UNIT 1 MATTER AND QUALITATIVE ANALYSIS

ARE YOU READY?
(Pages 2–3)

Knowledge and Understanding

1. (a) physical, quantitative
   (b) physical, quantitative
   (c) physical, qualitative
   (d) chemical
   (e) chemical

2. (a) Physical change: water molecules are changing state from liquid to gas. There is no change in the structure of the water molecule.
   (b) Chemical change: propane reacts with oxygen in the air to form carbon dioxide and water.
   (c) Chemical change: the iron is now rust (iron oxide)—a new substance has been formed.
   (d) Chemical change: the molecules found in the apple have reacted, producing different molecules. The change is irreversible: new substances have been formed.
   (e) Physical change: the sugar molecules have not undergone any chemical rearrangement in the tea. If the water from the tea is evaporated, the sugar molecules could be recovered along with the tea molecules.
   (f) Chemical change: the molecules in the egg have reacted, forming new molecules. The change is irreversible.
   (g) Physical change: the butter has changed state from solid to liquid, but the atoms within the butter molecules have not been rearranged.
   (h) Chemical change: the molecules in the wood react with oxygen in the air to form new substances, such as carbon dioxide, carbon monoxide, water, and ash. The change is irreversible.
   (i) Physical change: the copper molecules have not reacted to form a new substance.
   (j) Chemical change: the molecules that make up the candle have formed new substances. The change is irreversible.
   (k) Physical change: the water molecules found in snow have changed state from solid to liquid.

3. (a) malleability
   (b) conductivity
   (c) density
   (d) melting point
   (e) hardness

4. (a) Elements and compounds are pure substances. Elements are composed of only one type of atom (e.g., O₂, Cu, Pb) and cannot be broken down further into simple substances using chemical means. Compounds are composed of more than one type of atom in fixed ratios (e.g., H₂O, NaCl).
   (b) The solute and the solvent are the components of a solution. The solvent is the part of a solution that is in greater quantity, while the solute is the component in lesser quantity. The solute dissolves in the solvent. Air is an example of a solution. The solvent in air is nitrogen gas because it comprises 78% of the air solution. Oxygen, one of the solutes found in air, comprises approximately 21% of the air solution. Other solutes found in air include argon gas and carbon dioxide.
   (c) A mechanical mixture and a solution are types of mixtures with variable compositions. A mechanical mixture has more than one phase and is therefore heterogeneous. A pizza is an example of a mechanical mixture. A solution is a mixture that is homogeneous to the naked eye. Salt water is an example of a solution.
   (d) The term “homogeneous” describes a mixture in which the components are uniformly distributed. There is only one phase in a homogeneous mixture. Windshield washer fluid is an example of a homogeneous mixture. The term “heterogeneous” describes a mixture in which the components are not uniformly distributed. Italian salad dressing is an example of a heterogeneous mixture because you can distinguish between the oil, vinegar, oregano, and other herbs.
   (e) Protons and neutrons are both subatomic particles found in the nucleus of an atom. A proton carries a positive charge, whereas a neutron carries zero charge.
(f) In general, metals have the following physical properties: they are lustrous, ductile, malleable, and they conduct electricity. They are found on the left side of the periodic table. Copper is an example of a metal. Nonmetals, found on the right side of the periodic table, are brittle, that is, they break or shatter under mechanical stress. In addition, they are poor conductors of heat and electricity. Sulfur is an example of a nonmetal.

(g) An atom is the smallest particle of an element. A molecule is an entity composed of two or more atoms held together by covalent bonds. For example, an oxygen molecule is composed of two oxygen atoms (O₂), bonded together covalently.

(h) The atomic number is the number of protons in the nucleus of an atom. Each element has a different atomic number. The mass number is the number of protons and neutrons found in the nucleus of an atom. For example, helium has an atomic number of 2 and a mass number of 4. Therefore, helium contains two protons and two neutrons in its nucleus.

(i) A pure substance is composed of only one type of atom or molecule. For example, table salt, NaCl, is a pure substance because it is always composed of sodium ions and chloride ions in a 1:1 ratio. A mixture is composed of more than one type of pure substance in variable composition. Salt water is a mixture because different quantities of salt can be dissolved in water.

5. (a) element  
(b) compound  
(c) compound  
(d) mixture made up of two elements  
(e) mixture made up of two elements  
(f) mixture made up of two elements and one compound  
(g) mixture made up of one element and two compounds  
(h) mixture made up of one element and one compound

6. | Particle     | Relative mass | Relative charge | Location within atom |
<table>
<thead>
<tr>
<th></th>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td>proton</td>
<td>1</td>
<td>1+</td>
<td>nucleus</td>
</tr>
<tr>
<td>electron</td>
<td>0</td>
<td>1–</td>
<td>orbiting the nucleus</td>
</tr>
<tr>
<td>neutron</td>
<td>1</td>
<td>zero charge</td>
<td>nucleus</td>
</tr>
</tbody>
</table>

7. (a) fluorine, chlorine, bromine, iodine, astatine  
(b) lithium, sodium, potassium, rubidium, cesium, francium  
(c) helium, neon, argon, krypton, xenon, radon  
(d) beryllium, magnesium, calcium, strontium, barium, radium

8. | Chemical name | Chemical symbol | Atomic number | Number of protons | Number of neutrons | Mass number | Number of electrons |
<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>helium</td>
<td>He</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>sulfur</td>
<td>S</td>
<td>16</td>
<td>16</td>
<td>16</td>
<td>32</td>
<td>16</td>
</tr>
<tr>
<td>oxygen</td>
<td>O</td>
<td>8</td>
<td>8</td>
<td>8</td>
<td>16</td>
<td>8</td>
</tr>
<tr>
<td>neon</td>
<td>Ne</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>20</td>
<td>10</td>
</tr>
<tr>
<td>potassium</td>
<td>K</td>
<td>19</td>
<td>19</td>
<td>20</td>
<td>39</td>
<td>19</td>
</tr>
</tbody>
</table>

9. (a) calcium  
(b) oxygen  
(c) sodium  
(d) chlorine
10. (a) magnesium  
(b) boron  
(c) helium  
(e) oxygen  
(d) potassium  

11. (a) The elements in column A are metals.  
(b) The elements in column B are nonmetals.  
(c) calcium oxide, CaO; potassium fluoride, KF; aluminum nitride, AlN

Inquiry and Communication

12. Student answers will vary.  
(a) The individual components of this mixture can be separated from each other by using knowledge of their different physical properties. Sand and iron filings are solid, whereas rubbing alcohol and water are both liquids. This mixture can be passed through filter paper. The sand and iron filings will remain in the filter paper, and the alcohol–water mixture will pass through it. The water that remains mixed with the sand and iron filings will eventually evaporate. Since iron filings are magnetic, whereas sand is not, the iron filings can be separated from the sand using a magnet. For the remaining two components, rubbing alcohol has a lower boiling point than water. When the water–alcohol mixture is heated, the rubbing alcohol will evaporate first, leaving behind water.  
(b) mixture, magnet, paper towel, filter paper, large beaker, distillation apparatus, funnel, ring clamp, retort stand, Bunsen burner, 10-mL graduated cylinder, round-bottomed flask  
(c) Procedure  
Part A: Removal of Sand and Iron Filings from Liquid  
1. Pour the mixture through the filter paper. Collect the liquid flowing through the filter paper into a large beaker.  
2. Remove the sand and iron filings from the filter paper onto a paper towel.  
3. Pour the collected liquid through the filter paper a second time. Collect any additional sand and iron filings caught in the filter paper and add it to the pile on the paper towel. Allow the pile to dry.
Part B: Removal of Iron Filings
4. Use a magnet to collect the iron filings from the pile of sand and iron filings on the paper towel.
5. Using your fingers, sweep off the filings from the magnet onto another paper towel.
6. Repeat steps 4 and 5 until all the iron filings have been separated from the sand.

Part C: Separation of Alcohol and Water
7. Pour the liquid from the large beaker into a round-bottomed flask.
8. Turn on the water tap so that the condenser tube in the distillation apparatus has water running within its outer walls.
9. Light the Bunsen burner and place it under the round-bottomed flask.
10. When the temperature reaches approximately 78°C, the alcohol will start to boil. At this temperature, the distillate is alcohol.
11. Collect the distillate at the end of the condenser tube into a 10-mL graduated cylinder.
12. Stop collecting the distillate when the temperature has reached 82°C.
13. Distribute the gas into three test tubes. To determine whether the gas is hydrogen, invert the first test tube and place a burning splint just inside its mouth. If you hear a popping sound, the gas is hydrogen. To determine whether the gas is oxygen, invert the second test tube and place a glowing splint just inside its mouth. If the splint ignites, the gas is oxygen. To determine whether the gas is carbon dioxide, pour limewater into the third test tube. If a white precipitate forms, the gas is carbon dioxide.

