CHAPTER 3 CHEMICAL REACTIONS

Reflect on your Learning

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1. Clues that indicate that a chemical reaction has taken place include: a change in colour, a change in odour, formation of a gas/solid, release/absorption of heat.
2. Combustion, synthesis, decomposition, single displacement and double displacement reactions.
3. Whether or not one element displaces another in a compound depends on the relative reactivities of the two elements. The collision–reaction theory suggests that particles must collide with the correct orientation and at sufficient speed to react.

Try This Activity: Observing Chemical Change

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(a) A change in colour is evidence that a chemical change has taken place.
(b) Iron(II) sulfate and elemental copper

3.1 RECOGNIZING AND UNDERSTANDING CHEMICAL CHANGES

Try This Activity: The KMT in Action

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(a) The food colouring starts as a small drop, but soon begins to spread throughout the beaker of tap water.
(b) According to kinetic molecular theory, the motion of all particles results in random collisions. The food colouring particles collide with each other and with molecules of water, bounce off in different directions, and thus spread throughout the beaker of tap water.

Try This Activity: A Model for the Collision–Reaction Theory

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(a) When the box is gently shaken, the particles exhibit the continuous random motion of all particles of matter.
(b) The student is to count the number of free and combined particles, and to indicate the proportion of particles that have formed a “compound.”
(c) The vigorous shaking of the box represents the effect of higher temperature — greater speeds of the motion of particles.
(d) The student is to again count the number of free and combined particles, and to indicate the proportion of particles that have formed a compound. It is expected that a greater number of compounds will have formed.
(e) All of the particles may, or may not, have reacted.
(f) The collision–reaction theory suggests that particles must collide with the correct orientation and at sufficient speed to react. It is possible that there may not have been the correct orientation, and/or sufficient speed, for all particles to react.
(g) A lower number of particles within the same space should result in fewer collisions and a lower proportion of particles forming a compound.

PRACTICE

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Understanding Concepts

1. The formation of gas is evidence that a chemical reaction has occurred.
2. When gasoline evaporates (a physical change) it absorbs heat from its surroundings. A visual observation of this absorption of heat might lead to a conclusion that a chemical change has taken place. Thus it is important not to rely solely on visual observation when drawing conclusions about chemical change.
3. According to kinetic molecular theory, the motion of all particles results in random collisions. At lower temperatures, the colliding molecules of liquid gasoline and oxygen simply bounce off one another unchanged. However, at higher
temperatures, the molecules of gaseous gasoline and oxygen collide at greater speeds and with greater energy. In some collisions, the valence shells of the reactants overlap, and their electrons can be rearranged to form new bonds.

4. According to the collision–reaction theory, the occurrence of a chemical reaction is dependent on the energy and orientation of the collisions.

ACTIVITY 3.1.1 UNDERSTANDING CHEMICAL REACTIONS

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Analysis
(a) \( \text{CH}_4(\text{g}) + 2 \text{O}_2(\text{g}) \rightarrow \text{CO}_2(\text{g}) + 2 \text{H}_2\text{O}(\text{g}) \)
\( 2 \text{H}_2\text{O}(\text{l}) \rightarrow 2 \text{H}_2(\text{g}) + \text{O}_2(\text{g}) \)
\( \text{C}(\text{s}) + \text{O}_2(\text{g}) \rightarrow \text{CO}_2(\text{g}) \)

Synthesis
(b) The law of conservation of mass.

EXPLORE AN ISSUE TAKE A STAND: CATALYTIC CONVERTERS

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The student is to use the Internet to carry out research on catalytic converters, to assemble arguments for and against making catalytic converters compulsory in all vehicles, and to put together a presentation — pamphlet or video — aimed at people who are about to purchase a used vehicle.

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PRACTICE

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Understanding Concepts
5. (a) Change in colour, change in odour, formation of gas/solid, release/absorption of heat.
(b) Change in colour: iron nails that rust turn brownish in colour.
Change in odour: food that decomposes gives off an odour.
Formation of gas/solid: seltzer tablets added to water give off a gas.
6. (a) Reactant: the substances that combine in a chemical reaction.
(b) Product: the substances that are formed in a chemical reaction.
(c) Coefficient: a whole number indicating the ratio of formula units of each substance involved in a chemical reaction.
(d) Balanced: the reactants and products contain equal numbers of atoms of each type.
7. (a) \( 2 \text{H}_2(\text{g}) + \text{O}_2(\text{g}) \rightarrow 2 \text{H}_2\text{O}(\text{g}) \)
(c) \( \text{Pb}(\text{s}) + 2 \text{AgNO}_3(\text{aq}) \rightarrow 2 \text{Ag}(\text{s}) + \text{Pb(NO}_3)_2(\text{aq}) \)
(b) and (d) are balanced.

SECTION 3.1 QUESTIONS

(Page 113)

Understanding Concepts
1. (a) sodium chloride and water \( \rightarrow \) chlorine and hydrogen and sodium hydroxide
(b) \( 2 \text{NaCl}_\text{(aq)} + 2 \text{H}_2\text{O}(\text{l}) \rightarrow \text{Cl}_2(\text{s}) + \text{H}_2(\text{s}) + 2 \text{NaOH}_\text{(aq)} \)
(c) The reaction takes place in a sealed container because chlorine is a poisonous gas at SATP.
(d) The formation of gases — \( \text{Cl}_2(\text{s}) + \text{H}_2(\text{s}) \)
(e) \( \text{NaCl}_\text{(aq)} \) and \( \text{NaOH}_\text{(aq)} \) are ionic compounds, \( \text{H}_2\text{O}(\text{l}) \) is a molecular compound, \( \text{Cl}_2(\text{s}) + \text{H}_2(\text{s}) \) are molecular elements.
(f) \( \text{H}_2\text{O}(\text{l}) \) can be classified as a polar molecule.
(g) Chlorine compounds have different chemical properties than does chlorine gas.
3.2 COMBUSTION, SYNTHESIS, AND DECOMPOSITION REACTIONS

PRACTICE
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Understanding Concepts
1. Reactants: a substance for fuel, and oxygen; conditions: three things must be present - fuel, oxygen, and heat; products: common oxides of the elements making up the substance that is burned.
2. CO\(_2\)(g); H\(_2\)O(g); SO\(_2\)(g); NO\(_2\)(g); Fe\(_2\)O\(_3\)(s)
3. Carbon dioxide and water are products of the combustion of carbon compounds that have had a significant effect on the atmosphere, including making it warmer than it would otherwise be. This phenomenon is known as the "greenhouse effect."
   Gaseous oxides of nitrogen and sulfur are released from sources such as automobiles and coal-burning power plants. These oxides join the naturally produced oxides in the atmosphere, react with water vapour to form acids, and are responsible for the increased acidity of precipitation known as "acid rain."

