1

**Example of an appropriate procedure**

Δ*Q* = *mc*Δ*T*

1.00 × 102 mL of HCl and 1.00 × 102 mL of NaOH

Assume both solutions have the density of water.

 = 1.00 g/mL

Assume both have the same specific heat capacity as water.

 = 4.19 J/g•°C

Δ*Q* = (2.00 × 102 g)(4.19 )(34.6°C − 22.0°C)

Δ*Q* = +1.06 × 104 J

mol NaOH used = (1.00 )(1.00 ×10−1 L) = 1.00 × 1−1 mol

The water absorbs the heat so the reaction releases heat.

Δ*H* = −

Δ*H* = −1.06 × 102 

**Answer : The molar heat of neutralization is** −**1.06 × 102** ****

4

**Example of an appropriate solution**

1. Propane consumption

0.050 mole × 5.0 minutes = 0.25 mole

2. C3H8 + 5 O2 → 3 CO2 + 4 H2O + 1662 kJ

1 mole C3H8 = -1662 kJ

0.25 mol = *x*

*x* = -4.2 × 102 kJ

3. *Q*water = *m*•*c*•Δ*T*

*Q*water = −*Q*propane

Δ*T* =  =  = +67 °C

4. Δ*T* = *T*F − *T*i

+67 = *T*F − 25

92 °C = *T*F

**Answer:** The final temperature of the water will be **92 °C**.

5

|  |  |  |
| --- | --- | --- |
|  | **Endothermic** | **Exothermic** |
| a) | **X** |  |
| b) |  | **X** |
| c) |  | **X** |
| d) |  | **X** |

Give one mark for each correct answer.

6

C

7

B

8

C

9

**Example of an appropriate and complete answer**

|  |  |
| --- | --- |
| *Q* = | *mc*Δ*T* |
| *m* = | 100 g |
| *c* = | 4.19 J/g°C |
| Δ*T =* | 6.7°C |
|  |  |
| *Q* = | 2.81 kJ |

|  |  |
| --- | --- |
| mol NaOH = | 1.0 mol/1000 mL |
| = | 0.05 mol in 50 mL |

|  |  |
| --- | --- |
| Δ*H =* | -*Q*/n |
| Δ*H =* |  |
| Δ*H =* | -56.1 kJ/mol |

**Answer:** The heat of neutralization is **-56.1 kJ/mol**.

10

**Example of an appropriate and complete solution**

*Q* = *mc*Δ*T* for the oil

0.92  × 500.0 ~~mL~~ = 460 g

*Q* = 460 g × 2.01  × (300.0°C − 25.0°C)

= 250 000 J or 2.5 × 102 kJ of heat energy to increase the temperature of the oil

 × 2.5 × 102 kJ × 

= 42 g ethanol required

**Answer:** **42 g** of ethanol was burned to heat the oil.

11

A

12

D

14

Calculation of the heat of formation for propane

4 H2(g) + 3 C(s) → C3H8(g)

1. Transforming units

|  |  |  |
| --- | --- | --- |
| 35 ~~mg~~  | 1 | = 0.035 g |
| 1000 ~~mg~~ |

|  |  |  |
| --- | --- | --- |
| 1623 ~~J~~  | 1 kJ | = 1.623 kJ |
| 1000 ~~J~~ |

2. Changing the energy sign

The energy represents the amount of heat RELEASED by the combustion of propane: -1.623 kJ

3. Determining the molar heat of combustion for propane

1 mol  44.11 g  *x*

0.035 g  -1.623 kJ

|  |  |  |
| --- | --- | --- |
| ~~0.035 g~~  *x* | = | -1.623 kJ  44.11 g |
| ~~0.035 g~~ | 0.035 g |

*x* = -2045 kJ

Therefore 1 mol  44.11 g  -2045 kJ or = -2045 kJ/mol.

4. Application of Hess' Law

4 H2(g)  + ~~2 O~~2(g)  ~~4 H~~2~~O~~(g) Δ*H* = -968 kJ

3 C(s) + ~~3~~ O2(g)   ~~3 CO~~2(g)  Δ*H* = -1182 kJ

~~3 CO~~2(g) + ~~4 H~~2~~O~~(g)  C3H8(s) + ~~5 O~~2(g) Δ*H* = +2045 kJ

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

4 H2(g)  + 3 C(s)  C3H8(s)  Δ*H* = -105 kJ/mol

The molar heat of formation for propane is -105 kJ/mol.

