9.E: Energy and Chemistry (Exercises)

Exercises (Energy, and heat)

1. Define energy. How is work related to energy?

2. Give two units of energy and indicate which one is preferred.

3. Express the quantity of $422\ \text{J}$ in calories.

4. Express the quantity of $3.225\ \text{kJ}$ in calories.

5. Express the quantity 55.69cal in joules.

6. Express the quantity 965.33kcal in joules.

7. How does a Calorie differ from a calorie?

8. Express the quantity 965.33 Cal in joules.

9. What is the law of conservation of energy?

10. What does the word conserved mean as applied to the law of conservation of energy?

Answers

1. Energy is the ability to do work. Work is a form of energy.

3. 101cal

5. $233.0\ \text{J}$

7. A Calorie is actually a kilocalorie, or 1,000 calories.

9. The total energy of an isolated system does not increase or decrease.

Exercises (Work)

1. Give two definitions of work.

2. What is the sign on work when a sample of gas increases its volume? Explain why work has that sign.

3. What is the work when a gas expands from $3.00\ \text{L}$ to $12.60\ \text{L}$ against an external pressure of $0.888\ \text{atm}$?

4. What is the work when a gas expands from $0.666\ \text{L}$ to $2.334\ \text{L}$ against an external pressure of $2.07\ \text{atm}$?

5. What is the work when a gas contracts from $3.45\ \text{L}$ to $0.97\ \text{L}$ under an external pressure of 0.985 atm?

6. What is the work when a gas contracts from $4.66\ \text{L}$ to $1.22\ \text{L}$ under an external pressure of 3.97 atm?

7. Like work, the sign on heat can be positive or negative. What is happening to the total energy of a system if heat is positive?

8. Like work, the sign on heat can be positive or negative. What is happening to the total energy of a system if heat is negative?

9. What is the heat when $55.6\ \text{g}$ of Fe increase temperature from 25.6°C to 177.9°C ? The heat capacity of Fe is in Table 7.1 "Specific Heats of Various Substances".

10. What is the heat when $0.444\ \text{g}$ of Au increases temperature from 17.8°C to 222.5°C ? The heat capacity of Au is in Table 7.1 "Specific Heats of Various Substances".

11. What is the heat when $245\ \text{g}$ of H_2O cool from $355\ \text{K}$ to $298\ \text{K}$? The heat capacity of H_2O is in Table 7.1 "Specific Heats of Various Substances".

12. What is the heat when $100.0\ \text{g}$ of Mg cool from $725\ \text{K}$ to $552\ \text{K}$? The heat capacity of Mg is in Table 7.1 "Specific Heats of Various Substances".

13. It takes $452\ \text{J}$ of heat to raise the temperature of a $36.8\ \text{g}$ sample of a metal from 22.9°C to 98.2°C. What is the heat capacity of the metal?

14. It takes $2,267\ \text{J}$ of heat to raise the temperature of a $44.5\ \text{g}$ sample of a metal from 33.9°C to 288.3°C. What is the heat capacity of the metal?

15. An experimenter adds $336\ \text{J}$ of heat to a $56.2\ \text{g}$ sample of Hg. What is its change in temperature? The heat capacity of Hg is in Table 7.1 "Specific Heats of Various Substances".

16. To a $0.444\ \text{g}$ sample of H_2O, $23.4\ \text{J}$ of heat are added. What is its change in temperature? The heat capacity of H_2O is in Table 7.1 "Specific Heats of Various Substances".

17. An unknown mass of Al absorbs $187.9\ \text{J}$ of heat and increases its temperature from 23.5°C to 35.6°C. What is the mass of the aluminum? How many moles of aluminum is this?

18. A sample of He goes from 19.4°C to 55.9°C when $448\ \text{J}$ of energy are added. What is the mass of the helium? How many moles of helium is this?

Answers

1. Work is a force acting through a distance or a volume changing against some pressure.

3. $-864\ \text{J}$

5. $248\ \text{J}$

7. When heat is positive, the total energy of the system is increasing.

9. $3.80 \times 10^3\ \text{J}$

11. $-58,400\ \text{J}$

13. $0.163\ \text{J/g} \cdot {}^\circ\text{C}$

15. 43.0°C

17. $17.3\ \text{g}; 0.640\ \text{mol}$

Exercises (Enthalpy)

1. Under what circumstances are } q \text { and } \Delta H \text { the same? }

2. Under what circumstances are q and ΔH different?

3. Hydrogen gas and chlorine gas react to make hydrogen chloride gas with an accompanying enthalpy change of $-184\ \text{kJ}$. Write a properly balanced thermochemical equation for this process.