Technical Skills and Safety
14. (a) This action is unsafe. The student may cut herself with the broken glass through the paper towel. The broken glass may be coated with toxic or corrosive chemicals. Also, the student may not be able to collect all the pieces of broken glass with a paper towel, leaving behind an unsafe work area for other students. The student should have obtained a brush and dustpan from the teacher to collect the broken glass. The broken glass should have been placed in the container designated “Broken Glass” in the classroom.
(b) This action is unsafe. Rubbing one’s eyes does not remove the chemical, but further distributes it and allows it to be further absorbed by the eye, resulting in more irritation and damage. The student should have proceeded immediately to the eye wash station and flushed the eye with water for 10 min.
(c) This action is safe.
(d) This action is unsafe. The substances ingested may be poisonous. No chemicals should ever be ingested in a chemistry laboratory.
15. (a) compressed gas
(b) flammable and combustible materials
(c) corrosive materials

GETTING STARTED

TRY THIS ACTIVITY: AN INTRODUCTION TO QUALITATIVE ANALYSIS
(Page 7)
(a) Depending on the type of ink used, the banding pattern will vary. One possible colour pattern of bands, moving up the chalk, is blue, brown, red/orange, and yellow. If the steps were repeated using the same black ink and a similar piece of chalk, the pattern of colour would be identical. It would only vary in terms of distance between bands, which depends on how long the chalk was allowed to sit in the water.
(b) As the black ink moved up the chalk, it separated into its component colours.
(c) The separation distances between the bands vary.
(d) The most soluble ink molecules are yellow in colour and the least soluble ink molecules are blue in colour. An experiment that could be conducted to test this hypothesis is to obtain one yellow marker, one blue marker, and two pieces of chalk. One piece of chalk could be used to separate the components of yellow ink, while the second piece of chalk could be used to separate the components of blue ink. The chalk would be identical and the test would be conducted at the same time. The distance travelled up the chalk by each colour of ink would be recorded. If chromatography is based only on size of molecules, the yellow ink should travel farther up the chalk than the blue ink in the same amount of time.
(e) The observations are very similar to the prediction made in (a). The prediction is therefore valid.
(f) An advantage of this separation method is that it is quick, easy to set up, and produces qualitative results. Some disadvantages are that the colour separation is not definitive, and that it is difficult to quantify the results.
(g) Two changes in the procedure that might improve band separation include allowing the chalk to sit in the water for a longer period of time, and using a thinner ring of ink.

REFLECT ON YOUR LEARNING

(Page 7)

1. Some physical properties that may be used to identify matter include colour, odour, texture, boiling point, melting point, and conductivity. Some chemical properties that may be used to identify matter include behaviour in an acidic or alkaline environment.

2. Models are important in science because they allow scientists to communicate their ideas to other scientists. Models help scientists conceptualize, simplify, and/or clarify ideas. When coming up with models, scientists must think through their ideas and test them before presenting them to others.

3. Some careers in which people need to identify matter include forensics, environmental science, and chemistry. Forensic scientists examine crime scenes to find and analyze evidence from a crime scene for use in law enforcement. Environmental technicians test water samples to detect the presence of contaminants. Chemists need to identify different substances produced in a laboratory setting.

1.1 ACTIVITY: IDENTIFYING A MYSTERY POWDER

(Pages 8–9)

Observations

Student answers will vary depending on the powders chosen by the teacher. If the powders suggested in this teacher’s resource are used, the following observations will be made.

Table 1

<table>
<thead>
<tr>
<th>Powder</th>
<th>Appearance</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1) Aspirin</td>
<td>white crystalline powder, slightly yellow tint</td>
</tr>
<tr>
<td>(2) powdered sugar</td>
<td>fine white powder, becomes matted easily when touched</td>
</tr>
<tr>
<td>(3) sodium dihydrogen phosphate</td>
<td>fine white powder</td>
</tr>
<tr>
<td>(4) buffered Aspirin</td>
<td>fine white powder</td>
</tr>
<tr>
<td>(5) baking soda</td>
<td>very fine white powder, does not become matted when touched</td>
</tr>
<tr>
<td>(6) sodium monohydrogen phosphate</td>
<td>fine white powder</td>
</tr>
</tbody>
</table>

Table 2

<table>
<thead>
<tr>
<th></th>
<th>Aspirin</th>
<th>Powdered sugar</th>
<th>Sodium dihydrogen phosphate</th>
<th>Buffered Aspirin</th>
<th>Baking soda</th>
<th>Sodium monohydrogen phosphate</th>
</tr>
</thead>
<tbody>
<tr>
<td>water</td>
<td>insoluble</td>
<td>soluble</td>
<td>soluble</td>
<td>insoluble</td>
<td>soluble</td>
<td>soluble</td>
</tr>
<tr>
<td>universal</td>
<td>acidic</td>
<td>neutral</td>
<td>acidic</td>
<td>acidic</td>
<td>basic</td>
<td>basic</td>
</tr>
<tr>
<td>indicator</td>
<td>HCl (aq)</td>
<td>no reaction</td>
<td>no reaction</td>
<td>gas released</td>
<td>gas released</td>
<td>no reaction</td>
</tr>
<tr>
<td>Fe(NO₃)₃(aq)</td>
<td>brownish-purple</td>
<td>no reaction</td>
<td>no reaction</td>
<td>brownish-purple</td>
<td>no reaction</td>
<td>no reaction</td>
</tr>
<tr>
<td>I₂(aq)</td>
<td>blue-black</td>
<td>no reaction</td>
<td>no reaction</td>
<td>blue-black</td>
<td>no reaction</td>
<td>no reaction</td>
</tr>
</tbody>
</table>

Student answers in Table 3 will vary depending on which of the six powders the teacher chooses to be the mystery powder. If buffered Aspirin is provided, the observations will be as follows (on page 8).
Table 3 Mystery powder

<table>
<thead>
<tr>
<th>Test</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>water</td>
<td>insoluble</td>
</tr>
<tr>
<td>universal indicator</td>
<td>acidic</td>
</tr>
<tr>
<td>HCl(aq)</td>
<td>gas released</td>
</tr>
<tr>
<td>Fe(NO3)3(aq)</td>
<td>brownish-purple</td>
</tr>
<tr>
<td>I2(aq)</td>
<td>blue-black</td>
</tr>
</tbody>
</table>

Analysis
(a) Student answers will vary depending on the sample provided. The mystery powder is buffered Aspirin.
(b) The physical properties that were tested were solubility in water and pH.
(c) The chemical properties that were tested were the possible reactions between the sample and hydrochloric acid, iron(III) nitrate solution, and iodine solution, respectively.
(d) It was important to test the six samples first in order to learn about the properties of each powder. When the mystery powder was tested in the same way as the other six powders, it could be identified by comparing its properties to those of the other powders.
(e) Qualitative analysis was performed in this activity. Qualitative analysis involves the identification of a sample of matter based on its physical and chemical properties and comparing these properties to the properties of known substances. In this activity, a mystery powder was subjected to five different tests. The results of these tests were compared to the results of tests on six identified powders, enabling the student to identify the mystery powder.

Evaluation
(f) Student answers will vary depending on experience. In general, students should be quite confident given that they have performed five different tests on the mystery powder. Alternatively, if procedural errors have been made, students may not be able to conclusively identify their unknown.
(g) Additional tests that may be performed could include investigating the boiling point, melting point, and reactions with other solvents, such as ethanol.
(h) A source of error in this activity could be the small quantities of each of the powders used, making it difficult to detect physical and chemical changes. This source of error could be reduced by repeating the experiment or conducting it using larger quantities of powders. Cross-contamination is another possible source of error. To reduce this source of error, students could use a different toothpick for each well in the microtray.
(i) In many instances, forensic scientists are called to crime scenes to clarify the identity or origin of “evidence.” For example, a forensic scientist specializing in arson could be asked to examine the damage caused by the fire, to determine whether an accelerant was used, and, if so, to identify it. Another example is a ballistics expert, who may examine gun residue to determine the type of gun used to commit a crime.

1.2 BUILDING SCIENTIFIC KNOWLEDGE

TRY THIS ACTIVITY: THE BURNING CANDLE
(Page 11)

(a) Student answers will vary. Some examples of statements that may be made are: The flame of the candle is orange. The heat from the flame melts the candle wax. The candle was reduced in size by 20 mm. The flame of the candle is hot. The flame of the candle flickers. Melted wax runs down the side of the candle. As the hot liquid wax cools, it becomes solid.
(b) Student answers will vary. The statements provided in (a) may be classified as follows:
   Observation: The flame of the candle is orange. The candle was reduced in size by 20 mm. The flame of the candle flickers. The flame of the candle is hot.
   Inference: Melted wax runs down the side of the candle. The heat from the flame melts the candle wax. As the hot liquid wax cools, it becomes solid.
(c) Student answers will vary. In (b) above, there are equal numbers of inferences and observations.
(d) (i) Observation: The patient’s temperature is 39.8°C.
   Inference: The patient has a high fever.
(ii) Observation: The back wall of the bedroom is completely burned.
   Inference: The fire started in the mattress from careless smoking.

(iii) Observation: The soup is very spicy.
   Inference: Chili peppers must be one of the ingredients in the soup.

SECTION 1.2 QUESTIONS

(Page 12)

Understanding Concepts
1. (a) inference
   (b) observation
   (c) observation
   (d) inference
   (e) observation

2. A theory is an explanation of a large number of related observations. To come up with a theory, scientists must use their imaginations as well as empirical evidence collected from experiments. Even though a theory is grounded in observation, since it is an idea, it cannot be proven. Many theories are accepted as true, however, since a large amount of experimental evidence supports them. The more experimental testing a theory can withstand, the more credible it becomes.

