TOPIC 2:
ATOMIC STRUCTURE

Topic 2: Atomic Structure

C12-2-01 Describe qualitatively the electromagnetic spectrum in terms of frequency, wavelength, and energy.

C12-2-02 Recognize, through direct observation, that elements have unique line spectra.

Include: flame tests or gas discharge tubes and spectroscopes or diffraction gratings

C12-2-03 Describe applications and/or natural occurrences of line spectra.

Examples: astronomy, aurora borealis, fireworks, neon lights . . .

C12-2-04 Outline the historical development of the quantum mechanical model of the atom.

C12-2-05 Write electron configurations for elements of the periodic table.

Include: selected elements up to atomic number 36 (krypton)

C12-2-06 Relate the electron configuration of an element to its valence electron(s) and its position on the periodic table.

C12-2-07 Identify and account for periodic trends among the properties of elements, and relate the properties to electron configuration.

Include: atomic radii, ionic radii, ionization energy, and electronegativity

Suggested Time: 10 hours

Topic 2: Atomic Structure

SPECIFIC LEARNING OUTCOMES

C12-2-01: Describe qualitatively the electromagnetic spectrum in terms of frequency, wavelength, and energy.

C12-2-02: Recognize, through direct observation, that elements have unique line spectra.
Include: flame tests or gas discharge tubes and spectroscopes or diffraction gratings

C12-2-03: Describe applications and/or natural occurrences of line spectra.
Examples: astronomy, aurora borealis, fireworks, neon lights . . .

(3 hours)

SLO: C12-2-01
SLO: C12-2-02
SLO: C12-2-03

SUGGESTIONS FOR INSTRUCTION

Entry-Level Knowledge

In Grade 8 Science (8-2-07), students compared and contrasted various types of electromagnetic radiation with respect to energy, wavelength, frequency, and human perception. Students who have studied Grade 11 Physics (Topic 1: Waves) will be familiar with the terms *wavelength* and *frequency*.

General Learning Outcome Connections

GLO A1: Recognize both the power and limitations of science as a way of answering questions about the world and explaining natural phenomena.

GLO A3: Distinguish critically between science and technology in terms of their respective contexts, goals, methods, products, and values.

GLO A5: Recognize that science and technology interact with and advance one another.

GLO B2: Recognize that scientific and technological endeavours have been and continue to be influenced by human needs and the societal context of the time.

GLO B3: Identify the factors that affect health, and explain the relationships among personal habits, lifestyle choices, and human health, both individual and social.

GLO B5: Identify and demonstrate actions that promote a sustainable environment, society, and economy, both locally and globally.

GLO C1: Recognize safety symbols and practices related to scientific and technological activities and to their daily lives, and apply this knowledge in appropriate situations.

GLO C2: Demonstrate appropriate scientific inquiry skills when seeking answers to questions.

GLO C4: Demonstrate appropriate critical thinking and decision-making skills when choosing a course of action based on scientific and technological information.

GLO C5: Demonstrate curiosity, skepticism, creativity, open-mindedness, accuracy, precision, honesty, and persistence, and appreciate their importance as scientific and technological habits of mind.

GLO C6: Employ effective communication skills and use information technology to gather and share scientific and technological ideas and data.

GLO D3: Understand the properties and structures of matter, as well as various common manifestations and applications of the actions and interactions of matter.

GLO D6: Understand the composition of the universe, the interactions within it, and the implications of humankind's continued attempts to understand and explore it.

SKILLS AND ATTITUDES OUTCOMES

C12-0-S1: Demonstrate work habits that ensure personal safety and the safety of others, as well as consideration for the environment.

Include: knowledge and use of relevant safety precautions, Workplace Hazardous Materials Information System (WHMIS), and emergency equipment

C12-0-S4: Select and use scientific equipment appropriately and safely.

Examples: volumetric glassware, balance, thermometer . . .

C12-0-R1: Synthesize information obtained from a variety of sources.

Include: print and electronic sources, specialists, and other resource people

C12-0-T1: Describe examples of the relationship between chemical principles and applications of chemistry.

Assessing Prior Knowledge

Students' prior knowledge can be reviewed and/or assessed by using any of the KWL forms (e.g., Concept Map, Knowledge Chart, Think-Pair-Share—see *SYSTH*, Chapter 9).

TEACHER NOTES

The Electromagnetic Spectrum (C12-2-01)

One purpose of studying atomic structure is to understand the electron's role in the atom. Scientists at the turn of the twentieth century had just discovered this subatomic particle, but they did not fully understand the magnitudes of types of energy associated with an electron. By furthering their studies in this area, scientists hoped they could better explain the behaviour of substances in chemical reactions.