17

**Example of an appropriate and complete procedure**

Water absorbs heat

Qwater = *mc*Δ*T*

= 0.200 kg × 4.19 kJ/kg • °C × 4.0 ºC

= 3.3 kJ

The molar heat of neutralization is:

 = 

= −33 kJ/mol

**Answer:** The molar heat of neutralization is −33 kJ/mol.

18

A

20

B

21

**Example of an appropriate procedure**

|  |
| --- |
| x 2 (NH3(g) → 1/2 N2(g) + 3/2 H2(g)) Δ*H* = +46.0 kJ/mol  2 C(s) + 3 H2(g) → C2H6(g) Δ*H* = -84.5 kJ/mol  x 2 (1/2 N2(g) + O2(g) → NO2(g)) Δ*H* = +33.1 kJ/mol  x 2 (CO2(g) → C(s) + O2(g)) Δ*H* = +393.5 kJ/mol  2 NH3(g) → ~~1 N~~~~2~~(g) + ~~3 H~~~~2~~(g) Δ*H* = +92.0 kJ/mol  ~~2 C~~(s) + ~~3 H~~~~2~~(g) → C2H6(g) Δ*H* = -84.5 kJ/mol  ~~1 N~~~~2~~(g) + ~~2 O~~~~2~~(g) → 2 NO2(g) Δ*H* = +66.2 kJ/mol  2 CO2(g) → ~~2 C~~(s) + ~~2 O~~~~2~~(g) Δ*H* = +787.0 kJ/mol |
| 2 NH3(g) + 2 CO2(g) → C2H6(g) + 2 NO2(g) Δ*H* = +860.7 kJ/mol |

**Answer** The molar heat of production of ethane by this reaction is +860.7 kJ/mol

23

A

30

A

31

**Example of an appropriate process**

1. Heat absorbed by the water

*Q*water = *m*water × *c*water × Δ*T*water where Δ*T*water = 38.3C - 20.0C = 18.3C

*Q*water = 2000 g × 4.19 J/(g • C) × (18.3C)

*Q*water = 1.53 × 102 kJ

2. Mass of burnt paraffin

47.62 g - 44.10 g = 3.52 g

3. Heat released during combustion of one mole of paraffin

352 g/mol × 1.53 × 102 kJ/3.52 g = 1.53 × 104 kJ/mol

**Answer**

The heat released during the combustion of one mole of paraffin was 1.53 × 104 kJ.

32

**Example of an appropriate process**

1. Molar heat of combustion of C3H8 (g)

Δ*H* = *H*p - *H*r

Δ*H* = -2046 kJ/mol - 0 kJ/mol

Δ*H* = -2046 kJ/mol

2. Apply Hess= law

3 CO2 (g) + 4 H2O(g) → C3H8 (g) + 5 O2 (g) Δ*H* = +2046 kJ

4 C(s) + 3 O2 (g) → 3 CO2 (g) Δ*H* = -1182 kJ

4 H2 (g) + 2 O2 (g) → 4 H2O(g) Δ*H* = -968 kJ

Add the three equations

3 C(s) + 4 H2 (g) → C3H8 (g) Δ*H* = -104 kJ

**Answer**

The molar heat of formation of propane gas is -104 kJ/mol.

33

C

34

**Example of an appropriate procedure**

1. Heat absorbed by the water

*Q* = *mc*Δ*T*

*Q* = 2000 g × 4.19 J/(g•C) × 22.0C

*Q* = 184 kJ

2. Mass of paraffin burned

28.52 g − 24.29 g = 4.23 g

3. Number of moles of paraffin burned

352.77 g → 1 mol 

4.23 g → ?

1.20 × 10−2 mol

4. Molar heat of combustion of the paraffin in the candle

1.20 × 10−2 mol → 184 kJ 

1 mol → ?

15 333 kJ

Hence, the molar heat of combustion of the paraffin is 1.53 × 104 kJ/mol.

5. Difference between the molar heat of combustion of the paraffin in the candle and the molar heat of combustion of pure paraffin.

15 333 kJ/mol − 15 300 kJ/mol = 33 kJ/mol

**Answer**

|  |  |  |  |
| --- | --- | --- | --- |
| Is the paraffin in the candle relatively pure? | **X** | or |  |
|  | **Yes** |  | **No** |

35

**Example of an appropriate procedure**

1. Heat absorbed by the aqueous solutions

*Q* = *mc*Δ*T*

*Q* = 1000 g × 4.19 J/(g•C) × 20.0C

*Q* = 83.8 kJ

2. Number of moles of HCl

*c* = 

1.0 mol/L = 

*n* = 0.50 mol

3. Molar heat of neutralization of HCl

0.50 mol of HCl gives off 83.8 kJ

1 mol of HCl gives off ? 