3. Models can help convey an idea or a concept. A model is a visualization of a theory. Scientists use models to help describe and explore their ideas.

Making Connections
4. empirical knowledge comes directly from observation leads to the development of inference leads to the development of theoretical knowledge is simplified and presented in the form of a theory

5. In a court of law, the prosecution and the defence are both interested in only the presentation of facts. If witnesses make inferences, they are considered to be offering an opinion, which could sway a judge or jury. Also, the opinion may be invalid because witnesses may be misinterpreting what they observed. Unless the witness is an “expert,” then opinions are struck from court records.

6. Qualitative analysis is empirical because it is based on the physical and chemical properties of substances. Scientists compare the physical and chemical properties of an unidentified sample of matter to those of already identified substances in order to identify the unknown.

1.3 EARLY MODELS OF THE ATOM

TRY THIS ACTIVITY: AN ANALOGY TO PROBING THE ATOM

(Page 14)

(a) Student answers will vary depending on the object encased in the Plasticine. Student descriptions will focus on physical properties, such as the object’s size and shape. Students may also speculate on what the object is made of,
for example, metal. Students may also mention where within the Plasticine the object is placed (that is, near the edge or in the middle).

(b) Descriptions could be improved with the aid of other probing tools besides a pin. For example, a magnet could be inserted into the Plasticine. If a magnetic force is felt, then the type of material out of which the object is made could be narrowed down.

(c) Investigating the contents of a black box is similar to investigating the contents of an atom because in both cases, you cannot directly observe the contents. Instead, you must conduct tests or experiments that will help you to describe the contents. Your description is theoretical knowledge because it is not based on direct observation. Similarly, subatomic particles cannot be observed directly. Instead, through indirect experimental evidence, scientists gain theoretical knowledge about the contents and structure of the atom. An atom is different from a black box because it is much less tangible. Also, the contents of a black box can be eventually revealed by removing the Plasticine, whereas an understanding of the contents of an atom depends on theoretical knowledge.

(d) The pin represents the tools that scientists use to probe the atom.

(e) Student answers will vary. Possible answers include computers and elevators (how they work, and what parts they consist of).

SECTION 1.3 QUESTIONS

(Page 15)

Understanding Concepts
1. Empedocles’ and Democritus’ atomic models are not scientific models because they were not based on observation obtained through experimentation. Rather, their models are based on thought experiments.

2. Dalton’s atomic model consists of the following five ideas:
   - Matter consists of definite particles called atoms.
   - Each element is made up of its own type of atom.
   - Atoms of different elements have different properties.
   - Atoms of two or more elements can combine in constant ratios to form new substances.
   - Atoms cannot be created, destroyed, or subdivided in a chemical change.

3. (a) Ernest Rutherford
   (b) John Dalton
   (c) Ernest Rutherford
   (d) John Dalton

4. (a) The raisins represent the negatively charged electrons in an atom.
   (b) The bun represents the atom’s positively charged sphere.

5. (a) Democritus’ model was the result of a thought experiment. His model only described the atom as an indivisible particle. Dalton’s model is a more detailed description of the atom that includes some of its physical properties. Dalton’s model provided empirical support to Democritus’ idea.
   (b) The model of the atom was slow to evolve for three reasons. First, the technology available for probing the atom was limited. Second, until several hundred years ago, there were few people of independent means who were also interested in science as a hobby, and even fewer who were specifically interested in probing the atom. Third, it took many years for the scientific method to evolve. The alchemists, who lived during the Middle Ages, were the first group of people to record methodical observations with the purpose of answering a question.

6. (a) nucleus: the positively charged centre of an atom
   (b) proton: a positively charged subatomic particle found in the nucleus of an atom
   (c) electron: a negatively charged subatomic particle
   (d) neutron: an uncharged subatomic particle found in the nucleus of an atom

Making Connections
7. (a) Scientific knowledge is tentative because current models and theories are subject to change as new technology allows us to gather more information. The atomic model is an excellent example of the tentative nature of science. The atom has evolved from Democritus’ model of an indivisible particle to the current model of a positively charged centre containing neutrons and protons, with electrons in the space surrounding it. Electron behaviour is currently described using quantum mechanics.
   (b) As new technology is developed, scientists can further probe the atom. Shortly after cathode ray tubes were invented, J.J. Thomson proposed that atoms contain negatively charged particles. Without the cathode ray tube, electrons may not have been discovered.
(c) Each new generation of scientists builds on the work of previous generations of scientists. For example, Chadwick built on Rutherford’s model and proposed the presence of neutrons in the nucleus, in addition to protons.

1.4 THE ELECTROMAGNETIC SPECTRUM

SECTION 1.4 QUESTIONS

(Page 18)

Understanding Concepts
1. Radio waves have a longer wavelength than X rays, therefore, they have a lower frequency and less energy. When radio waves strike an object, they do not damage it. X rays have a much shorter wavelength than radio waves, and therefore a higher frequency and much more energy. When X rays strike soft objects like human tissue, they can cause damage.
2. The human eye can detect wavelengths in the visible range (400–700 nm).
3. When white light is directed through a prism, it separates into different colours. If white light did not consist of different colours, it would remain white when passed through a prism.
4. A continuous spectrum is an uninterrupted pattern of colours observed when a beam of white light is passed through a prism. An example of a continuous spectrum is a rainbow. A line spectrum is discontinuous. The lines, produced when light emitted by an element is directed through a prism, are separated by space with no colour. Hydrogen gas has a line spectrum.

Making Connections
5. (a) It is not safe for the technician to be in the same room during an X ray because the technician would be exposed to X rays each time an X-ray scan is taken: as many as several hundred scans per year. This amount of exposure exceeds the recommended levels of X-ray exposure for an individual. Patients are only exposed during their X-ray scan, therefore the risks are minimal.
   (b) Only the desired area to be X-rayed is exposed; the rest of the patient’s body is covered with a lead apron, which X rays cannot penetrate. Technicians wear badges that measure radiation levels in the radiation area, and keep detailed records of their cumulative lifetime dose.

1.5 ACTIVITY: IDENTIFYING GASES USING LINE SPECTRA

(Pages 19–20)

Observations
(a) The spectrum of sunlight is continuous.
(b) The spectrum of fluorescent light contains dark bands alternating with bands of coloured light.
(c) The spectrum of incandescent light consists of more red lines but fewer green-blue lines than the spectrum of fluorescent light.
(d) The line spectrum of hydrogen consists of four lines: red, green, blue, and indigo.
(e) Student drawings will vary depending on the elements they observe.

Analysis
(f) Student responses will depend on the spectra used.

Synthesis
(g) The spectrum of sunlight is a continuous spectrum. The spectra of some incandescent lights contain dark bands and more red lines than the spectrum of fluorescent light. The spectrum of fluorescent light also contains dark bands but is less green-blue than some incandescent spectra. Since sunlight, fluorescent light, and incandescent light all produce different spectra, the light energy they radiate is composed of different wavelengths.
(h) Student answers will vary depending on the gases that they observe. Neon and barium have a large number of spectral lines.
(i) Light spectroscopy may be used as a qualitative analysis technique because the spectrum of each element is unique. Light spectroscopy is used to identify the composition of stars as well as trace elements in food and building materials.

(j) Even though helium is the second most abundant element in the universe, it was only discovered about 140 years ago. It is the only element that was first discovered on the Sun and only later on Earth. In 1869, J. Norman Lockyer, a civil servant, examined the light coming from the Sun using a spectroscope and observed a yellow line that had not been seen before. That same year, Pierre Jules Cesar Janssen, a French astronomer, observed the same yellow line while working in India. Both astronomers tried to recreate their results in a laboratory, but failed. Lockyer proposed that the spectrum belonged to a new element but was ignored. It was not until 1895 that the element helium was discovered on Earth. William Ramsay, a Scottish chemist, was looking at the spectrum of gases emitted by the mineral cleveite. Ramsay observed a yellow line. He sent samples to Lockyer and William Crookes (cathode ray tubes), who confirmed that the yellow line produced by the gases from cleveite was the same line that Lockyer had seen years before. Given that helium is odourless, tasteless, generally nontoxic, and colourless, it is not surprising that it took so long for it to be discovered!

### 1.6 THE BOHR MODEL OF THE HYDROGEN ATOM

#### SECTION 1.6 QUESTIONS

**Understanding Concepts**

1. According to classical physics, the orbiting negatively charged electron should eventually run out of energy and collapse into the positively charged nucleus. From observation, we see that matter is very stable. We therefore infer that electrons do not collapse into the nuclei of atoms. Rutherford’s model of the atom could not explain why.

2. In Bohr’s and Rutherford’s models, the atom consists of a nucleus, with protons having a positive charge and neutrons carrying zero charge, surrounded by empty space. In Rutherford’s model, the electrons orbit the nucleus like planets around the Sun. In Bohr’s model, the electrons are found in fixed energy levels around the nucleus. The first energy level holds a maximum of two electrons, while the second energy level holds a maximum of eight electrons. The amount of potential energy an electron has depends on the energy level in which it is located.

3. Spectroscopy revealed that all the elements have characteristic line spectra. Bohr came up with his model of the atom to explain these observations. Spectroscopy provided the empirical evidence on which Bohr’s theory is based.