In Topic 2: Atomic Structure, the electromagnetic spectrum will be linked to atomic structure. The electromagnetic spectrum consists of electromagnetic radiation, which is the release and transmission of energy in the form of electromagnetic waves. These waves consist of an electric field and a magnetic field that are perpendicular to each other. The different components (gamma rays, X-rays, microwaves, visible light, and others) of the electromagnetic spectrum vary due to differences in wavelength and frequency, but they all travel at the same speed, 3×10^8 m/s. Energy is transferred by means of waves—more specifically with respect to atomic structure, electromagnetic waves.

Students should understand the relationship between wavelength (λ) and frequency (f) as an inverse one ($\lambda = 1/f$). However, they are not required to treat the relationship mathematically. It is more important for students to understand conceptually that over a given span of distance, if the wavelength of a disturbance is shortened (made smaller), then a greater number of waves would be able to fit into that distance (increase in frequency).

Topic 2: Atomic Structure

SPECIFIC LEARNING OUTCOMES

C12-2-01: Describe qualitatively the electromagnetic spectrum in terms of frequency, wavelength, and energy.

C12-2-02: Recognize, through direct observation, that elements have unique line spectra.

Include: flame tests or gas discharge tubes and spectroscopes or diffraction gratings

C12-2-03: Describe applications and/or natural occurrences of line spectra.

Examples: astronomy, aurora borealis, fireworks, neon lights . . .

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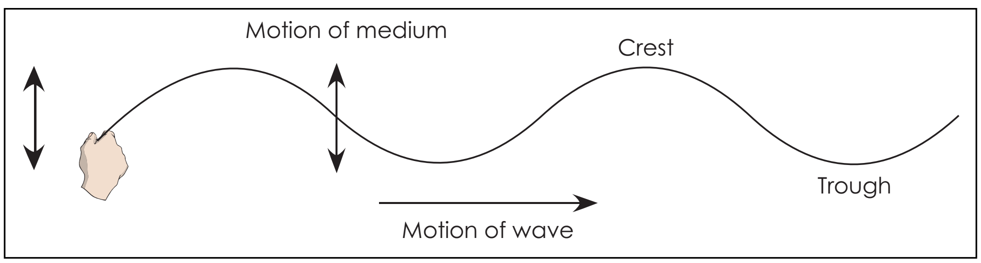
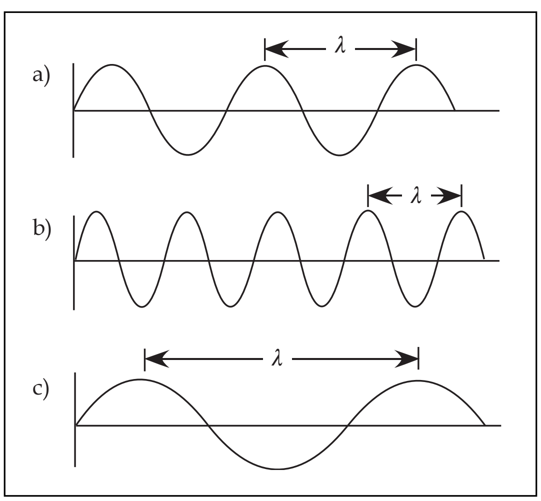
A coiled spring toy, for example, can be used to show the relationship between frequency and wavelength (see the following diagrams). Holding one end of the toy, move your hand back and forth slowly. This illustrates a large wavelength (the distance from one crest to the next successive crest) and a low frequency. Increasing the frequency of the back-and-forth movement of your hand will result in a smaller wavelength. In both cases, the speed of the wave is the same.



The following diagram shows clearly the relationship between wavelength (λ) and the number of cycles in a given space (*frequency* of the wave).



SKILLS AND ATTITUDES OUTCOMES

C12-0-S1: Demonstrate work habits that ensure personal safety and the safety of others, as well as consideration for the environment.

Include: knowledge and use of relevant safety precautions, Workplace Hazardous Materials Information System (WHMIS), and emergency equipment

C12-0-S4: Select and use scientific equipment appropriately and safely.

Examples: volumetric glassware, balance, thermometer . . .

C12-0-R1: Synthesize information obtained from a variety of sources.

Include: print and electronic sources, specialists, and other resource people

C12-0-T1: Describe examples of the relationship between chemical principles and applications of chemistry.

The *energy* of the various parts of the electromagnetic (em) spectrum is directly related to the *frequency* of the wave. If a wave has a high frequency, then it will contain a higher amount of energy. For example, gamma rays are high-energy waves due to their very high frequency (10^{20} Hz). Radio waves are low-energy waves, as their frequency is approximately 10^{6} Hz.