168 kJ

**Answer**

The molar heat of neutralization of the hydrochloric acid is −168 kJ/mol.

(Accept −170 kJ/mol)

**Name: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_**

**Date: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_**

1

The following chemical equation shows the neutralization reaction between hydrochloric acid (HCl) and sodium hydroxide (NaOH).

HCl(aq) + NaOH(aq) → NaCl(aq) + H2O(l)

In an experiment, 1.00 × 102 mL of 1.00 mol/L HCl was added to 1.00 × 102 mL of 1.00 mol/L NaOH in a calorimeter. Both solutions were at a temperature of 22.0°C before the reaction, and reached a maximum temperature of 34.6°C after being mixed in the calorimeter.

Calculate the molar heat of neutralization of **NaOH.**

(Note : Assume that both solutions have the same density and specific heat as water.)

4

Having stopped for dinner during your hike in the woods, you pour 1.5 litre of water at 25 ˚C into a kettle. Using a propane burner, you heat this water to make some tea. The burner is used to heat the water and consumes 0.050 moles of propane, C3H8, **every minute** for 5.0 minutes.

What will be the temperature of the water after five minutes of heating?

(Assume a 100% heat transfer from the burner to the water)

Equation of propane combustion:

**C3H8(g) + 5 O2(g) → 3 CO2(g) + 4 H2O(g) + 1662 kJ**

5

Determine whether each of the situations below is an example of an endothermic change or an exothermic change.

a) NH3(g) + 1/2 O2(g) + 138 kJ → NO(g) + 3/2 H2(g)

b)



c) The freezing of a lake in winter

d) 2 C(s) + 3 H2(g) → C2H6(g) Δ*H* = -85 kJ

6

Craving chocolate, Marco wants to make a good cup of hot chocolate using his propane burner. The instructions below are written on the package of hot chocolate mix.

|  |
| --- |
| ***INSTRUCTIONS***  1- Bring 200 mL of water to a boil.  2- Dissolve the entire package of mix into the water.  3- Taste. |

The temperature of the water from the faucet is 15 °C.

The following reaction represents the combustion of propane:

**C3H8(g) + 5 O2(g) → 3 CO2(g) + 4 H2O(g) + 2044.5 kJ**

What mass of propane must be burned to heat the water?

|  |  |  |  |
| --- | --- | --- | --- |
| A) | 0.27 g | C) | 1.53 g |
| B) | 0.65 g | D) | 1.80 g |

7

When one mole of glacial acetic acid, CH3COOH(l), is mixed with water to make an aqueous solution of acetic acid, 1.6 kJ is released.

When this prepared aqueous acetic acid solution is neutralized with an aqueous solution of sodium hydroxide, NaOH(aq), 50.0 kJ is released.

On the basis of this information, which of the following equations is correct?

|  |  |
| --- | --- |
| A) | CH3COOH(l) + NaOH(aq) + 49.4 kJ → NaCH3COO(aq) + H2O(l) |
| B) | CH3COOH(l) + NaOH(aq) → NaCH3COO(aq) + H2O(l) + 51.6 kJ |
| C) | CH3COOH(l) + NaOH(aq) + 51.6 kJ → NaCH3COO(aq) + H2O(l) |
| D) | CH3COOH(l) + NaOH(aq) → NaCH3COO(aq) + H2O(l) + 49.9 kJ |

8

Which of the following is the best definition of enthalpy?

|  |  |
| --- | --- |
| A) | It is the average kinetic energy of molecules. |
| B) | It is the amount of heat absorbed or released in reaction. |
| C) | It is the total energy within a substance. |
| D) | It is the heat of the products minus the heat of the reactants. |

9

A lab technician took 50 mL of a 1.0 mol/L solution of hydrochloric acid (HCl) to neutralize 50 mL of a 1.0 mol/L solution of sodium hydroxide (NaOH). The initial temperature of the two solutions was 22.5°C. The final mixing temperature was 29.2°C.

What was the molar heat of neutralization (Δ*H*) of the sodium hydroxide?

(Assume the specific heat of solution is equivalent to the specific heat of water.)

10

SternoTM, a solid, portable fuel also known as Canned Heat®, is burned in camp stoves or fondue pots. Its composition is mainly gelled ethanol, C2H5OH.

Cooking oil used in fondue pots has a specific heat capacity of 2.01 J/g°C and a density of 0.92 g/cm3.

