tbody>
</table>

Which gas occupies the smallest volume?

A) A

B) B

C) C

D) D

24. "The pressure of a given mass of gas varies directly with the absolute, Kelvin, temperature with the volume being kept constant." This statement illustrates

A) Charles’ Law

B) Avogadro’s Principle

C) Gay-Lussac’s Law

D) Dalton’s Law

E) Boyle’s Law

25. LiBr(s) → Li⁺(aq) + Br⁻(aq); ΔH = -11.4 kcal

LiBr dissolves in water according to the equation above. If 2.00 mol of LiBr is dissolved in 1000 mL of water at 0.00°C, what is the final temperature of the water?

A) 0.00°C

B) 11.4°C

C) -11.4°C

D) 22.8°C

E) -22.8°C
26. The density of a gas
   A) varies directly with the absolute temperature at constant pressure
   B) decreases as the mass of the gas increases
   C) varies inversely with the absolute temperature at constant pressure
   D) varies directly with absolute temperature at a constant volume
   E) varies inversely with pressure at constant temperature

27. I. Water boils at a higher temperature at low altitudes than at high altitudes

BECAUSE

II. the atmospheric pressure decreases as the altitude increases.

A) I is FALSE, II is TRUE
B) I is TRUE, II is FALSE
C) I and II are BOTH TRUE and II IS a correct explanation of I
D) I and II are BOTH FALSE
E) I and II are BOTH TRUE but II IS NOT a correct explanation of I

28. Base your answer to the following question on the image below.

If the atmospheric pressure is 730 torr, what is the pressure of the gas labeled A?

A) 695 torr   B) 795 torr   C) 765 torr   D) 630 torr   E) 35 torr

29. If 25 g of hydrogen gas in a closed container is heated from 0°C to 273°C the mass of the gas at 273°C will be

A) 25 g   B) $25 \times 273$ g   C) $25 \times \frac{273 g}{546}$   D) $25 \times \frac{546 g}{273}$   E) $25 \times \frac{1 g}{273}$

30. The random motion of gas molecules helps to explain the

A) compressibility of gases   B) transparency of gases
C) fixed volume of gases   D) fact that gases fill their container
E) low density of gases
31. For a confined gas, when the temperature is increased and the volume is decreased at the same time, the
   A) pressure increases  B) density decreases
   C) number of collisions decreases  D) molecules move slower
   E) average kinetic energy is decrease

32. Carbon tetrachloride, (CCl₄), melts at −23°C and boils at 76.8°C. At standard pressure, which has the highest average kinetic energy?
   A) CCl₄(l) at 0°C  B) CCl₄(g) at 100°C
   C) CCl₄(l) → CCl₄(g) at 76.8°C  D) CCl₄(s) at −50°C
   E) CCl₄(s) → CCl₄(l) at −23°C

33. Air pressure is graphed as a function of temperature. The extrapolated line intersects the horizontal axis at about −280°C. Which term is applied to this temperature value?

![Graph of air pressure vs. temperature]

   A) Freezing point  B) Triple point
   C) Absolute zero  D) Critical temperature
   E) Boiling point

34. When sulfuric acid, H₂SO₄, is added to water in a beaker, the container and its contents get hot. This shows that the solution reaction is

   A) exothermic and evolves energy  B) exothermic and absorbs energy
   C) endothermic and evolves energy  D) endothermic and absorbs energy
   E) none of the above

35. The temperature of a sample of carbon dioxide gas is a measure of its

   A) average potential energy  B) total potential energy
   C) average kinetic energy  D) kinetic and potential energy
   E) total kinetic energy
36. The table below shows mass and volume data for four samples of substances at 298 K and 1 atmosphere.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Mass (g)</th>
<th>Volume (mL)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>30.</td>
<td>60.</td>
</tr>
<tr>
<td>B</td>
<td>40.</td>
<td>50.</td>
</tr>
<tr>
<td>C</td>
<td>45.</td>
<td>90.</td>
</tr>
<tr>
<td>D</td>
<td>90.</td>
<td>120.</td>
</tr>
</tbody>
</table>

Which two samples could consist of the same substance?