Visible light, with its colours ranging from red to violet, is the portion of the electromagnetic spectrum that is detected by the human eye. A common mnemonic used to remember the colour spectrum is ROYGBIV. Ask students whether they can recall this mnemonic from previous study (ROYGBIV: red, orange, yellow, green, blue, indigo, violet). Within this range of colours, red light has the largest wavelength (small frequency). At the other end of the spectrum, violet light has the smallest wavelength (large frequency).

When an iron nail is heated in a Bunsen burner flame, it will glow bright red. The human eye is sensitive to the frequency and wavelength of the electromagnetic radiation within this range, and it is seen as red. If you place your hand near the iron nail, your hand will detect the warmth of the nail, which is represented by the infrared region of the electromagnetic spectrum.

Demonstrations

Several quick demonstrations can be performed to show the visible spectrum.

1. Hold up a glass prism to an overhead light and have students observe the white light that passes through the prism break apart into a range of colours, known as a spectrum. This can be projected on the classroom wall, ceiling, or overhead screen.
2. Have students look at light being diffracted by a CD. This also shows a spectrum of colours.

Topic 2: Atomic Structure

SPECIFIC LEARNING OUTCOMES

C12-2-01: Describe qualitatively the electromagnetic spectrum in terms of frequency, wavelength, and energy.

C12-2-02: Recognize, through direct observation, that elements have unique line spectra.

Include: flame tests or gas discharge tubes and spectroscopes or diffraction gratings

C12-2-03: Describe applications and/or natural occurrences of line spectra.

Examples: astronomy, aurora borealis, fireworks, neon lights . . .

(continued)

TEACHER NOTES

Line Spectra (C12-2-02)

Emission spectra can exist as continuous spectra or line spectra.

- A *continuous spectrum* shows all the wavelengths of light in an uninterrupted pattern, as demonstrated with the glass prism on the overhead. A common occurrence with which students should be familiar is the rainbow, an uninterrupted sequence of colours ranging from red to violet.
- A *line spectrum* consists of distinct bright lines appearing on a dark background that occur in different parts of the visible spectrum. This distinguishing feature of gaseous atoms provides scientists with a unique "fingerprint" for each element. Each element has its own unique line spectrum, as each element contains differing amounts of electrons or different energy levels. These bright lines indicate that only certain energies are possible within the atom. The brightness of spectral lines depends on how many photons of the same wavelength are emitted.

Demonstrations

Perform the following demonstrations:

1. In a darkened room, hold a Tesla coil near a graphite (carbon) rod secured by a clamp to a ringstand. The spark that results shows a lightning bolt, which is composed of the nitrogen spectrum. This can be related to natural occurrences of light spectra, such as a rainbow or the northern lights (*aurora borealis*). (The physics teacher in your school may have a Tesla coil.)
2. Apply an electric current through a dill pickle and cause it to glow. The excited sodium atoms emit a yellow light (589 nanometre) when they drop back down to the ground state. This demonstration can be found in the *Journal of Chemical Education* (see Learning Resources Links). Instructions for this demonstration are also found online.

   Sample Website:

   Lori's Chemistry Page. *Complete with the Glowing Pickle.* <http://myglowingpickle.com/> (30 Jan. 2012).

SKILLS AND ATTITUDES OUTCOMES

C12-0-S1: Demonstrate work habits that ensure personal safety and the safety of others, as well as consideration for the environment.

Include: knowledge and use of relevant safety precautions, Workplace Hazardous Materials Information System (WHMIS), and emergency equipment

C12-0-S4: Select and use scientific equipment appropriately and safely.

Examples: volumetric glassware, balance, thermometer . . .

C12-0-R1: Synthesize information obtained from a variety of sources.

Include: print and electronic sources, specialists, and other resource people

C12-0-T1: Describe examples of the relationship between chemical principles and applications of chemistry.

Laboratory Activities

The purpose of the suggested lab activities is to have students observe continuous spectra and line spectra. An analogy can be made to differentiate between these two types of spectra. A wheelchair ramp is similar to a continuous spectrum, whereas a staircase is similar to a line spectrum. Students should recognize that each element has its own unique line spectrum. For these lab activities, students can use commercially made spectroscopes or they can make their own.

1. Have students use prisms or spectroscopes to observe white light from an incandescent light bulb. Students will see a continuous spectrum of colours ranging from red to violet.

   Caution:
   Do not permit students to view sunlight directly.

   Have students view a fluorescent light bulb through the spectroscopes. They will observe line spectra superimposed on the visible light spectra (continuous spectra). This happens because some of the mercury atoms emit ultraviolet (UV) light, which is not visible to the human eye. This UV light is absorbed by the phosphor coating of the fluorescent tube. When these phosphor electrons return to the ground state, they give off a white light that has more blue and less red than sunlight (see Wilbraham, et al., *Prentice Hall Chemistry* 137). Different types of fluorescent tubes give off their own unique spectrum. An Internet search can direct you to the spectra of these tubes.