4. Propane (C_3H_8) reacts with elemental oxygen gas to produce carbon dioxide and liquid water with an accompanying enthalpy change of $-2,220\ \text{kJ}$. Write a properly balanced thermochemical equation for this process.

5. Nitrogen gas reacts with oxygen gas to make NO(g) while absorbing $180\ \text{kJ}$. Write a properly balanced thermochemical equation for this process.

6. Solid sodium reacts with chlorine gas to make solid sodium chloride while giving off $772\ \text{kJ}$. Write a properly balanced thermochemical equation for this process.

7. Hydrogen gas and chlorine gas react to make hydrogen chloride gas with an accompanying enthalpy change of $-184\ \text{kJ}$. Is this process endothermic or exothermic?

8. Propane (C_3H_8) reacts with elemental oxygen gas to produce carbon dioxide while giving off $2,220\ \text{kJ}$ of energy. Is this process endothermic or exothermic?

9. Nitrogen gas reacts with oxygen gas to make NO(g) while absorbing $180\ \text{kJ}$. Is this process exothermic or endothermic?

10. Sodium metal can react with nitrogen to make sodium azide (NaN_3) with a ΔH of $21.72\ \text{kJ}$. Is this process exothermic or endothermic?

11. Draw an energy level diagram for the chemical reaction in Exercise 8.

12. Draw an energy level diagram for the chemical reaction in Exercise 9. (See Figure 7.3 "Reaction Energy" for an example.)

13. In a $250\ \text{mL}$ solution, $0.25\ \text{mol}$ of KOH(aq) and $0.25\ \text{mol}$ of $\text{HNO}_3\text{(aq)}$ are combined. The temperature of the solution increases from 22.5°C to 35.9°C. Assume the solution has the same density and heat capacity of water. What is the heat of the reaction, and what is the ΔH of the reaction on a molar basis?

14. In a 600 mL solution, 0.50 mol of $Ca(OH)_2(aq)$ and 0.50 mol of $H_2SO_4(aq)$ are combined. The temperature of the solution increases by 22.3°C. What is the heat of the reaction, and what is the ΔH of the reaction on a molar basis? Assume the solution has the same density and heat capacity of water.

15. To warm 400.0 g of H_2O, 0.050 mol of ethanol (C_2H_5OH) is burned. The water warms from 24.6°C to 65.6°C. What is the heat of the reaction, and what is the ΔH of the reaction on a molar basis?

16.To warm 100.0 g of H_2O, 0.066 mol beeswax is burned. The water warms from 21.4°C to 25.5°C.

What is the heat of the reaction, and what is the ΔH of the reaction on a molar basis?

Answers

1. under conditions of constant pressure

3. $H_2(g) + Cl_2(g) \rightarrow 2HCl(g) \Delta H = -184$ kJ

5. $N_2(g) + O_2(g) \rightarrow 2NO(g) \Delta H = 180$ kJ

7. exothermic

9. endothermic

13. heat of reaction $= -14.0$ kJ; $\Delta H = -56.0$ kJ/mol of reactants

15. heat of reaction $= -68.6$ kJ; $\Delta H = -1,370$ kJ/mole of ethanol

Exercises (Hess's Law)

1. Define Hess's law.

2. What does Hess's law require us to do to the ΔH of a thermochemical equation if we reverse the equation?

3. If the ΔH for
$$C_2H_4 + H_2 \rightarrow C_2H_6$$
is -65.6 kJ, what is the ΔH for this reaction?
$$C_2H_6 \rightarrow C_2H_4 + H_2$$

4. If the ΔH for
$$2Na + Cl_2 \rightarrow 2NaCl$$
is -772 kJ, what is the ΔH for this reaction:
$$2NaCl \rightarrow 2Na + Cl_2$$

5. If the ΔH for
$$C_2H_4 + H_2 \rightarrow C_2H_6$$
is -65.6 kJ, what is the ΔH for this reaction?
$$2C_2H_4 + 2H_2 \rightarrow 2C_2H_6$$