A) A and C  B) B and C  C) A and B  D) C and D

37. A gas occupies a volume of 444 mL at 273 K and 79.0 kPa. What is the final kelvin temperature when the volume of the gas is changed to 1880 mL and the pressure is changed to 38.7 kPa?

A) 2360 K  B) 292 K  C) 31.5 K  D) 566 K

38. As the temperature of a gas is increased from 0°C to 10°C at constant pressure, the volume of the gas will

A) decrease by \(\frac{10}{273}\)  B) increase by \(\frac{1}{273}\)
C) decrease by \(\frac{1}{273}\)  D) increase by \(\frac{10}{273}\)

39. A reaction inside a bomb calorimeter caused the temperature of the bomb calorimeter (heat capacity 2500. J K\(^{-1}\)) to raise 3.000°C. What is the energy change for this reaction?

A) \(\Delta H = -7500.\) J  B) \(\Delta E = +7500.\) J
C) \(\Delta E = -7500.\) J  D) \(\Delta H = +7500.\) J
E) \(\Delta E = +7500.\) J

40. Based on the table below, what is the free energy change for the reaction \(\text{C}_2\text{H}_4(\text{g}) + 3 \text{ O}_2(\text{g}) \rightarrow 2 \text{ H}_2\text{O}(\text{g}) + 2 \text{ CO}_2(\text{g})?\)

<table>
<thead>
<tr>
<th>Reaction</th>
<th>(\Delta G^\circ,) kcal</th>
</tr>
</thead>
<tbody>
<tr>
<td>(\text{CH}_4(\text{g}) + 2 \text{ O}_2(\text{g}) \rightarrow \text{CO}_2(\text{g}) + 2 \text{ H}_2\text{O}(\text{g}))</td>
<td>-192</td>
</tr>
<tr>
<td>(2 \text{ CH}_4(\text{g}) \rightarrow \text{C}_2\text{H}_2(\text{g}) + \text{H}_2(\text{g}))</td>
<td>-16</td>
</tr>
<tr>
<td>(\text{C}_2\text{H}_2(\text{g}) \rightarrow \text{C}_2\text{H}_4(\text{g}) + \text{H}_2(\text{g}))</td>
<td>+24</td>
</tr>
<tr>
<td>(\text{H}_2(\text{g}) + \frac{1}{2} \text{O}_2(\text{g}) \rightarrow \text{H}_2\text{O}(\text{g}))</td>
<td>-55</td>
</tr>
</tbody>
</table>

A) +282 kcal  B) -408 kcal  C) \(-282\) kcal  D) +104 kcal  E) -104 kcal
Answer Key
Science Olympiad

1. B  36. A
2. D  37. D
3. E  38. D
5. B  40. C
6. D
7. B
8. A
9. A
10. E
11. B
12. D
13. E
14. B
15. A
16. B
17. D
18. B
19. A
20. E
21. A
22. E
23. C
24. A
25. D
26. C
27. C
28. C
29. A
30. D
31. A
32. B
33. C
34. A
35. C
a. The troposphere contains 75%-90% of atmospheric gases. Explain why.

gravity
b. The stratosphere contains about 10% of the atmospheric gases. Explain why jet planes tend to travel in this layer of the atmosphere.

* no weather in the stratosphere
* no water vapor
* jet stream
* no turbulence

c. The stratosphere contains the ozone layer. Explain the importance of the ozone layer to life on Earth AND give one example of a pollutant partly responsible for the breakdown of the ozone layer.

* protects Earth from UV radiation
* CFC's breakdown ozone

d. The thermosphere has increased temperature with increased altitude. Explain why.