   Students can make their own mini spectroscopes. Instructions can be found online.

   Sample Website:

   Schwabacher, Alan. "Mini Spectroscopes." *The Science of Stuff.* Rev. 8 Jan. 2002. University of Wisconsin, Department of Chemistry. <https://pantherfile.uwm.edu/awschwab/www/specweb.htm> (13 Jan. 2012).

2. Have students observe examples of emission line spectra using either gas discharge tubes (if available) or colour flames. See Appendix 2.1: Spectral Lines as a reference for the wavelength and colour of specific elements.

Topic 2: Atomic Structure

SPECIFIC LEARNING OUTCOMES

C12-2-01: Describe qualitatively the electromagnetic spectrum in terms of frequency, wavelength, and energy.

C12-2-02: Recognize, through direct observation, that elements have unique line spectra.

Include: flame tests or gas discharge tubes and spectroscopes or diffraction gratings

C12-2-03: Describe applications and/or natural occurrences of line spectra.

Examples: astronomy, aurora borealis, fireworks, neon lights . . .

(continued)

- **Gas Discharge Tubes**

  As students view the gas discharge tubes, have them draw the actual line spectra, indicate the colours, and note the approximate location of the spectral lines. See Appendix 2.2: Gas Discharge Tubes (BLM). Students should then compare their observed line spectra to the known line spectra in order to identify the element present in the gas mixture. For example, students should observe four spectral lines for hydrogen: violet, blue-violet, blue-green, and red. Point out to students that these visible spectral lines represent electron transitions from energy levels 3, 4, 5, and 6 to energy level 2. (Energy levels are addressed in greater detail in subsequent learning outcomes.)

Caution:
Teachers should handle the power supplies and the gas spectrum tubes. Students must exercise caution when viewing the spectrum tubes. These tubes get hot very quickly and can cause burns.

- **Metallic Salts**

  Students can view wooden splints that have been soaked for a few days in different solutions of metallic salts, such as 1/mol saturated solutions of barium, calcium, copper(II), potassium, and sodium. Students should be able to observe the specific colour of the metal for a brief moment.

Demonstration

Perform the following demonstration.

- **Flaming Salts**

  For this demonstration, ignite a series of salt solutions mixed in methanol and have students observe the colours given off. Refer to Appendix 2.3: Flaming Salts (Demonstration).

SKILLS AND ATTITUDES OUTCOMES

C12-0-S1: Demonstrate work habits that ensure personal safety and the safety of others, as well as consideration for the environment.

Include: knowledge and use of relevant safety precautions, Workplace Hazardous Materials Information System (WHMIS), and emergency equipment

C12-0-S4: Select and use scientific equipment appropriately and safely.

Examples: volumetric glassware, balance, thermometer . . .

C12-0-R1: Synthesize information obtained from a variety of sources.

Include: print and electronic sources, specialists, and other resource people

C12-0-T1: Describe examples of the relationship between chemical principles and applications of chemistry.

TEACHER NOTES

Applications and Natural Occurrences of Line Spectra (C12-2-03)

As students have now seen and drawn line spectra, they should be ready to discuss the applications and/or natural occurrences of line spectra. Students will be familiar with fireworks and neon lights. However, most students may not know, for example, that neon gas generates an orange-red light.

Spectral lines are produced by an atom in the excited state. First, the atom must absorb energy. Electrons are then raised to a higher energy level by absorbing energy. When the electron falls back down to a lower energy level, it simultaneously gives off a colour of light, which could also be referred to as a single wavelength, or a single frequency, or a single packet of energy being emitted. This corresponds to the distance that the electron travelled. Since many electron transitions are possible between energy levels, many spectral lines are produced by an atom in the excited state.

For the hydrogen atom, when the electron falls from energy level 3 down to energy level 2, a red colour is emitted. This should make sense, as the electron is falling the shortest distance, which corresponds to the lowest frequency of visible light, which is red. If an electron falls from energy level 4 to energy level 2, a green colour is emitted. If it falls from energy level 5 to energy level 2, an indigo colour is emitted. And, if it falls from energy level 6 to energy level 2, a violet colour is emitted.

Many chemistry texts give examples of line spectra for at least some elements. Viewing such examples will help students appreciate that each element has its own unique line spectrum. The line spectra could then be used to analyze a light source for its constituent elements. A typical application occurs in astronomy when an astronomer passes the light from a distant light source through a spectroscope to determine what elements were contained in the light. Light sources could be stars, nebula, supernova explosions in external galaxies, and so on. It is also possible for astronomers to detect forms of radiation other than visible light. For example, X-rays and gamma rays are emitted from very dense neutron stars, or emanate from black holes. It is also historically important that the element helium was first identified in the spectrum of the Sun before it was detected in Earth's atmosphere (and hence, named from the Greek *helios*, a reference to the Greek sun god). The historical link between physics and chemistry could be explored.