6. If the ΔH for
$$2C_2H_6 + 7O_2 \rightarrow 4CO_2 + 6H_2O$$
is $-2,650$ kJ, what is the ΔH for this reaction?
$$6C_2H_6 + 21O_2 \rightarrow 12CO_2 + 18H_2O$$

7. The ΔH for
$$C_2H_4 + H_2O \rightarrow C_2H_5OH$$
is -44 kJ. What is the ΔH for this reaction?
$$2C_2H_5OH \rightarrow 2C_2H_4 + 2H_2O$$

8. The ΔH for
$$N_2 + O_2 \rightarrow 2NO$$
is 181 kJ. What is the ΔH for this reaction?
$$NO \rightarrow 1/2\ N_2 + 1/2 O_2$$

9. Determine the ΔH for the reaction
$$Cu + Cl_2 \rightarrow CuCl_2$$

given these data:

$2\mathrm{Cu} + \mathrm{Cl_2} \rightarrow 2\mathrm{CuCl} \Delta H = -274 \text{ kJ}$

$2\mathrm{CuCl} + \mathrm{Cl_2} \rightarrow 2\mathrm{CuCl_2} \Delta H = -166 \text{ kJ}$

10. Determine ΔH for the reaction

$2\mathrm{CH_4} \rightarrow 2\mathrm{H_2} + \mathrm{C_2H_4}$

given these data:

$\mathrm{CH_4} + 2\mathrm{O_2} \rightarrow \mathrm{CO_2} + 2\mathrm{H_2O} \Delta H = -891 \text{ kJ}$

$\mathrm{C_2H_4} + 3\mathrm{O_2} \rightarrow 2\mathrm{CO_2} + 2\mathrm{H_2O} \Delta H = -1,411 \text{ kJ}$

$2\mathrm{H_2} + \mathrm{O_2} \rightarrow 2\mathrm{H_2O} \Delta H = -571 \text{ kJ}$

11. Determine ΔH for the reaction

$\mathrm{Fe_2(SO_4)_3} \rightarrow \mathrm{Fe_2O_3} + 3\mathrm{SO_3}$

given these data:

$4\mathrm{Fe} + 3\mathrm{O_2} \rightarrow 2\mathrm{Fe_2O_3} \Delta H = -1,650 \text{ kJ}$

$2\ \mathrm{S} + 3\mathrm{O_2} \rightarrow 2\mathrm{SO_3} \Delta H = -792 \text{ kJ}$

$2\mathrm{Fe} + 3\ \mathrm{S} + 6\mathrm{O_2} \rightarrow \mathrm{Fe_2(SO_4)_3} \Delta H = -2,583 \text{ kJ}$

12. Determine ΔH for the reaction

$\mathrm{CaCO_3} \rightarrow \mathrm{CaO} + \mathrm{CO_2}$

given these data:

$2\mathrm{Ca} + 2\mathrm{C} + 3\mathrm{O_2} \rightarrow 2\mathrm{CaCO_3} \Delta H = -2,414 \text{kJ}$

$\mathrm{CO_2} \rightarrow \mathrm{CO_2} \Delta H = -393.5 \text{ kJ2}$

$\mathrm{Ca} + \mathrm{O_2} \rightarrow 2\mathrm{CaO} \Delta H = -1,270 \text{ kJ}$

Answers

1. If chemical equations are combined, their energy changes are also combined.

3. $\Delta H = 65.6 \text{ kJ}$

5. $\Delta H = -131.2 \text{ kJ}$

7. $\Delta H = 88 \text{ kJ}$

9. $\Delta H = -220 \text{ kJ}$

11. $\Delta H = 570 \text{ kJ}$

Exercises (Formation Reactions)

1. Define formation reaction and give an example.

2. Explain the importance of formation reactions in thermochemical equations.

3. Which of the following reactions is a formation reaction? If it is not a formation reaction, explain why.
   a. $\mathrm{H_2(\ g) + S(s) \rightarrow H_2\ S(\ g)}$
   b. $\mathrm{2HBr(g) + Cl_2(\ g) \rightarrow 2HCl(g) + Br_2(\ell)}$

4. Which of the following reactions is a formation reaction? If it is not a formation reaction, explain why.
   a. $\mathrm{Fe(g) + 1/2O_2(\ g) \rightarrow FeO(s)}$
   b. $\mathrm{Hg(\ell) + 1/2O_2(\ g) \rightarrow HgO(s)}$