PRACTICE
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Understanding Concepts
4. (a) Decomposition — the product is a simpler elemental compound and an element.
   (b) Synthesis — the product is a more complex compound.
   (c) Synthesis — the product is a more complex compound.
5. (a) 2 Al\(_(s)\) + 3 F\(_2\)(g) \(\rightarrow\) 2 AlF\(_3\)(s) synthesis
   (b) 2 KCl\(_(s)\) \(\rightarrow\) 2 K\(_(s)\) + Cl\(_2\)(g) decomposition
   (c) S\(_8\)(s) + 8 O\(_2\)(g) \(\rightarrow\) 8 SO\(_2\)(g) synthesis (combustion)
   (d) CH\(_4\)(g) + 2 O\(_2\)(g) \(\rightarrow\) CO\(_2\)(g) + 2 H\(_2\)O(g) combustion
   (e) 2 Al\(_2\)O\(_3\)(s) \(\rightarrow\) 4 Al\(_(s)\) + 3 O\(_2\)(g) decomposition
   (f) 2 H\(_2\)(l) + O\(_2\)(g) \(\rightarrow\) 2 H\(_2\)O\(_(s)\) synthesis (combustion)
   (g) 2 FeBr\(_3\)(s) \(\rightarrow\) 2 Fe\(_(s)\) + 3 Br\(_2\)(g) decomposition
6. | Reaction Type | Reactants |
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<tr>
<td>Synthesis</td>
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<td>Decomposition</td>
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<td>Combustion</td>
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7. (a) 2 Na\(_(s)\) + Cl\(_2\)(g) \(\rightarrow\) 2 NaCl\(_(s)\) synthesis
   (b) 2 CuO\(_(s)\) \(\rightarrow\) 2 Cu\(_(s)\) + O\(_2\)(g) decomposition
   (c) Cu\(_(s)\) + Cl\(_2\)(aq) \(\rightarrow\) CuCl\(_2\)(s) synthesis
8. (a) 2 Li\(_2\)O\(_(s)\) \(\rightarrow\) 4 Li\(_(s)\) + O\(_2\)(g)
     2 Mg\(_2\)O\(_(s)\) \(\rightarrow\) 2 Mg\(_(s)\) + O\(_2\)(g)
     ZnCl\(_2\)(s) \(\rightarrow\) Zn\(_(s)\) + Cl\(_2\)(g)
     Mg\(_2\)(OH)\(_2\)(s) \(\rightarrow\) MgO\(_(s)\) + H\(_2\)O\(_(l)\)
9. Evaluation
   (a) The experimental design is not sufficient to identify all of the elements of the white powder. However, there is sufficient evidence to indicate that the white powder could be a metal carbonate of some sort. Carbonates will decompose when heated to produce a metal oxide and carbon dioxide gas.
   
   To identify the elements of the metal oxide, the melting point of the white powder could be determined and matched against known melting points of ionic solids.
   
   To identify the gas, the gas could be bubbled into a limewater solution. Carbon dioxide gas is indicated if limewater solution turns milky. The limewater undergoes a chemical change to form an insoluble white precipitate. Carbon dioxide gas is also indicated if a flaming splint, held at the mouth of the test tube, is extinguished.

Synthesis
(b) A thermal decomposition reaction of the general form \( AB \rightarrow A + B \)
(c) Calcium carbonate \( \rightarrow \) calcium oxide + carbon dioxide
\[
\text{CaCO}_3(s) \rightarrow \text{CaO}(s) + \text{CO}_2(g)
\]

10. The student is to use the Internet to investigate a vehicle exhaust pollutant, and to describe the chemical reactions that produce it and its harmful effects on living organisms. Also, the student is to develop a list of suggestions for reducing the production of this pollutant, and to discuss the pros and cons of implementing these suggestions from the perspective of a car manufacturer and from the perspective of an environmentalist.

11. The student is to use the Internet to investigate the properties of diesel fuel and gasoline, and the products of their combustion. Also, the student is to determine which fuel poses the greater threat to the environment.

12. The student is to use the Internet to research the chemical compositions of natural gas and propane, for use as alternative fuels for vehicles. Also, the student is to compare the products of combustion with those of gasoline.

SECTION 3.2 QUESTIONS
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Understanding Concepts
1. (a) The warning signs at gas stations are there to insure that people refrain from any activity that could result in the occurrence of a gasoline-related chemical reaction, such as a fire or an explosion.
   (b) A combustion reaction is the concern.
   (c) The necessary conditions for this reaction to proceed are fuel, oxygen, and heat.

2. (a) Butane — combustion reaction. Butane is a fuel.
   Butane + oxygen \( \rightarrow \) carbon dioxide + water
\[
2 \text{C}_4\text{H}_{10}(g) + 13 \text{O}_2(g) \rightarrow 8 \text{CO}_2(g) + 10 \text{H}_2\text{O}(g)
\]
   Calcium carbonate — thermal decomposition reaction. Carbonates will decompose when heated to produce a metal oxide and carbon dioxide gas.
   Calcium carbonate \( \rightarrow \) calcium oxide + carbon dioxide
\[
\text{CaCO}_3(s) \rightarrow \text{CaO}(s) + \text{CO}_2(g)
\]
   Li and Br — synthesis reaction. Two substances combine to form a single product.
   Lithium + bromine \( \rightarrow \) lithium bromide
\[
\text{Li}(s) + \text{Br}_2(l) \rightarrow \text{LiBr}(s)
\]
   Bluestone — decomposition reaction. Compounds consisting of more than two elements often decompose to form simpler compounds. When a hydrated salt is heated, the products are the anhydrous salt and water.
   Copper(II) sulfate pentahydrate \( \rightarrow \) copper(II) sulfate + water
\[
\text{CuSO}_4 \cdot 5 \text{H}_2\text{O}(s) \rightarrow \text{CuSO}_4(s) + 5 \text{H}_2\text{O}(g)
\]