Topic 2: Atomic Structure

SPECIFIC LEARNING OUTCOMES

C12-2-01: Describe qualitatively the electromagnetic spectrum in terms of frequency, wavelength, and energy.

C12-2-02: Recognize, through direct observation, that elements have unique line spectra.

Include: flame tests or gas discharge tubes and spectroscopes or diffraction gratings

C12-2-03: Describe applications and/or natural occurrences of line spectra.

Examples: astronomy, aurora borealis, fireworks, neon lights . . .

(continued)

Students may have used an open flame to observe line spectra. A familiar application of the spectra produced by elements is the manufacture of fireworks. The following is a selection of the colours of elements as they are ignited:

Barium: yellow-green

Strontium: bright red

Calcium: orange-red

Sodium: bright yellow

Potassium: light purple

Lithium: purple-red

Copper: green

The Internet contains a wealth of information on the chemistry and manufacture of fireworks (for sample websites, see Learning Resources Links).

Research

Students could research and write a report on an application or a natural occurrence of line spectra (e.g., astronomy, aurora borealis, fireworks, neon lights).

1. If sufficient time is available, students could research both fireworks and the use of line spectra for analysis. If gas discharge tubes were demonstrated in addressing the previous learning outcome, students will know that neon gas produces only the orange-red light, and other colours of discharge tubes are produced by other gases (e.g., argon produces green, helium produces pink-orange, krypton produces lavender, xenon produces blue).
2. Students could research "how astrophysicists can determine what elements make up Earth's Sun and other stars. In general, because a star is made up of hot, glowing gases, its emitted light can be gathered by a telescope and analyzed. From the atomic emission and absorption spectra of the light, the elements present in the star can be determined" (Dingrando, et al., *Glencoe Chemistry: Matter and Change, Teacher Wraparound Edition* 124).

SKILLS AND ATTITUDES OUTCOMES

C12-0-S1: Demonstrate work habits that ensure personal safety and the safety of others, as well as consideration for the environment.

Include: knowledge and use of relevant safety precautions, Workplace Hazardous Materials Information System (WHMIS), and emergency equipment

C12-0-S4: Select and use scientific equipment appropriately and safely.

Examples: volumetric glassware, balance, thermometer . . .

C12-0-R1: Synthesize information obtained from a variety of sources.

Include: print and electronic sources, specialists, and other resource people

C12-0-T1: Describe examples of the relationship between chemical principles and applications of chemistry.

SUGGESTIONS FOR ASSESSMENT

Paper-and-Pencil Tasks

1. Students should be able to do the following:
   - Draw a series of diagrams showing the relationship between the frequency and wavelength of an electromagnetic wave.
   - Relate the frequency of electromagnetic radiation with the amount of energy these waves contain.
   - Explain what happens to energy when frequency is doubled.
   - Explain what happens to energy when frequency is halved.
2. Following the lab activities suggested for learning outcome C12-2-02, have students compare the light spectrum observed in fluorescent light with that observed in incandescent light (see Appendix 2.4: Observing Continuous Spectra and Line Spectra).

Laboratory Skills

Students should be able to handle and use diffraction gratings, prisms, and spectroscopes safely.

Research Report

Students can prepare and present their research findings on one of the applications and/or natural occurrences of line spectra. Written reports, oral presentations, posters, models, multimedia presentations, or displays can be used. A rubric for Assessment of Research Project is provided in Appendix 11.

Topic 2: Atomic Structure

SPECIFIC LEARNING OUTCOMES

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C12-2-02: Recognize, through direct observation, that elements have unique line spectra.

Include: flame tests or gas discharge tubes and spectroscopes or diffraction gratings

C12-2-03: Describe applications and/or natural occurrences of line spectra.

Examples: astronomy, aurora borealis, fireworks, neon lights . . .

(continued)

LEARNING RESOURCES LINKS

Chemistry (Chang 260, 262, 268)

Chemistry (Zumdahl and Zumdahl 292, 304)

Chemistry: The Molecular Nature of Matter and Change (Silberberg 258, 264, 269)

Glencoe Chemistry: Concepts and Applications (Phillips, Strozak, and Wistrom 70, 73, 76)

Glencoe Chemistry: Matter and Change (Dingrando, et al. 118, 120, 128, 131, 138)

Glencoe Chemistry: Matter and Change, Teacher Wraparound Edition (Dingrando, et al. 124)

Nelson Chemistry 11, Ontario Edition (Jenkins, et al. 39, 635, 637)

Nelson Chemistry 12, Ontario Edition (van Kessel, et al. 39)

Nelson Chemistry 12: College Preparation, Ontario Edition (Davies, et al. 16)