* high energy X-rays and UV radiation from Sun are absorbed by rare air of thermosphere
2. Label the following diagram of the Carbon Cycle by placing the correct terms to represent the processes shown with the arrows.

1. combustion
2. cell respiration
3. photosynthesis
4. absorption/diffusion
5. consumption
6. decomposition
7. fossilization
8. mining/oil refining
3. Diborane (B₂H₆) is a highly reactive boron hydride, which was once considered as a possible rocket fuel for the U.S. space program. Calculate \( \Delta H \) for the synthesis of diborane from its elements, according to the equation. Show your work and put your final answer with proper units on the line at the bottom of this page.

\[
2\text{B(s)} + 3\text{H}_2(\text{g}) \rightarrow \text{B}_2\text{H}_6(\text{g})
\]

using the following data:

\[
\begin{array}{ccc}
\text{REACTION} & \Delta H \\
(a) 2\text{B(s)} + \frac{3}{2} \text{O}_2(\text{g}) & \rightarrow & \text{B}_2\text{O}_3(\text{s}) & -1273 \text{ kJ} \\
(b) \text{B}_2\text{H}_6(\text{g}) + 3 \text{O}_2 (\text{g}) & \rightarrow & \text{B}_2\text{O}_3(\text{s}) + 3\text{H}_2\text{O}(\text{g}) & -2035 \text{ kJ} \\
(c) \text{H}_2 (\text{g}) + \frac{1}{2} \text{O}_2(\text{g}) & \rightarrow & \text{H}_2\text{O}(\text{l}) & -286 \text{ kJ} \\
(d) \text{H}_2\text{O} (\text{l}) & \rightarrow & \text{H}_2\text{O}(\text{g}) & 44 \text{ KJ}
\end{array}
\]

Final Answer: \( \Delta H = +36 \text{ kJ} \)
**Sample Exercise 6.8 Hess's Law II**

Diborane (B₂H₆) is a highly reactive boron hydride, which was once considered as a possible rocket fuel for the U.S. space program. Calculate ΔH for the synthesis of diborane from its elements, according to the equation

\[
2\text{B}(s) + 3\text{H}_2(g) \rightarrow \text{B}_2\text{H}_6(g)
\]

using the following data:

<table>
<thead>
<tr>
<th>Reaction</th>
<th>ΔH</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a) (2 \text{B}(s) + \frac{3}{2}\text{O}_2(g) \rightarrow \text{B}_2\text{O}_3(s))</td>
<td>−1273 kJ</td>
</tr>
<tr>
<td>(b) (\text{B}_2\text{H}_6(g) + 3\text{O}_2(g) \rightarrow \text{B}_2\text{O}_3(s) + 3\text{H}_2\text{O}(g))</td>
<td>−2035 kJ</td>
</tr>
<tr>
<td>(c) (\text{H}_2(g) + \frac{3}{2}\text{O}_2(g) \rightarrow \text{H}_2\text{O}(l))</td>
<td>−286 kJ</td>
</tr>
<tr>
<td>(d) (\text{H}_2\text{O}(l) \rightarrow \text{H}_2\text{O}(g))</td>
<td>44 kJ</td>
</tr>
</tbody>
</table>

**Solution**

To obtain ΔH for the required reaction, we must somehow combine equations (a), (b), (c), and (d) to produce that reaction and add the corresponding ΔH values. This can best be done by focusing on the reactants and products of the required reaction. The reactants are \(\text{B}(s)\) and \(\text{H}_2(g)\), and the product is \(\text{B}_2\text{H}_6(g)\). How can we obtain the correct equation? Reaction (a) has \(\text{B}(s)\) as a reactant, as needed in the required equation. Thus reaction (a) will be used as it is. Reaction (b) has \(\text{B}_2\text{H}_6(g)\) as a reactant, but this substance is needed as a product. Thus reaction (b) must be reversed, and the sign of ΔH must be changed accordingly. Up to this point we have