Making Connections
3. (a) \( 2 \text{C}_8\text{H}_{18}(g) + 25 \text{O}_2(g) \rightarrow 16 \text{CO}_2(g) + 18 \text{H}_2\text{O}(g) \) — a combustion reaction.
   Gasoline often contains trace amounts of elemental sulfur, and when the gas is burned, the sulfur combines with oxygen to produce sulfur dioxide.
\[ S(s) + O_2(g) \rightarrow SO_2(g) \] 

 synthesis (combustion)

\[ 2 \text{SO}_2(g) + O_2(g) \rightarrow 2 \text{SO}_3(g) \] 

 synthesis (combustion)

\[ \text{SO}_3(g) + \text{H}_2\text{O}(l) \rightarrow \text{H}_2\text{SO}_4(aq) \] 

 synthesis

(b) Sulfur trioxide is a byproduct of the combustion of gasoline in car engines. In the atmosphere it reacts with condensed water on dust particles, producing sulfuric acid. Atmospheric sulfuric acid is one of the acids that is responsible for the increased acidity of precipitation known as acid rain.

4. (a) Nitrogen monoxide decomposes into nitrogen and oxygen.

\[ \text{Pt/Pd} \]

\[ 2 \text{NO}_2(g) \rightarrow \text{N}_2(g) + \text{O}_2(g) \]

(b) The platinum/palladium catalytic converter built into today’s automobiles catalyzes the decomposition of nitrogen monoxide — which is a combustion engine exhaust pollutant — into harmless nitrogen and oxygen.

3.3 SINGLE DISPLACEMENT REACTIONS

PRACTICE

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Understanding Concepts

1. In single displacement reactions, like displaces like – a metallic element takes the place of a metal in a compound; a nonmetallic element takes the place of a nonmetal in a compound.

2. An “activity series” is a list of elements arranged in order of their reactivity, based upon empirical evidence gathered from single displacement reactions.

3. (a) \[ \text{Zn}(s) + \text{CuCl}_2(aq) \rightarrow \text{Cu}(s) + \text{ZnCl}_2(aq) \]

(b) \[ \text{B}_2\text{O}_3(aq) + \text{CaCl}_2(aq) \rightarrow \text{NR} \]

(c) \[ \text{Pb}(s) + 2 \text{HCl}(aq) \rightarrow \text{H}_2(g) + \text{PbCl}_2(aq) \]

(d) \[ \text{Cl}_2(aq) + 2 \text{NaI}(aq) \rightarrow 2 \text{NaCl}(aq) + \text{I}_2(s) \]

(e) \[ \text{Ca}(s) + 2 \text{H}_2\text{O}(l) \rightarrow \text{H}_2(g) + \text{Ca(OH)}_2(aq) \]

(f) \[ \text{Au}(s) + \text{ZnSO}_4(aq) \rightarrow \text{NR} \]

(g) \[ \text{Sn}(s) + 2 \text{AgNO}_3(aq) \rightarrow 2 \text{Ag}(s) + \text{Sn(NO)}_3_2(aq) \]

(h) \[ 2 \text{Al}(s) + 3 \text{H}_2\text{O}(l) \rightarrow 3 \text{H}_2(g) + \text{Al}_2\text{O}_3(aq) \]

(i) \[ \text{Br}_2(aq) + \text{MgI}_2(aq) \rightarrow \text{MgBr}_2(aq) + \text{I}_2(s) \]

(j) \[ 2 \text{Al}(s) + 3 \text{ZnSO}_4(aq) \rightarrow 3 \text{Zn}(s) + \text{Al}_2\text{SO}_4_3(aq) \]

4. Generally speaking, the more reactive elements will replace the less reactive elements. Thus, within the metal group, the more reactive metal elements are the ones with low electronegativity values and they will replace metal elements with higher electronegativity values. For example, lithium has an electronegativity value of 1.0 and will replace potassium, which has an electronegativity value of 0.8. (It should be noted that there are a number of exceptions to this generalization.)

Within the nonmetal group, the more reactive nonmetal elements are the ones with high electronegativity values and they will replace nonmetal elements with lower electronegativity values. For example, fluorine has an electronegativity value of 4.0 and will replace chlorine, which has an electronegativity value of 3.0. (Again, it should be noted that there are a number of exceptions to this generalization.)

5. As you move from left to right within the same period, the elements of the periodic table show a general increase in electronegativity values. The most reactive metals are the ones with lower electronegativity values and are positioned at the left of a period. Thus, as you move from left to right within the same period, the metals become more electronegative and therefore less reactive. However, the most reactive nonmetals are the ones with high electronegativity values and are positioned at the right of a period. Thus, as you move from left to right within the same period, the nonmetals become more electronegative and therefore more reactive.
6. (a) The Goldschmidt process is a single displacement reaction.
   (b) \( \text{CrO}(s) \text{ or Cr}_2\text{O}_3(s), \text{MnO}(s), \text{BaO}(s) \)
   (c) \( 2 \text{Al}(s) + \text{Cr}_2\text{O}_3(s) \rightarrow 2 \text{Cr}(s) + \text{Al}_2\text{O}_3(s) \)
   \( 2 \text{Al}(s) + 3 \text{MnO}(s) \rightarrow 3 \text{Mn}(s) + \text{Al}_2\text{O}_3(s) \)
   \( 2 \text{Al}(s) + 3 \text{BaO}(s) \rightarrow \text{NR} \)
   (According to the activity series, aluminum is less reactive than barium and should not displace it from barium oxide. There should be no reaction.)
   (d) The more reactive aluminum displaces the chromium and manganese from their oxides, producing the pure metals of chromium and manganese, along with aluminum oxide.