4. An electron in its ground state is in the lowest possible energy level, where it is most stable. At this level, the electron does not emit any electromagnetic radiation because it cannot drop to a lower energy level. When an electron is in the excited state, it has absorbed energy and is in a higher energy level. An electron in the excited state can drop to a lower energy level and release a fixed amount of energy as electromagnetic radiation that appears in a line spectrum.

5. Bohr’s atomic model could only explain the line spectrum of hydrogen. It could not accurately predict the line spectra of more complex elements.

6. An electron in a lower energy level has less energy than an electron in a higher energy level. Therefore, when an electron drops from a higher energy level to a lower energy level, it emits the excess energy in the form of light.

7. Energy levels have a specific energy value. Electrons in the same energy level have the same amount of energy. To jump to a higher energy level, they must absorb a specific amount of energy. To drop to a lower energy level, they must release a specific amount of energy. Electrons cannot be found between energy levels.

**Applying Inquiry Skills**

8. Plug one of the discharge tubes into an electrical source. Observe the gas discharge tube through a spectroscope and record the line spectrum of the gas. To determine the identity of the gas, compare its line spectrum to the line spectra of identified gases in a resource. Repeat for the second discharge tube.

**Making Connections**

9. In Bohr’s atomic model, electrons can only possess specific amounts of energy, depending on the energy level in which they are found. When electrons of an element are excited, they always jump to specific higher energy levels. When the electrons drop to lower energy levels, they always release specific amounts of energy, equal to the difference between the higher and lower energy levels. Since each element has a unique electron configuration, it has a characteristic line spectrum.
TAKE A STAND: FAIR ACCESS

Statement: Ontarians should have the right to choose faster access to MRI and better treatment through personal funding.

**Table 1**

<table>
<thead>
<tr>
<th>Arguments that Support and Refute the Statement</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Arguments that support the statement</strong></td>
</tr>
<tr>
<td>People should have a right to spend their money as they desire and not be dictated to by government policy.</td>
</tr>
<tr>
<td>Private MRI clinics allow people to be diagnosed more quickly, thus easing the strain on the health care system. People's conditions can deteriorate further by waiting for an MRI for a year or more.</td>
</tr>
<tr>
<td>Doctors, nurses, and medical technologists will be enticed to stay in Canada with the option of working in the private sector. Private clinics will help stop the &quot;brain drain&quot; to the U.S.</td>
</tr>
<tr>
<td>Government monitoring will ensure that individuals do not jump queues for supplementary services.</td>
</tr>
<tr>
<td>Private clinics will alleviate the current stress on the public sector to provide MRIs.</td>
</tr>
<tr>
<td><strong>Arguments that refute the statement</strong></td>
</tr>
<tr>
<td>Individuals with more disposable income will have access to health care facilities faster than individuals with less disposable income. This inequality violates the premise upon which the Canadian Health Act is based: equal access to basic health services.</td>
</tr>
<tr>
<td>Serious cases are dealt with in a reasonable time span. OHIP pays for MRI provided in the U.S. if the service cannot be provided in Ontario.</td>
</tr>
<tr>
<td>Leaders in health care will be drawn to private clinics as a result of the &quot;profit&quot; generated. This consequence will eventually drain the public sector of the best doctors, nurses, and medical technologists. The public system, used by the majority of Ontarians, will be at a disadvantage.</td>
</tr>
<tr>
<td>Government monitoring is not effective. Audits are costly and time-consuming.</td>
</tr>
<tr>
<td>Government should consider alleviating the stress on hospitals by buying more up-to-date equipment, opening more public MRI clinics, and funding more programs to train MRI technologists, for whom there is a growing demand.</td>
</tr>
</tbody>
</table>

Student arguments will vary. The above arguments are some examples. The numbering of their points and the writing of position papers will also vary.

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**1.11 THE FORMATION OF IONIC COMPOUNDS**

**SECTION 1.11 QUESTIONS**

(Page 35)

**Understanding Concepts**

1. An electrolyte is a compound that, when dissolved in water, produces a solution that conducts electricity. A nonelectrolyte is a compound that, when dissolved in water, produces a solution that does not conduct electricity.

2. Atoms have a tendency to form ions when their outermost shells are not full and they need to gain or lose electrons in order to attain a stable octet structure. Metals have a tendency to lose their valence electrons to attain a full outer shell and become cations, whereas nonmetals tend to gain electrons to fill their outer shells and become anions.

3. Cations and anions form ionic bonds. Metals lose electrons and become cations, whereas nonmetals gain electrons and become anions. The strong electrostatic force of attraction between cations and anions results in the formation of an ionic bond.

4. (a) \( K^+ \)
   (b) \( C^6^- \)
   (c) \( S^2^- \)
   (d) \( Si^4^- \)
5. (a) $H^+$  
(b) $K^+$  
(c) $F^-$  
(d) $Mg^{2+}$  
(e) $S^{2-}$  

6. (a) $[H]^+$  
(b) $[K]^+$  
(c) $[F^-]$  
(d) $[Mg]^{2+}$  
(e) $[S^{2-}]$  

All the Lewis symbols have full outer shells (consisting of eight electrons). Positive ions have emptied their outermost shells, and negative ions have filled their outermost shells. The rule that is being followed is the octet rule.

7. (a) $K^+ + 2\cdot Cl^- \rightarrow K^+ \cdot Cl^-$  
(b) $Mg^{2+} + 2\cdot S^{2-} \rightarrow Mg^{2+} \cdot S^{2-}$

Applying Inquiry Skills

8. (a) Obtain a small sample of an ionic solid, such as a piece of chalk (calcium carbonate, CaCO$_3$). Use a low-voltage conductivity apparatus to test the electrical conductivity of the sample. Record your observations.  
(b) In liquid form, ionic compounds conduct electricity.  
(c) Ionic compounds are solids at room temperature. As solids, they are nonconductors of electricity. However, as liquids, they conduct electricity quite well. Some examples of molten ionic compounds are sodium chloride (melts at 801°C) and aluminum oxide, Al$_2$O$_3$ (melts at 2000°C). When dissolved in water, ionic compounds produce solutions that conduct electricity.  
(d) In the solid state, ionic compounds do not conduct electricity. In ionic solids, the ions are tightly held in the crystal structure, so they are not free to move and carry electric charge. When an ionic compound is melted, or dissolved (dissociated) in water, the attractive forces are overcome and the crystal breaks up. The ions are now free to move and carry electric charge.

1.12 COVALENT BONDING

PRACTICE (Page 39)

Understanding Concepts

1. The two bromine atoms are placed side by side.

$\cdot Br^+ \cdot Br^-$  

Electron pairs are arranged so that each bromine atom is surrounded by eight electrons, satisfying the octet rule. There is one shared pair of electrons.

$\cdot Br^+ \cdot Br^-$  

A line is drawn to represent the shared pair of electrons between the two bromine atoms.

$\cdot Br^+ \rightarrow Br^-$  

The final chemical equation is

$\cdot Br^+ + \cdot Br^-$ $\rightarrow$ $\cdot Br^+ \rightarrow Br^-$
2. The nitrogen atom is placed in the centre of the molecule, surrounded by three hydrogen atoms.

\[
\begin{array}{c}
\text{H} \\
\text{H} \\
\text{H} \\
\text{H}
\end{array}
\]

Electron pairs are arranged so that the nitrogen atom is surrounded by eight electrons, satisfying the octet rule. Hydrogen only requires two electrons in order to be stable. There is one shared pair of electrons between each hydrogen atom and the nitrogen atom.

\[
\begin{array}{c}
\text{H} \\
\text{N} \\
\text{H}
\end{array}
\]

Lines are drawn to represent the shared pair of electrons between the hydrogen atoms and the nitrogen atom.

\[
\begin{array}{c}
\text{H} \\
\text{N} \\
\text{H}
\end{array}
\]

The final chemical equation is

\[
3 \text{H} + \cdot \text{N} \rightarrow \text{H} \text{N} \text{H}
\]

3. The four hydrogen atoms surround the lone carbon atom in the centre.

\[
\begin{array}{c}
\text{H} \\
\text{H} \\
\text{H} \\
\text{H}
\end{array}
\]

Electron pairs are arranged so that the carbon atom is surrounded by eight electrons, satisfying the octet rule. Each hydrogen atom is also stable, with two electrons.

\[
\begin{array}{c}
\text{H} \\
\text{C} \\
\text{H}
\end{array}
\]

A line is drawn to represent the shared pair of electrons between the four hydrogen atoms and the carbon atom.

\[
\begin{array}{c}
\text{H} \\
\text{C} \\
\text{H}
\end{array}
\]

The final chemical equation is

\[
4 \text{H} + \cdot \text{C} \rightarrow \text{H} \text{C} \text{H}
\]

4. The silicon atom is placed between the two oxygen atoms.

\[
\begin{array}{c}
\text{O} \\
\text{Si} \\
\text{O}
\end{array}
\]

Electron pairs are arranged so that both oxygen atoms and the silicon atom are surrounded by eight electrons, satisfying the octet rule. There are two shared pairs of electrons between each oxygen atom and the silicon atom.