<table>
<thead>
<tr>
<th>Reaction</th>
<th>ΔH</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a) (2 \text{B}(s) + \frac{3}{2}\text{O}_2(g) \rightarrow \text{B}_2\text{O}_3(s))</td>
<td>−1273 kJ</td>
</tr>
<tr>
<td>− (b) (\text{B}_2\text{O}_3(s) + 3\text{H}_2\text{O}(g) \rightarrow \text{B}_2\text{H}_6(g) + 3\text{O}_2(g))</td>
<td>+(−2035 kJ)</td>
</tr>
<tr>
<td>Sum: (\text{B}_2\text{O}_3(s) + 2\text{B}(s) + \frac{3}{2}\text{O}_2(g) + 3\text{H}_2\text{O}(g) \rightarrow \text{B}_2\text{O}_3(s) + \text{B}_2\text{H}_6(g) + 3\text{O}_2(g))</td>
<td>ΔH (\rightarrow) 762 kJ</td>
</tr>
</tbody>
</table>

Deleting the species that occur on both sides gives

\[2\text{B}(s) + 3\text{H}_2\text{O}(g) \rightarrow \text{B}_2\text{H}_6(g) + \frac{3}{2}\text{O}_2(g)\]  \(\Delta H = 762\) kJ

We are closer to the required reaction, but we still need to remove \(\text{H}_2\text{O}(g)\) and \(\text{O}_2(g)\) and introduce \(\text{H}_2\text{O}(l)\) as a reactant. We can do this using reactions (c) and (d). If we multiply reaction (c) by 3 and add the result to the preceding equation, we have

<table>
<thead>
<tr>
<th>Reaction</th>
<th>ΔH</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 \times (c) (3[\text{H}_2(g) + \frac{3}{2}\text{O}_2(g) \rightarrow \text{H}_2\text{O}(l)])</td>
<td>3(−286 kJ)</td>
</tr>
<tr>
<td>Sum: (2\text{B}(s) + 3\text{H}_2(g) + \frac{3}{2}\text{O}_2(g) + 3\text{H}_2\text{O}(g) \rightarrow \text{B}_2\text{H}_6(g) + \frac{3}{2}\text{O}_2(g) + 3\text{H}_2\text{O}(l))</td>
<td>ΔH = −96 kJ</td>
</tr>
</tbody>
</table>

We can cancel \(\frac{3}{2}\text{O}_2(g)\) on both sides, but we cannot cancel the \(\text{H}_2\text{O}(l)\) because it is gaseous on one side and liquid on the other. This can be solved by adding reaction (d) multiplied by 3:

<table>
<thead>
<tr>
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<th>ΔH</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 \times (d) (3[\text{H}_2\text{O}(l) \rightarrow \text{H}_2\text{O}(g)])</td>
<td>3(44 kJ)</td>
</tr>
<tr>
<td>Sum: (2\text{B}(s) + 3\text{H}_2(g) + 3\text{H}_2\text{O}(g) \rightarrow \text{B}_2\text{H}_6(g) + 3\text{H}_2\text{O}(l))</td>
<td>ΔH = −96 kJ</td>
</tr>
<tr>
<td>3 \times (d) (3[\text{H}_2\text{O}(l) \rightarrow \text{H}_2\text{O}(g)])</td>
<td>3(44 kJ)</td>
</tr>
<tr>
<td>Sum: (2\text{B}(s) + 3\text{H}_2(g) + 3\text{H}_2\text{O}(g) + 3\text{H}_2\text{O}(l) \rightarrow \text{B}_2\text{H}_6(g) + 3\text{H}_2\text{O}(l) + 3\text{H}_2\text{O}(g))</td>
<td>ΔH = +36 kJ</td>
</tr>
</tbody>
</table>
Sample Exercise 6.8 Hess's Law II