7. (a) \( \text{titanium dioxide} + \text{carbon} + \text{chlorine} \rightarrow \text{titanium tetrachloride} + \text{carbon dioxide} \)
   \( \text{magnesium} + \text{titanium tetrachloride} \rightarrow \text{titanium} + \text{magnesium chloride} \)
   (b) \( 2 \text{Mg}(s) + \text{TiCl}_4(s) \rightarrow \text{Ti}(s) + 2 \text{MgCl}_2(s) \) single displacement reaction
   (c) For the metals, the lower the electronegativity, the more reactive the metal should be. Magnesium has a lower electronegativity value than titanium and is more reactive than titanium. Therefore magnesium displaces titanium, producing pure titanium along with magnesium chloride.

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Understanding Concepts
8. As a result of their greater reactivity, calcium and sodium are most commonly found in compounds, ores, rather than as elements. In order to extract these two elements from their ores, they must be reacted with metals that are higher in the activity series. However, according to the activity series, calcium and sodium are high in the activity series and are two of the most reactive elements, so they would tend not to be displaced by other metals in an aqueous environment.

Making Connections
9. (a) The student is to use the Internet to carry out research on a metallic element that is mined in Canada, with respect to how and where it is mined, extracted, and purified, and the uses of the metal.
   (b) The findings are to be compiled in a table that lists the positive and negative aspects. The table is to be used to help the student decide on changes that could be made in the way we use the metal or the way we obtain it. The student is to report on the findings.
   \[ \text{GO TO www.science.nelson.com, Chemistry 11, Teacher Centre} \]

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Understanding Concepts
10. Yellow brass is an alloy that comprises 70% copper by mass, and 30% zinc by mass. It is harder and more resistant to corrosion than copper alone.
    Stainless steel is an alloy that comprises a number of metals, but mainly comprises 79.06 – 81.06% iron by mass, and 16–18% chromium by mass. It is more resistant to corrosion than iron alone.

Making Connections
11. (a) The higher acidic nature of women’s skin causes some of the copper in the gold ring to dissolve, leaving deposits of dissolved copper. Women wear 18K gold rings because there is less copper content by mass in the 18K gold, thus reducing the amount of copper available to dissolve.
    (b) The 14K gold alloy is a solid solution that consists of gold, silver, copper, and zinc. The greenish stain that develops beneath a 14K gold bracelet is the result of acidic skin that has caused some of the copper in the gold bracelet to dissolve back into the liquid phase. The green copper stain becomes visible when the wearer’s body dissolves the copper faster than it absorbs it. This happens when there is profuse perspiration, or when our sweat becomes more acidic.
12. The student is to use the Internet to research the composition of various steels and to choose one alloy and list its properties and its applications. The student is then to write a short “infomercial” advertising the benefits of this material to potential users and to include any precautions necessary for its safe use.

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13. The student is to use the Internet to research the applications of aluminum and its alloys and the environmental issues surrounding aluminum production. The student is to use the findings to comment on the following statement: Risks to the environment posed by mining and refining aluminum are outweighed by the technological benefits of aluminum alloys.

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Making Connections
14. The student is to research one of the careers listed on page 135 or a related career, and write a report that:
(a) provides a general description of the nature of the work and how chemical reactions are involved;
(b) describes the educational background and the length of study required to obtain employment in this field;
(c) gives examples of programs offered by educational institutions leading to this career;
(d) forecasts employment trends for this field; and
(e) describes working conditions and salary.

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3.4 DOUBLE DISPLACEMENT REACTIONS

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Understanding Concepts
1. The following monatomic ions form compounds that have high solubility in water:
   Group 1 monatomic ions that form compounds with Cl^−, Br^−, and I^−.
   Group 1 and Group 2 monatomic ions that form compounds with S^{2−}.
2. NH_4^+ is the positive polyatomic ion that forms compounds that all have high solubility in water.
3. (a) KCl(aq) (b) Ca(NO_3)_2(aq) (c) Na_2SO_4(aq) (d) AgC_2H_3O_2(s) (e) NH_4Br(aq) (f) BaS(aq) (g) PbI_2(s) (h) Ca(OH)_2(s) (i) Fe(OH)_3(s) (j) PbSO_4(s) (k) Ca_3(PO_4)_2(s) (l) KNO_3(aq) (m) NH_4NO_3(aq) (n) CoCl_2(aq) (o) CaCO_3(aq)

PRACTICE
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Understanding Concepts
4. The reaction involves two ionic compounds as reactants.
5. (a) Cu(NO_3)_2(aq) + MgCl_2(aq) → CuCl_2(s) + Mg(NO_3)_2(aq)
   (b) 3 Ba(OH)_2(aq) + Fe_2(SO_4)_3(aq) → 3 BaSO_4(s) + 2 Fe(OH)_3(s)
   (c) Mg(OH)_2(s) + H_2SO_4(aq) → MgSO_4(aq) + 2 H_2O(l)
   (d) (NH_4)_2S(aq) + FeSO_4(aq) → (NH_4)_2SO_4(aq) + FeS(s)
6. \(AB + CD \rightarrow AD + CB\)
   As the equation above shows, the ions “change partners” to form products. This type of reaction commonly occurs in aqueous solutions.

7. (a) \(\text{KNO}_3(\text{aq})\)
   (b) \(\text{CaCl}_2(\text{aq})\)
   (c) \(\text{Mg(OH)}_2(\text{s})\)
   (d) \(\text{Al}_2(\text{SO}_4)_3(\text{aq})\)
   (e) \(\text{PbI}_2(\text{s})\)
   (f) \(\text{Ca}_3(\text{PO}_4)_2(\text{s})\)
   (g) \((\text{NH}_4)_2\text{CO}_3(\text{aq})\)

8. (a) \(2 \text{KCl}(\text{aq}) + \text{Cu(NO}_3)_2(\text{aq}) \rightarrow 2 \text{KNO}_3(\text{aq}) + \text{CuCl}_2(\text{s})\)
   (b) \(\text{MgCl}_2(\text{aq}) + \text{Ca(OH)}_2(\text{aq}) \rightarrow \text{Mg(OH)}_2(\text{s}) + \text{CaCl}_2(\text{aq})\)
   (c) \(3 \text{K}_2\text{SO}_4(\text{aq}) + 2 \text{AlCl}_3(\text{aq}) \rightarrow 6 \text{KCl}(\text{aq}) + \text{Al}_2(\text{SO}_4)_3(\text{aq})\)
   (d) \(\text{CuI}_2(\text{s}) + \text{PbSO}_4(\text{aq}) \rightarrow \text{CuSO}_4(\text{aq}) + \text{PbI}_2(\text{s})\)
   (e) \(3 \text{CaI}_2(\text{aq}) + \text{Pb}_3(\text{PO}_4)_2(\text{s}) \rightarrow 3 \text{PbI}_2(\text{s}) + \text{Ca}_3(\text{PO}_4)_2(\text{s})\)
   (f) \((\text{NH}_4)_2\text{S}(\text{aq}) + \text{CaCO}_3(\text{s}) \rightarrow \text{CaS}(\text{aq}) + (\text{NH}_4)_2\text{CO}_3(\text{aq})\)