\[
\begin{array}{c}
\text{O} \\
\text{Si} \\
\text{O}
\end{array}
\]

Lines are drawn to represent the shared pair of electrons between the oxygen atoms and the silicon atom. Two double bonds are formed.

\[
\text{O} = \text{Si} = \text{O}
\]

The final chemical equation is

\[
2 \text{O} + \cdot \text{Si} \rightarrow \text{O} = \text{Si} = \text{O}
\]
TRY THIS ACTIVITY: BUILDING MOLECULAR MODELS

(Page 44)

(a)
Table 2 Lewis Structures

<p>| | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>O₂</td>
<td>CO₂</td>
<td>H₂O</td>
<td>CH₄</td>
</tr>
</tbody>
</table>
| :O ≡ :O | :O ≡ C ≡ :O | :H | H
|   |   |   |   |
| H₂ | HCl | C₂H₂ | CCl₄ |
| H ─ H | H ─ :Cl | H ─ C ≡ C ─ H | :Cl |
|   | :Cl | :Cl ─ C ─ :Cl | :Cl |

(b) O₂—linear
CO₂—linear
H₂O—bent
CH₄—tetrahedral
H₂—linear
HCl—linear
C₂H₂—linear
CCl₄—tetrahedral

c) The holes in the round pieces represent the unpaired (bonding) electrons in the atom. The pegs or springs represent the shared electron pairs (the bonds).

d) The molecules that contain single bonds are H₂O, CH₄, H₂, HCl, and CCl₄. The molecules that contain double bonds are O₂ and CO₂. The molecule that contains a triple bond is C₂H₂.

e) The polar molecules are H₂O and HCl. Both these molecules consist of two or more atoms with electronegativities that differ such that one atom has a stronger attraction for the shared pair of electrons than the other atom. Opposite charges are found at opposite ends of each molecule, making it polar.

SECTION 1.12 QUESTIONS

(Page 45)

Understanding Concepts

1. (a) Sulfur and oxygen form two covalent bonds. Both elements are nonmetals. Since each element has six electrons in its outermost shell, to satisfy the octet rule, they must share electrons.

   (b) Sodium and iodine form an ionic bond. Sodium has one electron in its outermost shell and is a metal, whereas iodine has seven electrons in its outermost shell and is a nonmetal. Sodium loses its valence electron to become stable, and iodine gains an electron in its outermost shell. Each atom follows the octet rule.

   (c) Bromine and bromine form covalent bonds because bromine is a nonmetal and each atom must share electrons in order to satisfy the octet rule.

2. (a) :F ≡ :F

   (b) H ─ H

   (c) :O ≡ :O

   (d) H ─ S ─ H
3. H₂S is a polar molecule because it has polar covalent bonds and a bent shape, with opposite charges at opposite ends. All the other molecules are nonpolar. Due to their symmetry, any polar bonds are cancelled out, or there are no polar bonds (e.g., H₂).

4. In a covalent bond, two atoms share a pair of electrons. Ionic bonds form as a result of the transfer of electrons from one atom to another. As a result, one atom becomes a cation while the other atom becomes an anion. The electrostatic force of attraction between the oppositely charged ions results in the formation of an ionic bond. In both ionic and covalent bonds, the octet rule is satisfied: all atoms end up with a full outer shell.

5. (a) Beryllium has a higher electronegativity than strontium because beryllium is in period 2, whereas strontium is in period 5. Beryllium has a smaller atomic radius than strontium and therefore a stronger pull on its valence electrons than strontium.

(b) Chlorine has a higher electronegativity than sodium because chlorine has a higher atomic number and therefore more protons in its nucleus than sodium. It therefore has a stronger pull on its valence electrons than sodium.

6. (a) H—F
(b) C—O
(c) O—H
(d) P—Cl
(e) N—H
(f) P—O
(g) C—N

7. If the polar bonds are identical and arranged symmetrically around a central atom, their combined pulls cancel each other and the molecule is nonpolar. There are no opposite charges at opposite ends.

8. (a) An intermolecular bond is a bond between two or more molecules.
(b) Dipole–dipole forces form between polar molecules because the slightly positive end of one molecule is attracted to the slightly negative end of a neighbouring molecule. London dispersion forces form between polar and nonpolar molecules due to temporary imbalances in the positions of electrons in the atoms that make up the molecules.

9. **Table 3 Intermolecular Forces**

<table>
<thead>
<tr>
<th>Molecule</th>
<th>Intermolecular force(s) (LDF, DDF, or both)</th>
</tr>
</thead>
<tbody>
<tr>
<td>hydrogen, H₂</td>
<td>LDF</td>
</tr>
<tr>
<td>carbon tetrachloride, CCl₄</td>
<td>LDF</td>
</tr>
<tr>
<td>hydrogen sulfide, H₂S</td>
<td>LDF, DDF</td>
</tr>
</tbody>
</table>

10. The boiling point of methane is much lower than the boiling point of hydrogen bromide because methane in a nonpolar molecule whereas hydrogen bromide is polar. The intermolecular bonds that form between methane molecules (LDFs) are fewer and weaker than the intermolecular bonds that form between hydrogen bromide molecules (LDFs and DDFs). Less energy is required to break the bonds between methane molecules, resulting in a lower boiling point.

**Applying Inquiry Skills**

11. **Prediction**
(a) The molecules that will be affected by the charged object are NCl₃ and H₂O because these molecules are polar.

**Observations**
(b) Samples 1 and 2 could be Br₂ and CCl₄. Samples 3 and 4 could be NCl₃ and H₂O.

**Analysis**
(c) A charged object attracts or repels a thin stream of liquids composed of polar molecules, NCl₃ and H₂O, but it has no effect on liquids composed of nonpolar molecules, Br₂ and CCl₄.

**Synthesis**
(d) The polar molecules, NCl₃ and H₂O, are slightly positively charged at one end and slightly negatively charged at the other end due to their shape and the presence of polar covalent bonds. Thus, the end of the polar molecule that has the opposite charge of the charged object will move toward the charged object.
The liquids were affected by both positive and negative charges because the polar molecules of the liquids are positively charged at one end and negatively charged at the other end. A positively charged object attracts the negatively charged end of the polar molecule, while a negatively charged object attracts the positively charged end of the polar molecule.
1.14 CHEMICAL REACTIONS

SECTION 1.14 QUESTIONS

(Page 53)

Understanding Concepts

1. (a) decomposition reaction—a compound is broken down into two elements  
(b) synthesis reaction—two elements combine to form a compound  
(c) decomposition reaction—a complex compound is broken down into two simpler compounds

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

3. A synthesis reaction is the combination of two or more simple substances to form a more complex substance. A combustion reaction is the rapid combination of oxygen and another element or compound to form new substances. Thus, a combustion reaction is a type of synthesis reaction where one of the reactants is oxygen. For example, \(4 \text{Na}_\text{s} + \text{O}_2\text{g} \rightarrow 2 \text{Na}_2\text{O}_\text{s}\) is a combustion reaction as well as a synthesis reaction.

4. (a) \(\text{Zn}_\text{s} + \text{CuCl}_2\text{aq} \rightarrow \text{ZnCl}_2\text{aq} + \text{Cu}_\text{s}\)  
(b) \(\text{Ca}_\text{s} + 2 \text{HCl}_\text{aq} \rightarrow \text{CaCl}_2\text{aq} + \text{H}_2\text{g}\)  
(c) \(2 \text{Na}_\text{s} + 2 \text{H}_2\text{O}_\text{l} \rightarrow 2 \text{NaOH}_\text{aq} + \text{H}_2\text{g}\)

5. In general, a synthesis reaction involves the reaction of two elements to form a new compound. A decomposition reaction involves the breaking down of a compound into elements or simpler compounds. A single displacement reaction is a reaction between an element and a compound. A double displacement reaction occurs between two compounds.

6. The general equation for a synthesis reaction is \(\text{A} + \text{B} \rightarrow \text{AB}\), whereas the general equation for a decomposition reaction is \(\text{AB} \rightarrow \text{A} + \text{B}\). The decomposition reaction is the reverse of the synthesis reaction and vice versa. They are therefore opposite reactions.