At a dinner party, the temperature of 500.0 mL of cooking oil in a fondue pot was increased from 25.0°C to 300.0°C.



Given that ethanol burns as follow:

C2H5OH(s) + 3 O2(g) → 2 CO2(g) + 3 H2O(g) Δ*H* = -278 kJ/mol

How many grams of ethanol were burned in order to heat the oil to 300°C?

11

Barbeque propane gas, C3H8, burns according to the following equation:

**C3H8 (g) + 5 O2 (g) → 3 CO2 (g) + 4 H2O (g)**

How many grams of propane are needed to provide the 980 kJ required to cook a salmon steak?

|  |  |
| --- | --- |
|  | ∆*H*f (kJ/mol) |
| 3 C(s) + 4 H2(g) → C3H8(g) | -103.8 |
| C(s) + O2(g) → CO2(g) | -394.0 |
| H2(g) + ½ O2(g) → H2O(g) | -241.8 |

|  |  |  |  |
| --- | --- | --- | --- |
| A) | 21.1 g | C) | 9.6 g |
| B) | 19.1 g | D) | 10.6 g |

12

In the petro-chemical industry it is often necessary to ''crack'' larger molecules into smaller molecules, as shown in the reaction below.

**C4H9OH(l) + 4 H2(g) → 4 CH4(g) + H2O(g)**

What is the Δ*H* of this reaction?

You may use any of the reactions in the table below in your work.

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Δ*H* of Reactions**  **in kilojoules per mole of product**  **T = 25°C P = 101.0 kPa** | | | | | | | |
|  | | |  | |  | | Δ*H* |
|  | C(s) | + | O2(g) | → | CO2(g) |  | -393 kJ |
|  | C(s) | + | 2 H2(g) | → | CH4(g) |  | -76 kJ |
|  | 4 C(s) + 5 H2(g) + | | 1/2 O2(g) | → | C4H9OH(l) |  | -326 kJ |
|  | H2(g) | + | 1/2 O 2(g) | → | H2O(g) |  | -242 kJ |
|  | H2(g) | + | 1/2 O 2(g) | → | H2O(l) |  | -285 kJ |

|  |  |  |  |
| --- | --- | --- | --- |
| A) | -263 kJ | C) | -318 kJ |
| B) | -872 kJ | D) | -220 kJ |

14

The molar heat of formation for water is -242 kJ/mol and is represented by the following equation:

H2(g) +  O2(g) → H2O(g)

The molar heat of formation for carbon dioxide is -394 kJ/mol and is represented by the following equation:

C(s) + O2(g) → CO2(g)

The combustion of 35 mg of propane, C3H8(g), releases 1623 J and is represented by the following equation:

C3H8(g) + 5 O2(g)  3 CO2(g) + 4 H2O(g)

Using this information, determine the molar heat of formation for propane, represented by the following equation:

4 H2(g) + 3 C(s) → C3H8(g)

17

A student conducts the following experiment to determine the heat of neutralization for a solution of KOH using a solution of HCl to neutralize the KOH.

The student pours 100 mL of a solution containing 0.1 moles of KOH into 100 mL of a solution containing 0.1 moles of HCl. Both solutions are initially at 23°C.

After mixing the two solutions, the student records a final temperature of 27°C.

Calculate the molar heat of neutralization for KOH using the results given above.

|  |  |  |
| --- | --- | --- |
| **Initial** |  | **Final** |
|  |  |  |

18

The following diagram shows the change in enthalpy of the substances involved in a chemical reaction.



Given this diagram, which of the following statements is true?

|  |  |
| --- | --- |
| A) | During this reaction, more energy is absorbed than released. |
| B) | This reaction takes place spontaneously. |
| C) | The Δ*H* for this reaction is negative. |
| D) | This reaction is exothermic. |

20

Consider this equation:

**AgNO3(s) → Ag+(aq) + NO3−(aq) Δ*H* = 23 kJ/mol**

Which of the following statements is true?

|  |  |
| --- | --- |
| A) | The enthalpy of the products is 23 kJ/mol less than the enthalpy of the reactants. |
| B) | The enthalpy of the products is 23 kJ/mol more than the enthalpy of the reactants. |
| C) | 23 kJ are necessary to break the bonds in one mole of AgNO3(s). |
| D) | 23 kJ are necessary to form the bonds in one mole of AgNO3(s). |

21

The chemical reaction below can be used to produce ethane. (C2H6(g)) :

**2 NH3(g) + 2 CO2(g) → C2H6(g) + 2 NO2(g)**

Using the following equations, calculate the molar heat of production of ethane by the reaction given above.