9. (a) single displacement
   (b) double displacement

10. (a) \(\text{Cl}_2(\text{g}) + 2 \text{NaBr}(\text{aq}) \rightarrow 2 \text{NaCl}(\text{aq}) + \text{Br}_2(\text{g})\)
    (b) \(\text{H}_2\text{SO}_4(\text{aq}) + 2 \text{NaOH}(\text{aq}) \rightarrow 2 \text{H}_2\text{O}(\text{l}) + \text{Na}_2\text{SO}_4(\text{aq})\)
    (c) \(3 \text{Ca(NO}_3)_2(\text{aq}) + 2 \text{Na}_3\text{PO}_4(\text{aq}) \rightarrow \text{Ca}_3(\text{PO}_4)_2(\text{s}) + 6 \text{NaNO}_3(\text{aq})\)

11. (a) \(\text{Al}(\text{s}) + 3 \text{AgNO}_3(\text{aq}) \rightarrow 3 \text{Ag}(\text{s}) + \text{Al(NO}_3)_3(\text{aq})\)
    (b) \(\text{Cl}_2(\text{g}) + 2 \text{NaBr}(\text{aq}) \rightarrow 2 \text{NaCl}(\text{aq}) + \text{Br}_2(\text{g})\)
    (c) \(\text{Zn}(\text{s}) + \text{H}_2\text{SO}_4(\text{aq}) \rightarrow \text{H}_2(\text{g}) + \text{ZnSO}_4(\text{aq})\)
    (d) \(2 \text{AgNO}_3(\text{aq}) + \text{MgCl}_2(\text{aq}) \rightarrow 2 \text{AgCl}(\text{s}) + \text{Mg(NO}_3)_2(\text{aq})\)
    (e) \(\text{Na}_2\text{C}_2\text{O}_4(\text{aq}) + \text{CaCl}_2(\text{aq}) \rightarrow \text{CaC}_2\text{O}_4(\text{aq}) + 2 \text{NaCl}(\text{aq})\)
    (f) \(2 \text{Na}(\text{s}) + \text{H}_2\text{O}(\text{l}) \rightarrow \text{H}_2(\text{g}) + 2 \text{NaOH}(\text{aq})\)
    (g) \(3 \text{KOH}(\text{aq}) + \text{FeCl}_3(\text{aq}) \rightarrow 3 \text{KCl}(\text{aq}) + \text{Fe(OH)}_3(\text{s})\)

12. (a) \(\text{Ca}_3(\text{PO}_4)_2(\text{s})\) calcium phosphate
    (b) \(3 \text{H}_2\text{SO}_4(\text{aq}) + \text{Ca}_3(\text{PO}_4)_2(\text{s}) \rightarrow 2 \text{H}_3\text{PO}_4(\text{aq}) + 3 \text{CaSO}_4(\text{s})\)
    (c) The simple procedure of “filtering” could be employed to isolate aqueous phosphoric acid from the solid calcium phosphate.
    (d) If sodium phosphate is used in place of calcium phosphate as a reactant, the products of the reaction would be aqueous phosphoric acid and aqueous sodium sulfate. Sodium sulfate is highly soluble at SATP, and would pass through a simple filter. Thus the simple procedure of filtering would not be sufficient to isolate the phosphoric acid. The fertilizer manufacturer would prefer to avoid the additional costs that would be associated with a more involved process of isolating the phosphoric acid.
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<th>Anion</th>
<th>Cl⁻</th>
<th>Br⁻</th>
<th>NO₃⁻</th>
<th>C₂H₃O₂⁻</th>
<th>PO₄³⁻</th>
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<td>lead(II) hydroxide, tertiary ionic, sdr with zinc will occur</td>
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### Word and chemical equation examples:

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<th>Fe(C₂H₃O₂)₃</th>
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<th>Fe(OH)₃(s)</th>
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</tr>
</tbody>
</table>

### NOTE: All substances aqueous (aq), unless noted otherwise. sdr stands for “single displacement reaction.”
2.  
1. octane + oxygen → carbon dioxide + water  
   \[ 2 \text{C}_8\text{H}_{18}(g) + 25 \text{O}_2(g) \rightarrow 16 \text{CO}_2(g) + 18 \text{H}_2\text{O}(g) \]

Rain becomes slightly acidic due to the presence of carbon dioxide, which dissolves in atmospheric moisture and reacts to form very dilute carbonic acid, \(H_2\text{CO}_3(aq)\). Carbon dioxide gas also contributes to the greenhouse effect, which may lead to global warming and dramatic climate changes.

2. sulfur + oxygen → sulfur dioxide  
   \[ \text{S(s)} + \text{O}_2(g) \rightarrow \text{SO}_2(g) \]

Sulfur dioxide joins the naturally produced oxides in the atmosphere, and reacts with water vapor to form acids, and is responsible for the increased acidity of precipitation known as acid rain.

3. nitrogen + oxygen → nitrogen monoxide  
   \[ \text{N}_2(s) + \text{O}_2(g) \rightarrow 2 \text{NO}(g) \]

Nitrogen monoxide joins the naturally produced oxides in the atmosphere, and reacts with water vapor to form acids, and is responsible for the increased acidity of precipitation known as acid rain.

4. nitrogen monoxide + oxygen → nitrogen dioxide  
   \[ 2 \text{NO}(g) + \text{O}_2(g) \rightarrow 2 \text{NO}_2(g) \]

Nitrogen dioxide joins the naturally produced oxides in the atmosphere, and reacts with water vapor to form acids, and is responsible for the increased acidity of precipitation known as acid rain.