7. (a) \(\text{Al}_\text{s} + 3 \text{AgNO}_3\text{aq} \rightarrow \text{Al(NO}_3\text{)}_3\text{aq} + 3 \text{Ag}_\text{s}\) single displacement reaction  
(b) zinc + sulfuric acid \(\rightarrow\) zinc sulfate + hydrogen gas  
\(\text{Zn}_\text{s} + \text{H}_2\text{SO}_4\text{aq} \rightarrow \text{ZnSO}_4\text{aq} + \text{H}_2\text{g}\) single displacement reaction  
(c) aqueous magnesium chloride + aqueous silver nitrate \(\rightarrow\) solid silver chloride + aqueous magnesium nitrate  
\(\text{MgCl}_2\text{aq} + 2 \text{AgNO}_3\text{aq} \rightarrow 2 \text{AgCl}_\text{s} + \text{Mg(NO}_3\text{)}_2\text{aq}\) double displacement reaction  
(d) sodium + water \(\rightarrow\) sodium hydroxide + hydrogen gas  
\(2 \text{Na}_\text{s} + 2 \text{H}_2\text{O}_\text{l} \rightarrow 2 \text{NaOH}_\text{aq} + \text{H}_2\text{g}\) single displacement reaction  
(e) \(3 \text{KOH}_\text{aq} + \text{FeCl}_3\text{aq} \rightarrow \text{Fe(OH)}_3\text{aq} + 3 \text{KCl}_\text{aq}\) double displacement reaction
Applying Inquiry Skills

8. Prediction

(a) \[ 2 \text{Li}_2\text{O}(s) \rightarrow 4 \text{Li}^+(aq) + \text{O}_2(g) \]
(b) \[ 2 \text{MgO}(s) \rightarrow 2 \text{Mg}^{2+}(aq) + \text{O}_2(g) \]
(c) \[ \text{ZnCl}_2(s) \rightarrow \text{Zn}^{2+}(aq) + 2\text{Cl}^-(aq) \]

Making Connections

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

\[ 2 \text{NO}(g) \xrightarrow{\text{Pt/Pd}} \text{N}_2(g) + \text{O}_2(g) \]

(b) Catalytic converters help to reduce the amounts of carbon monoxide, hydrocarbons, and nitrogen oxides in car exhaust, which are responsible for smog, acid rain, and pollution. A catalytic converter is shaped like a honeycomb and is attached to a car’s exhaust pipe. It is coated with platinum and palladium, which act as catalysts (substances that speed up a chemical reaction but are recovered at the end) in the decomposition reactions of hydrocarbons to water and carbon monoxide, of carbon monoxide to carbon dioxide, and of nitrogen oxides to nitrogen and oxygen. Since the products of these reactions do not contribute to air pollution, catalytic converters are effective tools in reducing air contaminants from cars.

10. (a) Student answers will vary depending on the metal they have chosen. Copper is a metal that is rarely found in elemental form. Most copper is mined as a carbonate or oxide ore.

(b) Copper carbonate and copper oxide are treated with dilute sulfuric acid to leach the copper out as copper(II) sulfate solution. For copper oxide, the reaction is

\[ \text{CuO}(s) + \text{H}_2\text{SO}_4(aq) \rightarrow \text{CuSO}_4(aq) + \text{H}_2\text{O}(l) \]

If the copper(II) sulfate solution reacts with iron, the copper is displaced, according to the following reaction equation:

\[ \text{CuSO}_4(aq) + \text{Fe}(s) \rightarrow \text{FeSO}_4(aq) + \text{Cu}(s) \]

The copper has now been recovered in its elemental state.

(c) The types of reactions used to purify copper are a double displacement reaction,

\[ \text{CuO}(s) + \text{H}_2\text{SO}_4(aq) \rightarrow \text{CuSO}_4(aq) + \text{H}_2\text{O}(l) \]

and a single displacement reaction,

\[ \text{CuSO}_4(aq) + \text{Fe}(s) \rightarrow \text{FeSO}_4(aq) + \text{Cu}(s) \]

(d) Copper mine tailings (leftover earth) are usually piled up or spread around a copper mine site. These tailings have essentially no organic matter, are highly acidic, and represent an environmental threat from blowing dust, erosion, and runoff. Also, if they run into bodies of water, they can cause damage to marine or freshwater ecosystems.

1.15 USING SOLUBILITY RULES TO PREDICT PRECIPITATE FORMATION

PRACTICE

(Page 57)

Understanding Concepts

1. (a) lead(II) nitrate + sodium chloride \(\rightarrow\) lead(II) chloride + sodium nitrate

lead(II) chloride—low solubility

sodium nitrate—soluble

aqueous lead(II) nitrate + aqueous sodium chloride \(\rightarrow\) solid lead(II) chloride + aqueous sodium nitrate

\[ \text{Pb(NO}_3)_2(aq) + \text{NaCl}(aq) \rightarrow \text{PbCl}_2(s) + \text{NaNO}_3(aq) \]

(b) sodium sulfate + calcium chloride \(\rightarrow\) calcium sulfate + sodium chloride

calcium sulfate—low solubility

sodium chloride—soluble

aqueous sodium sulfate + aqueous calcium chloride \(\rightarrow\) solid calcium sulfate + aqueous sodium chloride

\[ \text{Pb(NO}_3)_2(aq) + 2\text{NaCl}(aq) \rightarrow \text{PbCl}_2(s) + 2\text{NaNO}_3(aq) \]
\[ \text{Na}_2\text{SO}_4(\text{aq}) + \text{CaCl}_2(\text{aq}) \rightarrow \text{CaSO}_4(\text{s}) + 2 \text{NaCl}(\text{aq}) \]

(c) magnesium acetate + silver nitrate \(\rightarrow\) silver acetate + magnesium nitrate
silver acetate—low solubility
magnesium nitrate—soluble
aqueous magnesium acetate + aqueous silver nitrate \(\rightarrow\) solid silver acetate + aqueous magnesium nitrate
\[ \text{Mg(C}_2\text{H}_3\text{O}_2)\text{2}(\text{aq}) + \text{AgNO}_3(\text{aq}) \rightarrow \text{AgC}_2\text{H}_3\text{O}_2(\text{s}) + \text{Mg(NO}_3)\text{2}(\text{aq}) \]

(d) sodium acetate + potassium chloride \(\rightarrow\) sodium chloride + potassium acetate
potassium acetate—soluble
sodium chloride—soluble
sodium acetate + potassium chloride \(\rightarrow\) no reaction

PRACTICE

(Page 60)

2. (a) barium chloride + silver nitrate \(\rightarrow\) silver chloride + barium nitrate
silver chloride—low solubility
barium nitrate—soluble
aqueous barium chloride + aqueous silver nitrate \(\rightarrow\) solid silver chloride + aqueous barium nitrate
\[ \text{BaCl}_2(\text{aq}) + \text{AgNO}_3(\text{aq}) \rightarrow \text{AgCl}(\text{s}) + \text{Ba(NO}_3)\text{2}(\text{aq}) \]

(b) zinc chloride + lead(II) nitrate \(\rightarrow\) lead(II) chloride + zinc nitrate
lead(II) chloride—low solubility
zinc nitrate—soluble
aqueous zinc chloride + aqueous lead(II) nitrate \(\rightarrow\) solid lead(II) chloride + aqueous zinc nitrate
\[ \text{ZnCl}_2(\text{aq}) + \text{Pb(NO}_3)\text{2}(\text{aq}) \rightarrow \text{PbCl}_2(\text{s}) + \text{Zn(NO}_3)\text{2}(\text{aq}) \]

SECTION 1.15 QUESTIONS

(Page 62)

Understanding Concepts

1. (a) PbSO\textsubscript{4}—low solubility
(b) (NH\textsubscript{4})\textsubscript{2}S—soluble
(c) AgNO\textsubscript{3}—soluble
(d) AgCl—low solubility
(e) CaCO\textsubscript{3}—low solubility
(f) NH\textsubscript{4}OH—soluble
(g) Ba(OH)\textsubscript{2}—soluble

2. (a) strontium nitrate + sodium sulfate \(\rightarrow\) strontium sulfate + sodium nitrate
strontium sulfate—low solubility
sodium nitrate—soluble
Strontium sulfate, SrSO\textsubscript{4}, precipitates.
(b) sodium acetate + silver nitrate \(\rightarrow\) silver acetate + sodium nitrate
silver acetate—low solubility
sodium nitrate—soluble
Silver acetate, AgC₂H₃O₂, precipitates.

(c) barium nitrate + ammonium phosphate → barium phosphate + ammonium nitrate
barium phosphate—low solubility
ammonium nitrate—soluble
Barium phosphate, Ba₃(PO₄)₂, precipitates.

(d) sodium hydroxide + calcium nitrate → calcium hydroxide + sodium nitrate
calcium hydroxide—low solubility
sodium nitrate—soluble
Calcium hydroxide, Ca(OH)₂, precipitates.

3. (a) Sr(NO₃)₂(aq) + Na₂SO₄(aq) → SrSO₄(s) + 2 NaNO₃(aq)
Sr²⁺ + 2 NO₃⁻ + 2 Na⁺ + SO₄²⁻ → SrSO₄(s) + 2 Na⁺ + 2 NO₃⁻ (total ionic equation)
Sr⁺ + 2 NO₃⁻ + 2 Na⁺ + SO₄²⁻ → SrSO₄(s) + 2 Na⁺ + 2 NO₃⁻ (net ionic equation)

(b) NaC₂H₃O₂(aq) + AgNO₃(aq) → AgC₂H₃O₂(s) + NaNO₃(aq)
Na⁺ + C₂H₃O₂⁻ + Ag⁺ + NO₃⁻ → AgC₂H₃O₂(s) + Na⁺ + NO₃⁻ (total ionic equation)
Ag⁺ + C₂H₃O₂⁻ → AgC₂H₃O₂(s) (net ionic equation)

(c) 3 Ba(NO₃)₂(aq) + 2 (NH₄)₃PO₄(aq) → Ba₃(PO₄)₂(s) + 6 NH₄NO₃(aq)
3 Ba⁺ + 6 NO₃⁻ + 6 NH₄⁺ + 2 PO₄³⁻ → Ba₃(PO₄)₂(s) + 6 NH₄⁺ + 6 NO₃⁻ (total ionic equation)
3 Ba⁺ + 2 PO₄³⁻ → Ba₃(PO₄)₂(s) (net ionic equation)

(d) 2 NaOH(aq) + Ca(NO₃)₂(aq) → Ca(OH)₂(s) + 2 NaNO₃(aq)
2 Na⁺ + 2 OH⁻ + Ca²⁺ + 2 NO₃⁻ → Ca(OH)₂(s) + 2 Na⁺ + 2 NO₃⁻ (total ionic equation)
Ca²⁺ + 2 OH⁻ → Ca(OH)₂(s) (net ionic equation)

Making Connections
4. Pollutants in natural water can enter the water cycle through runoff from agricultural areas or landfills, or industrial tailings ponds. Some pollutants are toxic and/or noxious at extremely low concentrations, so they may be dangerous even if they have very low solubility.