McGraw-Hill Ryerson Inquiry into Chemistry (Chastko, et al. 169)

Prentice Hall Chemistry (Wilbraham, et al. 126, 137, 138, 141, 142)

Line Spectra

Chemistry (Chang 268)

Chemistry: The Molecular Nature of Matter and Change (Silberberg 264)

Glencoe Chemistry: Concepts and Applications (Phillips, Strozak, and Wistrom 235)

Nelson Chemistry 11, Ontario Edition (Jenkins, et al. 637)

Nelson Chemistry 12: College Preparation, Ontario Edition (Davies, et al. 17, 489)

SKILLS AND ATTITUDES OUTCOMES

C12-0-S1: Demonstrate work habits that ensure personal safety and the safety of others, as well as consideration for the environment.

Include: knowledge and use of relevant safety precautions, Workplace Hazardous Materials Information System (WHMIS), and emergency equipment

C12-0-S4: Select and use scientific equipment appropriately and safely.

Examples: volumetric glassware, balance, thermometer . . .

C12-0-R1: Synthesize information obtained from a variety of sources.

Include: print and electronic sources, specialists, and other resource people

C12-0-T1: Describe examples of the relationship between chemical principles and applications of chemistry.

Investigations

Glencoe Chemistry: Concepts and Applications (Phillips, Strozak, and Wistrom)
MiniLab 2.2: Line Emission Spectra of Elements, 77

Glencoe Chemistry: Matter and Change (Dingrando, et al.)
ChemLab 5: Line Spectra, 142

Nelson Chemistry 11, Ontario Edition (Jenkins, et al.)
Investigation 1.4.1: Atomic Spectra, 40
Activity 1.4.1: Creating a Flame Test Key, 42

Nelson Chemistry 12, Ontario Edition (van Kessel et al.)
Activity 3.4.1: Line Spectra, 212

Nelson Chemistry 12: College Preparation, Ontario Edition (Davies, et al.)
Identifying Gases Using Line Spectra, 19
Flame Tests, 23

Prentice Hall Chemistry (Wilbraham, et al.)
Small-Scale LAB: Atomic Emission Spectra, 137
Quick LAB: Flame Tests, 142

Demonstration

Gilbert, George L. "Tested Demonstrations: Sodium D Line Emission from Pickle." *Journal of Chemical Education* 70.3 (Mar. 1993): 250–251.

Websites

Edward M. Gouge. "A Flame Test Demonstration Device." *Journal of Chemical Education* 65.6 (June 1988): 544. Available online at <http://pubs.acs.org/doi/abs/10.1021/ed065p544> (13 Jan. 2012).

Glencoe Online. "An Internet WebQuest: The History of Fireworks." *WebQuest Science*. <www.glencoe.com/sec/science/webquest/content/fireworks.shtml> (1 Feb. 2012).

This website presents the history and components of fireworks.

HowStuffWorksVideos. *Fireworks Videos*. 1998–2012. <http://videos.howstuffworks.com/science/fireworks-videos-playlist.htm#video-8329> (13 Jan. 2012).

This website offers a series of videos showing how fireworks work.

Topic 2: Atomic Structure

SPECIFIC LEARNING OUTCOMES

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Examples: astronomy, aurora borealis, fireworks, neon lights . . .

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Lori's Chemistry Page. *Complete with the Glowing Pickle.* <http://myglowingpickle.com/> (30 Jan. 2012).

Pyro Universe. Home Page. <www.pyrouniverse.com> (31 Jan. 2012).

This website presents a history of fireworks and a glossary of pyrotechnic terms.

Schwabacher, Alan. "Mini Spectroscopes." *The Science of Stuff.* Rev. 8 Jan. 2002. University of Wisconsin. Department of Chemistry. <https://pantherfile.uwm.edu/awschwab/www/specweb.htm> (13 Jan. 2012).

University of Colorado at Boulder. "Spectral Line." *Physics 2000: Science Trek.* <www.colorado.edu/physics/2000/quantumzone/index.html> (1 Feb. 2012).

This website shows a continuous spectrum for light and line spectra for various elements.

Appendices

Appendix 2.1: Spectral Lines

Appendix 2.2: Gas Discharge Tubes (BLM)

Appendix 2.3: Flaming Salts (Demonstration)

Appendix 2.4: Observing Continuous Spectra and Line Spectra

Selecting Learning Resources

For additional information on selecting learning resources for Grade 11 and Grade 12 Chemistry, see the Manitoba Education website at <www.edu.gov.mb.ca/k12/learnres/bibliographies.html>.

SKILLS AND ATTITUDES OUTCOMES

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Examples: volumetric glassware, balance, thermometer . . .

C12-0-R1: Synthesize information obtained from a variety of sources.

Include: print and electronic sources, specialists, and other resource people

C12-0-T1: Describe examples of the relationship between chemical principles and applications of chemistry.