5. sulfur trioxide + water → sulfuric acid  
   \[ \text{SO}_3(s) + \text{H}_2\text{O}(l) \rightarrow \text{H}_2\text{SO}_4(aq) \]

Sulfur trioxide reacts with water vapor to form sulfuric acid, and is responsible for the increased acidity of precipitation known as acid rain.

6. nitrogen monoxide → nitrogen + oxygen  
   \[ \text{N}_2\text{O}(g) + \text{Pt/Pd} \rightarrow \text{N}_2(g) + \text{O}_2(g) \]

The platinum/palladium catalytic converter built into today’s automobiles catalyzes the decomposition of nitrogen monoxide — which is a combustion engine exhaust pollutant — into harmless nitrogen and oxygen.

**Applying Inquiry Skills**

3. **Analysis**
   (a) Y would be highest in the activity series, followed by Z, and then X, as indicated below:

   \[
   \begin{array}{c}
   \text{Y} \\
   \text{Z} \\
   \text{X}
   \end{array}
   \]

   (b) Y and Z would be located higher in the activity series than hydrogen. X would be located lower in the activity series than hydrogen, unless in fact it is actually hydrogen.

   Using empirical evidence gathered in many experiments, scientists have been able to list the elements in order of their reactivity. The empirical evidence has shown that the more reactive element will replace the less reactive element. Since Y and Z showed evidence of reaction in water and acid - bubbles were observed - it is evident that Y and Z have reacted with the water and the acid to displace hydrogen and produce hydrogen gas. And since Y and Z displaced hydrogen, they cannot be hydrogen. The only possible choice for hydrogen would be X.

**Synthesis**

(c) X would appear higher in order than Y, as you descend the group.

   For metals, the lower the electronegativity value, the more reactive the metal should be. As the evidence showed Y to be more reactive than X, it would be expected to have a lower electronegativity value than X. And since electronegativity values decrease as you move down a group, it makes sense that X would appear higher in order than Y, as you descend the group.

   Y would appear to be further to the left in order than Z, as you move from left to right within the same period.

   For metals, the lower the electronegativity value, the more reactive the metal should be. As the evidence showed Y to be more reactive than Z, it would be expected to have a lower electronegativity value than Z. And since electronegativity values increase as you move from left to right within the same period, it makes sense that Y would appear further to the left in order than Z, as you move from left to right within the same period.
(d) Assign the following element identities:

\[ X = Li \]
\[ Y = Na \]
\[ Z = Mg \]

\[ 2 \text{Li}(s) + 2 \text{H}_2\text{O}(l) \rightarrow \text{H}_2(g) + 2 \text{LiOH}(aq) \]
\[ 2 \text{Li}(s) + 2 \text{HCl}(aq) \rightarrow \text{H}_2(g) + 2 \text{LiCl}(aq) \]
\[ 2 \text{Na}(s) + 2 \text{H}_2\text{O}(l) \rightarrow \text{H}_2(g) + 2 \text{NaOH}(aq) \]
\[ 2 \text{Na}(s) + 2 \text{HCl}(aq) \rightarrow \text{H}_2(g) + 2 \text{NaCl}(aq) \]
\[ \text{Mg}(s) + 2 \text{H}_2\text{O}(l) \rightarrow \text{H}_2(g) + \text{Mg(OH)}_2(s) \]
\[ \text{Mg}(s) + 2 \text{HCl}(aq) \rightarrow \text{H}_2(g) + \text{MgCl}_2(aq) \]

(e) All reactions are single displacement reactions.

With respect to the reaction with water:

Use a lighted splint to ignite the gas produced. A “pop” sound when ignited indicates hydrogen gas. The aqueous solution could be tested with pH paper to determine if it is basic. These tests would indicate that the reaction was a single displacement type, with the metal displacing hydrogen in the water (H\(_2\text{O}(l)\)) to produce hydrogen gas and a metal hydroxide.

With respect to the reaction with acid:

Use a lighted splint to ignite the gas produced. A “pop” sound when ignited indicates hydrogen gas. The aqueous solution could be evaporated and the remaining compound analyzed to determine if it is a metal chloride. These tests would indicate that the reaction was a single displacement type, with the metal displacing hydrogen in the acid (HCl\(_{aq}\)) to produce hydrogen gas and a metal chloride.

Making Connections

4. (a) \[ 2\text{K}(s) + \text{BeCl}_2(s) \xrightarrow{\text{Pt}} \text{Be}(s) + 2 \text{KCl}(l) \] single displacement

(b) Beryllium chloride should be stored dry within air and water vapour tight sealed containers. The substance should only be handled in environmentally enclosed and controlled areas, and all required protective equipment such as gas masks, protective clothing, and protective gloves should be worn.

5. (a) \[ \text{C}(s) + \text{SiO}_2(l) \rightarrow \text{Si}(l) + \text{CO}_2(g) \] single displacement

\[ \text{Si}(s) + 2 \text{Cl}_2(g) \rightarrow \text{SiCl}_4(l) \] synthesis

\[ 2 \text{Mg}(s) + \text{SiCl}_4(l) \rightarrow \text{Si}(s) + 2 \text{MgCl}_2(aq) \] single displacement

(b) Emissions of carbon dioxide gas (a product of the first reaction) cause rain to become slightly acidic. Carbon dioxide gas also contributes to the greenhouse effect, which may lead to global warming and dramatic climate changes.

CHAPTER 3 REVIEW

(Page 146)

Understanding Concepts

1. The kinetic molecular theory states that all matter is made up of particles in continuous random motion.

A gas has widely separated molecules in constant, chaotic motion. The average kinetic energy of the molecules is much larger than the energy associated with the attractive forces between them.

With liquids, the attractive forces between molecules have energies comparable to the kinetic energies of the molecules. The attractive forces are able to hold the molecules close to each other. However, the attractive forces are not strong enough to hold the molecules rigidly in place. In fact, molecules within a liquid are able to move in a more or less chaotic fashion, allowing liquids to be poured, and to flow to take the shape of their container.