1/2 N2(g) + 3/2 H2(g) → NH3(g) Δ*H* = -46.0 kJ/mol

2 C(s) + 3 H2(g) → C2H6(g) + 84.5 kJ

1/2 N2(g) + O2(g) + 33.1 kJ → NO2(g)

C(s) + O2(g) → CO2(g)  Δ*H* = -393.5 kJ/mol

23

Examine the following heats of formation.

2 Al(s) + 3/2 O2(g) → Al2O3(s) Δ*H* = ‑ 1675 kJ/mol

2 Fe(s) + 3/2 O2(g) → Fe2O3(s) Δ*H* = ‑ 838 kJ/mol

Use these heats of formation to calculate the unknown Δ*H* for the reaction given below.

Fe2O3(s) + 2 Al(s) → Al2O3(s) + 2 Fe(s) Δ*H* = ?

|  |  |  |  |
| --- | --- | --- | --- |
| A) | ‑837 kJ/mol | C) | ‑2514 kJ/mol |
| B) | +837 kJ/mol | D) | +2514 kJ/mol |

30

The oxidation of nitrogen dioxide, NO2, is represented by the following chemical equation :

4 NO2(g) + O2(g) → 2 N2O5(g) Δ*H* = ?

You must find the heat of reaction, Δ*H*, for this oxidation process using the information provided in the following chemical equations.

 N2(g) + O2(g) → NO2(g) Δ*H* = +34 kJ

N2(g) + O2(g) → N2O5(g) Δ*H* = +15 kJ

What is the heat of reaction for the oxidation of NO2(g)?

|  |  |  |  |
| --- | --- | --- | --- |
| A) | -106 kJ | C) | +49 kJ |
| B) | -19 kJ | D) | +166 kJ |

31

A student used a calorimeter to determine the heat released during the combustion of one mole of paraffin, C25H52. She made the following observations :

|  |  |
| --- | --- |
| Volume of water in the calorimeter  Initial temperature of the water  Final temperature of the water  Mass of paraffin before combustion  Mass of paraffin after combustion | 2000 mL  20.0°C  38.3°C  47.62 g  44.10 g |

**Note** : All the heat released during the combustion of the paraffin was absorbed by the water in the calorimeter.

Given the above observations, how much heat was released during the combustion of one mole of paraffin?

32

The formation of propane gas, C3H8(g), from its elements is represented by the following chemical equation :

3 C(s) + 4 H2(g) → C3H8(g)

A scientist conducted an experiment at a certain temperature to determine the molar heat of formation of propane gas. The following diagram shows the test results, where the zero value has been arbitrarily assigned.



The scientist found the following information in a handbook.

H2O(g) → H2(g) + O2(g) Δ*H* = +242 kJ

C(s) + O2(g) → CO2(g) Δ*H* = -394 kJ

Given this data, what is the molar heat of formation of propane gas?

34

A student was asked to check the purity of the paraffin, C25H52, in a candle. Knowing that the molar heat of combustion of pure paraffin is 15 300 kJ/mol, she conducted an experiment to determine the molar heat of combustion of the paraffin in the candle. She used a calorimeter and made the following observations:

|  |  |
| --- | --- |
| Mass of the candle at the beginning of the experiment  Mass of the candle at the end of the experiment  Initial temperature of the water in the calorimeter  Final temperature of the water in the calorimeter  Volume of water in the calorimeter | 28.52 g  24.29 g  20.0°C  42.0°C  2000 mL |

Note : All the heat released during the combustion of the paraffin was absorbed by the water in the calorimeter.

Given the observations above, can the student conclude that the paraffin in the candle is relatively pure?

Note : (The paraffin in the candle is relatively pure if the difference between its molar heat of combustion and the molar heat of combustion of pure paraffin is between 0 and 350 kJ/mol).

35

While storing different products in a laboratory cabinet, a technician found a flask containing 500 mL of an old 1.0 mol/L solution of hydrochloric acid, HCl. The technician decided to neutralize this substance before disposing of it because he knew that it was harmful when discharged into the environment.

To do this, he poured 500 mL of a 1.0 mol/L basic solution into the flask containing the old solution. He then observed that the temperature of the resulting solution rose by 20.0C.

Note : Assume that the density and specific heat capacity of each aqueous solution are the same as those of water.

What is the molar heat of neutralization of the hydrochloric acid?

|  |  |  |  |
| --- | --- | --- | --- |
|  |  |  |  |