NOTES

Topic 2: Atomic Structure

SPECIFIC LEARNING OUTCOME

C12-2-04: Outline the historical development of the quantum mechanical model of the atom.

(1.5 hours)

SLO: C12-2-04

SUGGESTIONS FOR INSTRUCTION

Entry-Level Knowledge

In Grade 9 Science (S2-2-02), students investigated the historical progression of ideas with respect to the atomic model. Students were also required to draw simplified Bohr models up to atomic number 18 (argon) (S1-2-05).

TEACHER NOTES

Historical Development of Quantum Mechanical Model

The historical development of the quantum mechanical model of the atom is a complex, theoretical topic. Most chemistry texts provide information on this topic, but the extent and complexity of the treatment varies. The presentation to students should be as logical and as simple as possible. The following suggested sequence of events omits Einstein's contribution, as the photoelectric effect is not relevant to the historical progression.

In 1913, Danish physicist Niels Bohr (1885–1962) proposed a *model for the hydrogen atom*, which states that when radiation is absorbed by an atom, an electron jumps from the ground state to a higher unstable energy level (excited state). This electron eventually loses energy and changes to a lower energy level by emitting energy in the form of light. Using arguments based on electrostatic interactions and Newtonian physics, Bohr showed that the energies of the electron in the hydrogen atom could be calculated by a simple relationship involving the Rydberg constant and a whole number that later became known as the *principal quantum number* (n).

Johannes Robert Rydberg (1854–1919), a Swedish physicist who did his most important work on spectroscopy, found a simple relationship relating the various lines in the spectra of the elements. His expression included a constant that later became known as the *Rydberg constant*. The values that Bohr calculated compared

General Learning Outcome Connections

GLO A1: Recognize both the power and limitations of science as a way of answering questions about the world and explaining natural phenomena.

GLO A2: Recognize that scientific knowledge is based on evidence, models, and explanations, and evolves as new evidence appears and new conceptualizations develop.

GLO A4: Identify and appreciate contributions made by women and men from many societies and cultural backgrounds that have increased our understanding of the world and brought about technological innovations.

GLO D3: Understand the properties and structures of matter, as well as various common manifestations and applications of the actions and interactions of matter.

SKILLS AND ATTITUDES OUTCOMES

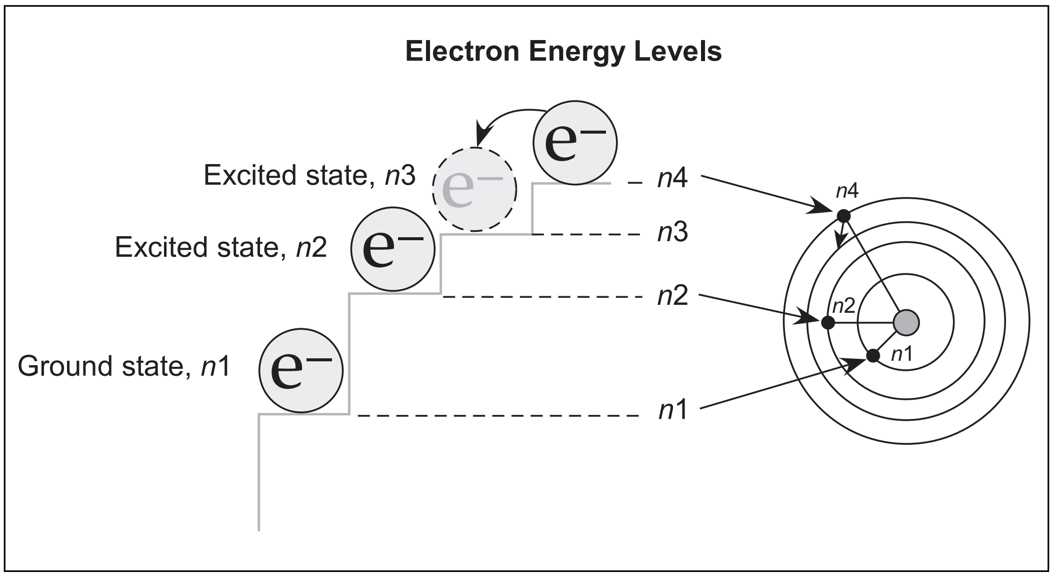
C12-0-N1: Explain the roles of theory, evidence, and models in the development of scientific knowledge.

C12-0-N2: Describe, from a historical perspective, how the observations and experimental work of many individuals led to modern understandings of matter.

C12-0-N3: Describe how scientific knowledge changes as new evidence emerges and/or new ideas and interpretations are advanced.

favourably with the experimental values that had been observed earlier. This provided strong evidence for the veracity of his model.