1.16 ACTIVITY: ANALYZING A HOUSEHOLD CLEANING PRODUCT

(Page 63)

Materials
(a) Student answers will vary depending on the cleaning product chosen. Possible ions are ammonium ions and/or hydroxide ions. We will need a solution containing calcium ions.

Observations
Table 1 Precipitation Reactions

<table>
<thead>
<tr>
<th>Ionic solution</th>
<th>Reacting ions</th>
<th>Formation of precipitate? (P or NP)</th>
<th>Precipitate formed</th>
<th>Ion present</th>
</tr>
</thead>
<tbody>
<tr>
<td>OH⁻</td>
<td>Ca²⁺</td>
<td>P</td>
<td>calcium hydroxide, Ca(OH)₂</td>
<td>OH⁻</td>
</tr>
</tbody>
</table>

Student answers will vary depending on which cleaning product they are using.
Analysis
(b) Student answers will vary. In the example, hydroxide ions are present in the cleaning product.
(c) Qualitative analysis of consumer products is integral to maintaining product standards. If products are not subjected to quality control tests, manufacturers could produce defective or unsafe products that may harm consumers, who will then no longer buy the product. Manufacturers of all kinds of products (food, mechanical, technological, etc.) depend on quality control technicians to ensure that products meet proper standards.
(d) \( \text{Ca}^{2+} + 2 \text{OH}^- \rightarrow \text{Ca(OH)}_2 \)

Evaluation
(e) Student answers will vary. Calcium chloride was effective in causing hydroxide ions to precipitate.

1.17 ACTIVITY: DETERMINING THE PRESENCE OF IONS IN A SOLUTION

(Page 64)

Experimental Design
(a) Using the flow chart in Figure 1 of the Student Text, the presence of ferrocyanide, chloride, and sulfate ions will be tested, one at a time, using precipitation reactions. If a precipitate forms, it will be removed using a centrifuge. After removing the precipitate, the remaining supernate will be further tested for any remaining ion(s).

Procedure
(b) Student answers will vary. A sample procedure is provided below.
1. Obtain a sample solution from the teacher and place it in the test-tube rack.
2. Obtain three test tubes from the teacher, each containing one of the following solutions: silver nitrate, \( \text{AgCl} \)\(_{\text{aq}} \), barium nitrate, \( \text{Ba(NO}_3\text{)}_2 \)\(_{\text{aq}} \), and zinc nitrate, \( \text{Zn(NO}_3\text{)}_2 \). Place these test tubes in the test-tube rack.
3. Carefully pour the sample solution from the test tube into a centrifuge tube so that the centrifuge tube is full.
4. Using an eyedropper, add a few drops of zinc nitrate solution to the sample solution. Observe what happens. Record your observations. If a precipitate forms, continue adding zinc nitrate solution until no more precipitate forms, then go to step 5. If no precipitate forms, go to step 7.
5. Place the centrifuge tube containing the precipitate into the centrifuge. (Your teacher will give you specific instructions on how to use the centrifuge in your school). Spin for approximately 1 min.
6. Remove the centrifuge tube and slowly decant the supernate into a clean centrifuge tube. Place the centrifuge tube containing the precipitate into the test-tube rack.
7. Using a clean eyedropper, add a few drops of barium nitrate solution to the sample solution or supernate. Observe what happens. Record your observations. If a precipitate forms, continue adding barium nitrate solution until no more precipitate forms, then go to step 8. If no precipitate forms, go to step 10.
8. Place the centrifuge tube containing the precipitate into the centrifuge. Spin for approximately 1 min.
9. Remove the centrifuge tube and slowly decant the supernate into a clean centrifuge tube. Place the centrifuge tube containing the precipitate into the test-tube rack.
10. Using a clean eyedropper, add a few drops of silver nitrate solution to the sample solution or supernate. Observe what happens. Record your observations.
Synthesis
(j) Other tests that could be performed to increase confidence in results include flame emission spectroscopy and thermal emission spectroscopy.

UNIT 1 REVIEW
(Pages 71–73)

Understanding Concepts
1. (a) An observation is a statement based on what you see, hear, taste, touch, and smell. An inference is a judgment or opinion based on observations and conclusions from testing. An example of an observation is “The water is boiling.” An example of an inference is “Since the water is boiling, it must be hot.”
(b) Empirical knowledge comes directly from observations. Theoretical knowledge is based on ideas created to explain observations. An example of empirical knowledge is “Water boils at 100°C.” Theoretical knowledge that explains this observation is “When water boils, water molecules have gained enough kinetic energy to escape the liquid state and enter the gaseous state.”
(c) A theory is an explanation of a large number of related observations. A model is a representation of a theory that helps scientists visualize a theory as well as test it. An example of a theory is the kinetic molecular theory. An example of a model is Bohr’s model of the atom.

2. empirical knowledge
   comes directly from
   observation
   based on ideas
   created from
   theoretical knowledge
   leads to the
   development of
   inference
   is simplified and
   presented in the
   form of a
   theory
   can be visualized
   and tested using
   models

3. Table 1 History of Atomic Theory

<table>
<thead>
<tr>
<th>Scientist</th>
<th>Contribution to atomic theory</th>
</tr>
</thead>
<tbody>
<tr>
<td>John Dalton</td>
<td>Matter consists of particles called atoms that are unique to each element.</td>
</tr>
<tr>
<td>J.J. Thomson</td>
<td>The atom is like a raisin bun, with negatively charged electrons scattered within a positively charged sphere.</td>
</tr>
<tr>
<td>Ernest Rutherford</td>
<td>The atom contains a dense positive core (the nucleus) that consists of positively charged subatomic particles known as protons. Negatively charged electrons orbit the nucleus like planets around the Sun.</td>
</tr>
</tbody>
</table>
James Chadwick  
| The atom’s nucleus consists of protons as well as particles without electric charge, called neutrons. |

Niels Bohr  
| Electrons spin around the nucleus of an atom in fixed orbits or energy levels. The energy of electrons is quantized. |

4. (a) Blue light has a higher frequency. It has a shorter wavelength, therefore more cycles of light energy can pass through a given point in a specific time.
(b) Blue light has more energy. A higher frequency means more energy.
5. A rainbow is an example of a continuous spectrum because it is an uninterrupted pattern of colours.
6. (a) An electron jumps from the ground state to an excited state by absorbing a quantum of energy; that is, the electron must absorb energy equal to the difference in energy between its ground state and the excited state.
(b) The electron possesses more energy in the excited state.
(c) When an electron returns from the excited state to the ground state, it releases the same amount of energy as it absorbed to reach the excited state.
7. The energy of an electron is said to be quantized because an electron must possess a specific amount of energy in order to be in a given energy level. To jump to a higher energy level, it must absorb a specific amount of energy. To drop to a lower energy level, it must release a specific amount of energy.
8. Spectroscopy is the experimental observation of line spectra. Since every element has a characteristic line spectrum, spectroscopy can be used to observe the line spectrum of a gas, and identify the gas by comparing its spectrum to the spectra of identified gases.
9. When a substance is subjected to a flame test, the heat of the flame is a source of energy that can be absorbed by the electrons in the sample. The excess energy causes the electrons to become excited and jump to higher energy levels. When the electrons fall back to their ground state, they release their excess energy in the form of light. If the light released is in the visible spectrum, it will change the colour of the flame.
10. Solutions containing an ionic solute conduct electricity because ionic solutes consist of anions and cations. When an ionic compound is dissolved in water, anions are attracted to the positively charged electrode of a cell, and cations are attracted to the negatively charged electrode. The movement of ions causes current to flow in the circuit.
11. (a) \[^{+}\]Na\[^-\]
(b) \[^{+}\]Ca\[^{+}\]
(c) \(\text{O}\)
(d) \(\text{O}^-\)
(e) \(\text{O}^-\)
(f) \[^{-}\]Cl\[^-\]
12. The chloride ion is negatively charged because it has gained one electron. The sodium ion and the calcium ion are both positively charged. Sodium has lost one electron, while calcium has lost two electrons.
13. Sodium and fluorine in (a) and magnesium and chlorine in (c) form ionic compounds because both pairs of atoms consist of a metal and a nonmetal. The metal loses one or more electrons and becomes a cation, while the nonmetal gains one or more electrons and becomes an anion. The electrostatic force of attraction between cations and anions results in the formation of an ionic bond.
14. Covalent and ionic bonds are formed between atoms in order to satisfy the octet rule. Covalent bonds involve the sharing of electrons between nonmetals, whereas ionic bonds involve the transfer of electrons between metals and nonmetals (cations and anions).
15. (a) \(\text{H} \quad \text{N} \quad \text{H}\)
(b) \(\text{O} \quad \text{O}^+\)
(c) \(\text{O} \quad \text{O}^+\)
(d) \(\text{N} \quad \text{N}^-\)
16. Water is a polar molecule because it consists of two kinds of atoms, one of which—oxygen—has a higher electronegativity than the two hydrogen atoms. The two shared electron pairs between the two hydrogen atoms and the oxygen atom spend more time near the oxygen atom, giving it a slightly negative charge. The two hydrogen atoms therefore have a slight positive charge. Since the water molecule has a bent shape, the oxygen side of the molecule is slightly negatively charged and the hydrogen side is slightly positively charged, resulting in a polar molecule.