With solids, the intermolecular attractions are sufficiently strong enough to hold the molecules rigidly in place. The average kinetic energy of the molecules is much smaller than the energy associated with the attractive forces between them. The particles of a solid are not free to move. However, the molecules within a solid may undergo vibrational motion.
2. The collision–reaction theory suggests that particles must collide with the correct orientation and at sufficient speed to react. Chemical reactions will not occur when the collision orientation is not correct, and/or when the speed of collision is not sufficient.

3. (a) \( S_8 + 8 \text{O}_2 \rightarrow 8 \text{SO}_2 \) synthesis (combustion)
   (b) \( \text{HBr} + \text{NaOH} \rightarrow \text{NaBr} + \text{H}_2\text{O} \) double displacement
   (c) \( \text{N}_2 + 3 \text{H}_2 \rightarrow 2 \text{NH}_3 \) synthesis
   (d) \( \text{PtCl}_4 \rightarrow \text{Pt} + 2 \text{Cl} \) decomposition
   (e) \( 2 \text{MgO} + \text{Si} \rightarrow 2 \text{Mg} + \text{SiO}_2 \) single displacement
   (f) \( \text{Na}_2\text{S} + 2 \text{HCl} \rightarrow 2 \text{NaCl} + \text{H}_2\text{S} \) double displacement
   (g) \( \text{P}_4 + 5 \text{O}_2 \rightarrow \text{P}_4 \text{O}_{10} \) synthesis (combustion)
   (h) \( \text{Zn} + 2 \text{HCl} \rightarrow \text{ZnCl}_2 + \text{H}_2 \) single displacement

4. (a) potassium chlorate \( \rightarrow \) potassium chloride + oxygen
   \[ 2 \text{KClO}_3(s) \rightarrow 2 \text{KCl}(s) + 3 \text{O}_2(g) \] (decomposition)
   (b) sodium + water (HOH) \( \rightarrow \) hydrogen + sodium hydroxide
   \[ 2 \text{Na}(s) + 2 \text{H}_2\text{O}(l) \rightarrow \text{H}_2(g) + 2 \text{NaOH} \] (single displacement)
   (c) carbon + oxygen \( \rightarrow \) carbon dioxide
   \[ \text{C}(s) + \text{O}_2(g) \rightarrow \text{CO}_2(g) \] (combustion)
   (d) zinc + sulfuric acid \( \rightarrow \) zinc sulfate + hydrogen
   \[ \text{Zn}(s) + \text{H}_2\text{SO}_4(aq) \rightarrow \text{ZnSO}_4(aq) + \text{H}_2(g) \] (single displacement)
   (e) silver nitrate + potassium iodide \( \rightarrow \) silver iodide + potassium nitrate
   \[ \text{AgNO}_3(aq) + \text{KI}(aq) \rightarrow \text{AgI}(s) + \text{KNO}_3(aq) \] (double displacement)
   (f) sodium sulfate + barium chloride \( \rightarrow \) barium sulfate + sodium chloride
   \[ \text{Na}_2\text{SO}_4(aq) + \text{BaCl}_2(aq) \rightarrow \text{BaSO}_4(s) + 2 \text{NaCl}(aq) \] (double displacement)
   (g) iron + oxygen \( \rightarrow \) iron(III) oxide
   \[ 4 \text{Fe}(s) + 3 \text{O}_2(g) \rightarrow 2 \text{Fe}_2\text{O}_3(s) \] (combustion/synthesis)
   (h) sulfur trioxide + water \( \rightarrow \) sulfuric acid
   \[ \text{SO}_3(g) + \text{H}_2\text{O}(g) \rightarrow \text{H}_2\text{SO}_4(aq) \] (synthesis)

5. (c) calcium sulfate; (h) silver iodide; (i) copper(I) chloride; (j) lead(II) sulfate are all of low solubility

6. \[ \text{Na}_2\text{SO}_4(aq) + \text{Ca(NO}_3)_2(aq) \rightarrow 2 \text{NaNO}_3(aq) + \text{CaSO}_4(s) \]
   \[ \text{KI}(aq) + \text{AgNO}_3(aq) \rightarrow \text{KNO}_3(aq) + \text{AgI}(s) \] (double displacement)
   \[ \text{NaCl}(aq) + \text{CuNO}_3(aq) \rightarrow \text{NaNO}_3(aq) + \text{CuCl}(s) \]
   \[ \text{Na}_2\text{SO}_4(aq) + \text{Pb(NO}_3)_2(aq) \rightarrow 2 \text{NaNO}_3(aq) + \text{PbSO}_4(s) \]

7. By referring to the relevant activity series. A metal will be displaced by a metal above it in the series; a nonmetal will be similarly displaced by a nonmetal.

8. (a) \( 2 \text{Li}(s) + 2 \text{H}_2\text{O}(l) \rightarrow \text{H}_2(g) + 2 \text{LiOH(aq)} \)
   (b) \( 2 \text{K}(s) + 2 \text{H}_2\text{O}(l) \rightarrow \text{H}_2(g) + 2 \text{KOH(aq)} \)
   (c) \( \text{Cu}(s) + 2 \text{AgNO}_3(aq) \rightarrow 2 \text{Ag}(s) + \text{Cu(NO}_3)_2(aq) \)
   (d) \( \text{Fe}(s) + \text{NaCl}(aq) \rightarrow \text{NR} \)
   (e) \( \text{Mg}(s) + \text{Ca(NO}_3)_2(aq) \rightarrow \text{NR} \)
   (f) \( 2 \text{Al}(s) + 6 \text{HCl}(aq) \rightarrow 3 \text{H}_2(g) + 2 \text{AlCl}_3(aq) \)
   (g) \( \text{Pb}(s) + \text{Cu(NO}_3)_2(aq) \rightarrow \text{Cu}(s) + \text{Pb(NO}_3)_2(aq) \)
   (h) \( \text{F}_2(g) + 2 \text{HCl}(aq) \rightarrow \text{Cl}_2(g) + 2 \text{HF(aq)} \)
   (i) \( \text{I}_2(s) + \text{NaBr}_2(aq) \rightarrow \text{NR} \)

9. (a) single displacement
   (b) solid iodine and potassium chloride
(c) \( \text{Cl}_2(g) + 2 \text{KI(aq)} \rightarrow \text{I}_2(s) + 2 \text{KCl(aq)} \)

(d) Chlorine, being more electronegative, displaces the iodide ion.