5. Which of the following reactions is a formation reaction? If it is not a formation reaction, explain why
   a. $\mathrm{H_2(\ g) + S(s) + 2O_2(\ g) \rightarrow H_2SO_4(\ell)}$
   b. $\mathrm{C_3H_8(\ g) + 5O_2(\ g) \rightarrow 3CO_2(\ g) + 4H_2O(\ell)}$

6. Which of the following reactions is a formation reaction? If it is not a formation reaction, explain why.
   a. $\mathrm{Zn(s) + 2HCl(aq) \rightarrow ZnCl_2(aq) + H_2(\ g)}$
   b. $\mathrm{2Na(s) + C(s) + 3/2O_2(\ g) \rightarrow Na_2CO_3(\ s)}$

7. Write a proper formation reaction for each substance.
   a. $H_3PO_4(s)$
   b. $Na_2O(s)$
   c. $C_3H_7OH(\ell)$

8. Write a proper formation reaction for each substance.
   a. $N_2O_5(g)$
   b. $BaSO_4(s)$
   c. $Fe(OH)_3(s)$

9.Write a proper formation reaction for each substance.
   a. $C_{12}H_{22}O_{11}(s)$
   b. $Zn(NO_3)_2(s)$
   c. $Al(OH)_3(s)$

10. Write a proper formation reaction for each substance.
   a. \mathrm{O}_3(\mathrm{~g})
   b. $Na_2O_2(s)$
   c. $PCl_5(g)$

11. Write this reaction in terms of formation reactions.

$$MgCO_3(s) \rightarrow MgO(s) + CO_2(g)$$

12. Write this reaction in terms of formation reactions.

$$2NO + 4NO_2 \rightarrow 2\ N_2O_5 + N_2$$

13. Write this reaction in terms of formation reactions.

$$2CuCl(s) \rightarrow Cu(s) + CuCl_2(s)$$

14. Write this reaction in terms of formation reactions.

$$SiH_4 + 4\ F_2 \rightarrow SiF_4 + 4HF$$

15. Determine the enthalpy change of this reaction. Data can be found in Table 7.2 "Enthalpies of Formation for Various Substances".

$$CH_2O(g) + O_2 \rightarrow CO_2(g) + H_2O(\ell)$$

16. Determine the enthalpy change of this reaction. Data can be found in Table 7.2 "Enthalpies of Formation for Various Substances".

$$2AgBr(s) + Cl_2(g) \rightarrow 2AgCl(s) + Br_2(\ell)$$

17. Determine the enthalpy change of this reaction. Data can be found in Table 7.2 "Enthalpies of Formation for Various Substances".

$$Mg(s) + N_2O_5(g) \rightarrow MgO(s) + 2NO_2(g)$$

18. Determine the enthalpy change of this reaction. Data can be found in Table 7.2 "Enthalpies of Formation for Various Substances".

$$2C_6H_6(l) + 15O_2(g) \rightarrow 12CO_2(g) + 6H_2O(\ell)$$

Answers

1. A formation reaction is a reaction that produces one mole of a substance from its elements.
Example: $C(s) + O_2(g) \rightarrow CO_2(g)$

3. a. formation reaction
b. It is not the formation of a single substance, so it is not a formation reaction.

5. a. formation reaction
b. It is not the formation of a single substance, so it is not a formation reaction.

7. a. $3/2H_2(g) + P(s) + 2O_2(g) \rightarrow H_3PO_4(s)$
b. $2Na(s) + 1/2O_2(g) \rightarrow Na_2O(s)$
c. $3C(s) + 1/2O_2(g) + 4H_2(g) \rightarrow C_3H_7OH(\ell)$

9. a. $12C(s) + 11H_2(g) + 11/2O_2(g) \rightarrow C_{12}H_{22}O_{11}(s)$
b. $Zn(s) + N_2(g) + 3O_2(g) \rightarrow Zn(NO_3)_2$
c. $Al(s) + 3/2O_2(g) + 3/2H_2(g) \rightarrow Al(OH)_3(s)$

11. a. $MgCO_3(s) \rightarrow Mg(s) + C(s) + 3/2O_2(g)$
b. $Mg(s) + 1/2O_2(g) \rightarrow MgO(s)$
c. $C(s) + O_2(g) \rightarrow CO_2(g)$