Diborane (B₂H₆) is a highly reactive boron hydride, which was once considered as a possible rocket fuel for the U.S. space program. Calculate ΔH for the synthesis of diborane from its elements, according to the equation

\[ 2\text{B}(s) + 3\text{H}_2(g) \rightarrow \text{B}_2\text{H}_6(g) \]

using the following data:

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<th>Reaction</th>
<th>ΔH</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a) (2\text{B}(s) + \frac{3}{2}\text{O}_2(g) \rightarrow \text{B}_2\text{O}_3(s))</td>
<td>(-1273\text{ kJ})</td>
</tr>
<tr>
<td>(b) (\text{B}_2\text{H}_6(g) + 3\text{O}_2(g) \rightarrow \text{B}_2\text{O}_3(s) + 3\text{H}_2\text{O}(g))</td>
<td>(-2035\text{ kJ})</td>
</tr>
<tr>
<td>(c) (\text{H}_2(g) + \frac{1}{2}\text{O}_2(g) \rightarrow \text{H}_2\text{O}(l))</td>
<td>(-286\text{ kJ})</td>
</tr>
<tr>
<td>(d) (\text{H}_2\text{O}(l) \rightarrow \text{H}_2\text{O}(g))</td>
<td>(44\text{ kJ})</td>
</tr>
</tbody>
</table>

Solution

To obtain ΔH for the required reaction, we must somehow combine equations (a), (b), (c), and (d) to produce that reaction and add the corresponding ΔH values. This can be best done by focusing on the reactants and products of the required reaction. The reactants are \(\text{B}(s)\) and \(\text{H}_2(g)\), and the product is \(\text{B}_2\text{H}_6(g)\). How can we obtain the correct equation? Reaction (a) has \(\text{B}(s)\) as a reactant, as needed in the required equation. Thus reaction (a) will be used as it is. Reaction (b) has \(\text{B}_2\text{H}_6(g)\) as a reactant, but this substance is needed as a product. Thus reaction (b) must be reversed, and the sign of ΔH must be changed accordingly. Up to this point we have

\[
\begin{align*}
\text{(a)} & \quad 2\text{B}(s) + \frac{3}{2}\text{O}_2(g) \rightarrow \text{B}_2\text{O}_3(s) \quad \Delta H = -1273\text{ kJ} \\
- \text{(b)} & \quad \text{B}_2\text{O}_3(s) + 3\text{H}_2\text{O}(g) \rightarrow \text{B}_2\text{H}_6(g) + 3\text{O}_2(g) \quad \Delta H = -(−2035\text{ kJ}) \\
\text{Sum:} & \quad \text{B}_2\text{O}_3(s) + \frac{3}{2}\text{O}_2(g) + 5\text{H}_2\text{O}(g) \rightarrow \text{B}_2\text{H}_6(g) + \text{B}_2\text{H}_6(g) + 3\text{O}_2(g) \quad \Delta H = 762\text{ kJ}
\end{align*}
\]

(Deleting the species that occur on both sides gives

\[ 2\text{B}(s) + 3\text{H}_2\text{O}(g) \rightarrow \text{B}_2\text{H}_6(g) + \frac{3}{2}\text{O}_2(g) \quad \Delta H = 762\text{ kJ} \]

We are closer to the required reaction, but we still need to remove \(\text{H}_2\text{O}(g)\) and \(\text{O}_2(g)\) as a reactant. We can do this using reactions (c) and (d). If we multiply reaction (c) and its ΔH value by 3 and add the result to the preceding equation, we have

\[
\begin{align*}
3 \times \text{(c)} & \quad 3[\text{H}_2\text{O}(l) \rightarrow \text{H}_2\text{O}(g)] \quad \Delta H = 3(−286\text{ kJ}) \\
\text{Sum:} & \quad 2\text{B}(s) + 3\text{H}_2(g) + \frac{3}{2}\text{O}_2(g) + 3\text{H}_2\text{O}(g) \rightarrow \text{B}_2\text{H}_6(g) + \frac{3}{2}\text{O}_2(g) + 3\text{H}_2\text{O}(l) \quad \Delta H = -96\text{ kJ}
\end{align*}
\]