10. (a) Assume their elemental states: fluorine, bromine, nitrogen. Nitrogen gas is unreactive; fluorine is more reactive than bromine as it has a higher electronegativity.

(b) rubidium, potassium, magnesium. Rubidium is less electronegative than potassium, which is more reactive than magnesium.

**Applying Inquiry Skills**

11. (a) \( 2 \text{Li(s)} + 2 \text{H}_2\text{O(l)} \rightarrow \text{H}_2\text(g) + 2 \text{LiOH(aq)} \)

Reasons:
- Group 1 metals are soft and silvery
- water is colourless
- the gas test indicates hydrogen
- the litmus test indicates one of the products is a base
- the flame test (bright red) indicates that lithium could be a constituent of one of the products

(b) Reasonably sure. We don’t know if the metal floated when it was put in the liquid (lithium would). If we assume the liquid was pure water, the metal in the reaction could be strontium (flame test).

\( \text{Sr}_2\text{(s)} + 2 \text{H}_2\text{O(l)} \rightarrow \text{H}_2\text(g) + \text{Sr(OH)}_2\text{(aq)} \)

To be sure that the metal wasn’t strontium, another sample of the metal could be observed when it is put in water. If it floats (as lithium would), it can’t be strontium (density 2.6 g/cm\(^3\)). A chemical test would involve adding sulfuric acid to the product solution. Strontium sulfate has low solubility, but lithium sulfate has high solubility. If sulfuric acid were added to the solution, and strontium ions were present, strontium sulfate should precipitate in a double displacement reaction:

\( \text{Sr(OH)}_2\text{(aq)} + \text{H}_2\text{SO}_4\text{(aq)} \rightarrow 2 \text{H}_2\text{O(l)} + \text{SrSO}_4\text{(aq)} \)

It is also possible the liquid was water, but containing one or more solutes, for example, an acid. A test with pH paper or litmus paper would test for this kind of solute.

12. part 1: step 1, \( \text{Ni(OH)}_2\text{(s)} \) should form and be filtered

step 2, adding the barium chloride should result in the precipitation of \( \text{BaSO}_4\text{(s)} \)

\( \text{NiSO}_4\text{(aq)} + 2 \text{NaOH(aq)} \rightarrow \text{Na}_2\text{SO}_4\text{(aq)} + \text{Ni(OH)}_2\text{(s)} \)

\( \text{Na}_2\text{SO}_4\text{(aq)} + \text{BaCl}_2\text{(aq)} \rightarrow 2 \text{NaCl(aq)} + \text{BaSO}_4\text{(s)} \)

both are double displacement reactions

part 2: step 5, the mass of the crucible and contents should increase due to the synthesis of \( \text{MgO(s)} \) as the magnesium combusts

\( 2 \text{Mg} + \text{O}_2 \rightarrow 2 \text{MgO(s)} \)

part 3: step 6, small bubbles may form on the zinc as the zinc slowly replaces hydrogen in water in a single displacement reaction; after the addition of sulfuric acid, gas should be generated more vigorously in another single displacement reaction. The small amount of zinc hydroxide produced in the first reaction should also react with the sulfuric acid in a double displacement reaction.

step 7, the gas will pop, indicating hydrogen

\( \text{Zn(s)} + 2 \text{H}_2\text{O(l)} \rightarrow \text{H}_2\text(g) + \text{Zn(OH)}_2\text{(s)} \)

\( \text{Zn} + \text{H}_2\text{SO}_4\text{(aq)} \rightarrow \text{H}_2\text(g) + \text{ZnSO}_4\text{(aq)} \)

\( \text{Zn(OH)}_2\text{(s)} + \text{H}_2\text{SO}_4\text{(aq)} \rightarrow \text{ZnSO}_4\text{(aq)} + 2 \text{H}_2\text{O(l)} \)

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

**Making Connections**

13. Barium sulfate is a low-solubility solid. Because it does not dissolve, no barium ions are freed into solution within the patient and so there are no toxic effects.

14. Students are to investigate the refining process for a major industrial element, including any chemical reactions.

GO TO www.science.nelson.com, Chemistry 11, Teacher Centre.
UNIT 1 REVIEW

(Page 150)

Understanding Concepts

1. (a) iodine-127: p = 53; e = 53; n = 74 (127 \(11002^{53}\))
   (b) phosphorus-32: p = 15; e = 15; n = 17 (32 \(11002^{15}\))
   (c) Cu-64 (copper-64): p = 29; e = 29; n = 35 (64 \(11002^{29}\))
   (d) Hg-203 (mercury-203): p = 80; e = 80; n = 123 (203 \(11002^{80}\))

2. Comparison of Radiation

<table>
<thead>
<tr>
<th>Radiation Type</th>
<th>Mass (u)</th>
<th>Speed</th>
<th>Charge</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alpha particles</td>
<td>4u</td>
<td>relatively low</td>
<td>2+</td>
</tr>
<tr>
<td>Beta particles</td>
<td>very small</td>
<td>high</td>
<td>1-</td>
</tr>
<tr>
<td>Gamma rays</td>
<td>none (for now)</td>
<td>speed of light</td>
<td>0</td>
</tr>
</tbody>
</table>

3. 

4. (a) Bromine and fluorine each have seven electrons in their outer shell.
   (b) After the removal of the first electron, the nuclear charge has not been reduced, but the number of electrons has been. The pull of the nucleus on the remaining valence electron should be stronger. As a result it will take more energy to remove the second electron.
   (c) In order to achieve a full octet (full outer shell of electrons), oxygen must gain two electrons, producing the \(O^{2-}\) ion.
   (d) Argon has a full outer shell of electrons, which is a very stable arrangement.
   (e) Fluorine requires one electron to reach a stable octet and it has few electrons shielding the charge of the nucleus. As a result it has a high electron affinity.

5. The phenomenon of radioactivity indicated that atoms could change, i.e., that Dalton’s model of an indivisible, ball-like atom was flawed. That radiation often consisted of charged particles (alpha and beta) indicated that the atom had positive and negative components.

6. (a) mercury; transition metal
   (b) halogen
   (c) alkali metal
   (d) alkaline earth metal
   (e) halogen
   (f) noble gas