13. a. $2 \times [CuCl(s) \rightarrow Cu(s) + 1/2Cl_2(g)]$
b. $Cu(s) \rightarrow Cu(s)$
c. $Cu(s) + Cl_2(g) \rightarrow CuCl_2(s)$

15. $\Delta H = -563.44$ kJ

17. $\Delta H = -546.7$ kJ

Additional Exercises

1. What is the work when 124 mL of gas contract to 72.0 mL under an external pressure of 822 torr?
2. What is the work when 2,345 mL of gas contract to 887 mL under an external pressure of 348 torr?
3. A 3.77 L volume of gas is exposed to an external pressure of 1.67 atm. As the gas contracts, 156 J of work are added to the gas. What is the final volume of the gas?
4. A 457 mL volume of gas contracts when 773 torr of external pressure act on it. If 27.4 J of work are added to the gas, what is its final volume?
5. What is the heat when 1,744 g of Hg increase in temperature by 334°C? Express your final answer in kJ.
6. What is the heat when 13.66 kg of Fe cool by 622°C? Express your final answer in kJ.
7. What is final temperature when a 45.6 g sample of Al at 87.3°C gains 188 J of heat?
8. What is final temperature when 967 g of Au at 557°C lose 559 J of heat?
9. Plants take CO_2 and H_2O and make glucose ($C_6H_{12}O_6$) and O_2. Write a balanced thermochemical equation for this process. Use data in Table $9.E.1$ of Section 7.7
10. Exercise 9 described the formation of glucose in plants, which take in CO_2 and H_2O and give off O_2. Is this process exothermic or endothermic? If exothermic, where does the energy go? If endothermic, where does the energy come from?
11. The basic reaction in the refining of aluminum is to take $Al_2O_3(s)$ and turn it into Al(s) and $O_2(g)$. Write the balanced thermochemical equation for this process. Use data in Table $9.E.1$ of Section 7.7
12. Is the enthalpy change of the reaction

    $H_2O(\ell) \rightarrow H_2O(g)$

    zero or nonzero? Use data in Table $9.E.1$ of Section 7.7
13. What mass of H_2O can be heated from 22°C to 80°C in the combustion of 1 mol of CH_4? You will need the balanced thermochemical equation for the combustion of CH_4. Use data in Table $9.E.1$ of Section 7.7
14. What mass of H_2O can be heated from 22°C to 80°C in the combustion of 1 mol of C_2H_6? You will need the balanced thermochemical equation for the combustion of C_2H_6. Use data in Table $9.E.1$ of Section 7.7
15. What is the enthalpy change for the unknown reaction?

    $Pb(s) + Cl_2(g) \rightarrow PbCl_2(s)\ \Delta H = -359$ kJ$PbCl_2(s) + Cl_2(g) \rightarrow PbCl_4(\ell)\ \Delta H = ?Pb(s) + 2Cl_2(g) \rightarrow PbCl_4(\ell)\ \Delta H = -329$ kJ
16. What is the enthalpy change for the unknown reaction?

    $P(s) + 3/2Br_2(\ell) \rightarrow PBr_3(\ell)\ \Delta H = -185$ kJ$PI_3(s) \rightarrow P(s) + 3/2I_2(s)\ \Delta H = ?PI_3(s) + 3/2Br_2(\ell) \rightarrow PBr_3(\ell) + 3/2I_2(s)\ \Delta H = -139$ kJ
17. What is the ΔH for this reaction? The label *gra* means graphite, and the label *dia* means diamond. What does your answer mean?

C(s, gra) → C(s, dia)

18. Without consulting any tables, determine the ΔH for this reaction. Explain your answer.

$H_2O(\ell, 25°C) \rightarrow H_2O(\ell, 25°C)$

Answers

1. 4.69 L
3. 80.97 kJ
5. 91.9°C
7. $6CO_2(g) + 6H_2O(\ell) \rightarrow C_6H_{12}O_6(s) + 6O_2(g)$ ΔH = 2,799 kJ
9. $2Al_2O_3(s) \rightarrow 4Al(s) + 3O_2(g)$ ΔH = 3351.4 kJ
11. 3,668 g
13. ΔH = 30 kJ
15. 5.70 J
17. ΔH = 1.897 kJ; the reaction is endothermic.