We can cancel the \(\frac{3}{2}\text{O}_2(g)\) on both sides, but we cannot cancel the \(\text{H}_2\text{O}(g)\) because it is gaseous on one side and liquid on the other. This can be solved by adding reaction (d), multiplied by 3:

\[
\begin{align*}
3 \times \text{(d)} & \quad 3[\text{H}_2\text{O}(l) \rightarrow \text{H}_2\text{O}(g)] \quad \Delta H = 3(44\text{ kJ}) \\
2\text{B}(s) + 3\text{H}_2(g) + 3\text{H}_2\text{O}(g) \rightarrow \text{B}_2\text{H}_6(g) + 3\text{H}_2\text{O}(l) \quad \Delta H = -96\text{ kJ} \\
\text{Sum:} & \quad 2\text{B}(s) + 3\text{H}_2(g) + 3\text{H}_2\text{O}(g) + 3\text{H}_2\text{O}(l) \rightarrow \text{B}_2\text{H}_6(g) + 3\text{H}_2\text{O}(l) + 3\text{H}_2\text{O}(g) \quad \Delta H = +36\text{ kJ}
\end{align*}
\]
**Procedure:**
1. Accurately measure 50.0 mL of 1.0 M hydrochloric acid solution into your calorimeter and 50.0 mL of 1.0 M sodium hydroxide into a 250 mL beaker.
2. Record the temperatures and volumes of each solution.
3. Add the sodium hydroxide solution to the acid solution in the styrofoam cup. Stir the mixture with the thermometer and record the highest temperature reached.
4. Discard the solution as directed by the event supervisors.

**Data Table:**

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Volume of 1.0 M HCl solution used</td>
<td>50.0 mL</td>
</tr>
<tr>
<td>Volume of 1.0 M NaOH solution used</td>
<td>50.0 mL</td>
</tr>
<tr>
<td>Initial temperature of the NaOH solution (before mixing)</td>
<td>18.0°C</td>
</tr>
<tr>
<td>Highest final temperature of mixture</td>
<td>24.0°C</td>
</tr>
</tbody>
</table>

**Calculations:** Show all work.

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Calculations (Show all work!)</td>
<td></td>
</tr>
<tr>
<td><strong>1.</strong> Change in temperature</td>
<td></td>
</tr>
<tr>
<td>[24.0°C - 18.0°C = 6.0°C]</td>
<td>6.0°C</td>
</tr>
<tr>
<td><strong>2.</strong> Moles of HCl used</td>
<td></td>
</tr>
<tr>
<td>[\text{mo1} = \text{M} \times \text{V} = \frac{(1.0)(50.0)}{1000} = 0.50 \text{ mol}]</td>
<td>0.50 \text{ mol}</td>
</tr>
<tr>
<td><strong>3.</strong> Moles of NaOH used</td>
<td></td>
</tr>
<tr>
<td>[\text{mo1} = \frac{(4.18)(6.6)}{5.0} = \text{mo1} ]</td>
<td>\text{mo1}</td>
</tr>
<tr>
<td><strong>4.</strong> Energy released</td>
<td></td>
</tr>
<tr>
<td>[q = mcA\Delta T]</td>
<td></td>
</tr>
<tr>
<td>[q = (100 \text{g})(4.18)(6.6°C) = 2758.8 \text{ J}]</td>
<td>2758.8 \text{ J}</td>
</tr>
<tr>
<td><strong>5.</strong> Heat of reaction</td>
<td></td>
</tr>
<tr>
<td>[\Delta H = \frac{(-1)(2758.8)}{0.050} = -55176 \text{ J/mo1}]</td>
<td>(-55176 \text{ J/mo1})</td>
</tr>
<tr>
<td>((-55.2 \text{ KJ/mo1}))</td>
<td></td>
</tr>
</tbody>
</table>