17. Carbon tetrachloride is a nonpolar molecule, even though it has four polar covalent bonds, because the four chlorine atoms are arranged symmetrically about the central carbon atom in a tetrahedral shape. As a result, no one end of the molecule is more polar than another end.

18. Nonpolar molecules composed of many atoms have higher melting points than nonpolar molecules composed of fewer atoms because the molecules with many atoms experience more London dispersion forces, and therefore require more energy to break these intermolecular bonds.

19. (a) synthesis
(b) single displacement
(c) decomposition
(d) synthesis
(e) double displacement

20. (a) could be considered a combustion reaction because oxygen is a reactant.

21. (a) sodium chloride + silver nitrate → silver chloride + sodium nitrate
silver chloride—low solubility
sodium nitrate—soluble
aqueous sodium chloride + aqueous silver nitrate → solid silver chloride + aqueous sodium nitrate
NaCl(aq) + AgNO₃(aq) → AgCl(s) + NaNO₃(aq)

(b) copper(II) chloride + sodium nitrate → sodium chloride + copper(II) nitrate
sodium chloride—soluble
 copper(II) nitrate—soluble
aqueous copper(II) chloride + aqueous sodium nitrate → no reaction

(c) sodium sulfide + lead(II) nitrate → lead(II) sulfide + sodium nitrate
lead(II) sulfide—low solubility
sodium nitrate—soluble
aqueous sodium sulfide + aqueous lead(II) nitrate → solid lead(II) sulfide + aqueous sodium nitrate
Na₂S(aq) + Pb(NO₃)₂(aq) → PbS(s) + 2 NaNO₃(aq)

(d) potassium hydroxide + ammonium chloride → potassium chloride + ammonium hydroxide
potassium hydroxide—soluble
ammonium hydroxide—soluble
aqueous potassium hydroxide + aqueous ammonium chloride → no reaction

22. (a) NaCl(aq) + AgNO₃(aq) → AgCl(s) + NaNO₃(aq)
Na⁺ + Cl⁻ + Ag⁺ + NO⁻³ → AgCl(s) + Na⁺ + NO⁻³ (total ionic equation)
Na⁺ + Cl⁻ + Ag⁺ + NO⁻³ → AgCl(s) + Na⁺ + NO⁻³
Ag⁺ + Cl⁻ → AgCl(s) (net ionic equation)
(c) Na₂S(aq) + Pb(NO₃)₂(aq) → PbS(s) + 2 NaNO₃(aq)
2 Na⁺ + S²⁻ + Pb²⁺ + 2 NO⁻³ → PbS(s) + 2 Na⁺ + 2 Na⁺ + 2 NO⁻³ (total ionic equation)
2 Na⁺ + S²⁻ + Pb²⁺ + 2 NO⁻³ → PbS(s) + 2 Na⁺ + 2 Na⁺ + 2 NO⁻³
Pb²⁺ + S²⁻ → PbS(s) (net ionic equation)

23. (a) Since different metallic compounds impart a different colour to a flame as a result of the excitation of the electrons in the metal ion within the compound, the presence of a metal ion can be detected using a flame test.
(b) Since each element has a characteristic line spectrum, spectroscopy can be used to identify a substance by comparing its line spectrum to the line spectra of identified substances.
(c) The presence of an ion in solution can be detected by adding a compound that causes the ion to precipitate from the solution.

**Applying Inquiry Skills**

24. Some experimental techniques that may be used to help classify and identify the substance are spectroscopy, precipitation reactions, and flame tests.

25. Student answers will vary. Refer to the solutions for Investigation 1.16 for details.
26. (a) Solid A is an ionic solid because it has a high melting point and boiling point. It also conducts electricity in aqueous solution. Substance B is a molecular solid because it has a low melting point and boiling point and does not conduct electricity when in aqueous solution.

(b) Other tests that may be performed include solubility in polar and nonpolar solvents as well as testing for hardness and odour.

27. **Analysis**

(a) Substance 1 is an ionic compound: NaCl$_{(aq)}$
Substance 2 is an acid: HCl$_{(aq)}$
Substance 3 is soluble but not ionic: C$_2$H$_5$OH$_{(aq)}$
Substance 4 is a base: Ba(OH)$_2$(aq)

**Synthesis**

(b) The water is used as a control. The results of the conductivity and litmus tests are the dependent variable. The different substances that are dissolved in water are the independent variables. Since water is used to prepare the solutions for each of the different substances, any change in the dependent variable from the control results can be attributed to the changing independent variable.

(c) Solutions 1, 2, and 4 all have high conductivities, and could have been involved in somebody getting electrocuted. The most likely solution is NaCl$_{(aq)}$. When NaCl$_{(aq)}$, HCl$_{(aq)}$, and Ba(OH)$_2$(aq) are dissolved in water, the positive and negative ions dissociate. The ions can then carry an electric current. The electronegativity difference between the constituent atoms of C$_2$H$_5$OH$_{(aq)}$ results in polar covalent bonds—C$_2$H$_5$OH is a polar molecule. It does not dissociate into positive and negative ions, so the solution does not conduct electricity and could not have been involved in an electrocution.

\[
\begin{align*}
\text{[Na]}^+ & \quad \text{[Cl]}^- \\
\text{[H]}^+ & \quad \text{[Cl]}^- \\
\text{[Ba]}^{2+} & \quad 2\text{[OH]}^- \\
\text{H} & \quad \text{H} \\
\text{H} & \quad \text{C} \quad \text{C} \quad \text{OH} \\
\text{H} & \quad \text{H}
\end{align*}
\]

**Making Connections**

28. (a) Fe$_{3+}$(aq) + 3 OH$^-$$_{(aq)}$ $\rightarrow$ Fe(OH)$_3$(s)

(b) Centrifugation to remove the precipitate is the most likely method.

29. It is safe for patients to drink a wet sample of barium sulfate because it has very low solubility. Barium sulfate does not dissociate into ions in the patient’s gastrointestinal tract; therefore, the toxic barium ions are not absorbed by the body.

30. In a court of law, the prosecution or defence must prove, without a reasonable doubt, that the accused is guilty or innocent. Every technique can only test one characteristic of a substance at a time. If evidence that has undergone only one qualitative analysis test is introduced, it may be questioned based on the limits of the technique used, and deemed insufficient. Also, other substances could produce the same result.

31. American currency has many security features that deter counterfeiting. The denomination of the bill is printed in ink that changes colour depending on which way you tilt it. Each banknote has a serial number that starts with a letter. Right below that letter is the corresponding number of that letter in the alphabet. For example, if the serial number starts with a letter B, the number 2 appears right below since the letter B is the second letter of the alphabet. The paper on which American currency is printed is made of a blend of cotton and linen that also has a watermark specific to the denomination of the currency. American currency uses Intaglio printing (raised parts of the currency), has fibres embedded within it that fluoresce, and a vertical insert (slim bar) that has the denomination of the note. You can check some of these features simply by studying and touching the note. You may also use a UV light source, which causes the fibres of genuine notes to fluoresce. Counterfeit notes either fluoresce completely or not at
all. Iodine pens may also be used to check for counterfeit notes. Iodine turns brown in the presence of starch. Since banknote paper is made of cotton and linen fibres, an iodine pen should have no effect on the currency. If a brown colour appears on the bill, the iodine has reacted with starch and the bill is counterfeit. Canadian currency does not have watermarks, nor does it use paper made of cotton and linen. There are no inserts in Canadian currency. Canadian and American banknotes both have microprinting, Intaglio printing, embedded fluorescent fibres, and serial numbers.

32. In order to become an MRI technologist in Canada, you must first have a diploma in radiography, nuclear medicine, or radiation therapy from an accredited technical institution or community college. Two places where you can then obtain your MRI technologist training are the Michener Institute for Health Sciences in Toronto or Red River Community College in Winnipeg. The Michener Institute Program is 15 months long, whereas the Red River Community College Program is 6 months long. Courses offered in these programs include a physics and chemistry review, biochemistry and physiology review, pathology, advanced patient care, computer skills, professional communications, and MRI.

Extension

33. Hard water contains 400–600 mg/L of calcium ions and magnesium ions. Soft water has an ion concentration of less than 50 mg/L. Hard water does not remove soil completely, causing white fabrics to become grayed and dingy. As soil deposits accumulate, fabrics feel harsh and stiff. Zeolites are porous, symmetrical molecular sieves that trap calcium and magnesium ions, thereby reducing the hardness of water and enabling laundry detergents to work better.