The following illustration shows the increase in potential energy as an electron moves from the ground state to different excited states. The diagram illustrates the energy levels.



Physicists were both mystified and intrigued by Bohr's model of the atom. They questioned why the energies of electrons allowed only certain energies (later called *quantization*). Apparently, even Bohr was not able to provide a logical explanation.

In 1924, French physicist Louis de Broglie (1892–1987) proposed a solution. He reasoned that if light waves can behave like a stream of particles, then perhaps particles such as electrons could similarly behave like waves. In his discussions, he related the circumference of an atomic orbit to the wavelength of an electron travelling around the nucleus. Shortly after de Broglie introduced this relationship, American physicists Clinton Joseph Davisson (1881–1958) and Lester Halbert Germer (1896–1972) and English physicist George Paget Thomson (1892–1975) actually demonstrated that electrons do possess wavelike properties.

Topic 2: Atomic Structure

SPECIFIC LEARNING OUTCOME

C12-2-04: Outline the historical development of the quantum mechanical model of the atom.

(continued)

New questions then arose over the position of the electron. If an electron can act as a wave, how can its precise location be defined within the atom? This led German physicist Werner Heisenberg (1901–1976) to develop the *Heisenberg uncertainty principle*, which states that it is impossible to know with certainty both the momentum (or velocity) and the position of a particle at the same time.

Bohr made a significant contribution to our understanding of atoms, but his theory did not provide a complete description of electronic behaviour within the atom. In 1926, Austrian physicist Erwin Schrödinger (1887–1961), using complex differential calculus, developed an equation that describes the energies and behaviour of submicroscopic particles. The importance of this equation is analogous to the contributions of Isaac Newton in terms of our understanding of the position and motion of particles. While Newton's discussion focused on large, macroscopic bodies, Schrödinger provided a novel, probabilistic view of the microscopic world. For instance, Schrödinger's equation represents the statistical probability of finding an electron in a particular volume of space in the atom. The work of Schrödinger contributed to beginning a new era in physics and chemistry that culminated in the articulation of a new mechanics—namely, *quantum mechanics*.

Animation: Electron Orbits

Have students view an animation that shows the absorption and emission of photons by a hydrogen atom. Students will observe how an electron absorbs energy and travels to a higher orbital around the nucleus. Then the electron in this excited state emits a photon and drops back down to a lower energy level. Students should note that the electron is not very stable in the excited state and it prefers to drop back down to a lower energy orbital.

Sample Websites:

University of Colorado at Boulder. "Atomic Spectra." *Physics 2000: Science Trek*. <www.colorado.edu/physics/2000/quantumzone/lines2.html> (3 Aug. 2012).

This animation allows students to click on an orbital to move a hydrogen electron either up or down. A corresponding wave of light is either absorbed or emitted.

Visionlearning, Inc. "Bohr's Atom: Quantum Behavior in Hydrogen." *Library*. <www.visionlearning.com/library/flash_viewer.php?oid=1347&mid=51> (3 Aug. 2012).

This animation allows students to excite a hydrogen atom up through four orbits and then allow it to fall back to any lower orbit down to its ground state. A brief pulse of light will be emitted at each fall, with the numerical value of that wavelength displayed.

SKILLS AND ATTITUDES OUTCOMES

C12-0-N1: Explain the roles of theory, evidence, and models in the development of scientific knowledge.

C12-0-N2: Describe, from a historical perspective, how the observations and experimental work of many individuals led to modern understandings of matter.

C12-0-N3: Describe how scientific knowledge changes as new evidence emerges and/or new ideas and interpretations are advanced.

Learning Activity/Demonstration: Bohr's Atomic Theory and Emission Spectrum

Have students model emission spectra using the following items:

- small coloured balls (or coloured markers)—representing different photons with energies corresponding to their colours
- floor space—representing the ground state
- a chair, a tall stool, and a table counter—representing the higher energy levels

The gap between the floor and the chair needs to be larger than the gap between the chair and stool. The counter must be higher than the stool.

The teacher (or a student) plays the role of an electron that jumps between different energy levels.

- The teacher gives red, yellow, blue, violet, and black balls to students, while keeping a red, a blue, and a violet ball. The first student throws a violet ball at the teacher. While catching the ball, the teacher jumps from the floor (first energy level) onto the stool (third energy level). This represents the absorption of a violet photon. The teacher immediately takes a violet ball (e.g., out of his or her pocket), throws it in a different direction than the incoming ball's direction, and jumps down to the floor. This represents the release of a photon and corresponds to the violet line in the hydrogen emission spectrum.
- If a student throws a blue ball, the teacher jumps onto the chair (second energy level). The teacher releases a blue ball from his or her pocket, and throws it in a different direction than the incoming ball's direction, and jumps down to the floor. This represents the release of a photon and corresponds to the blue line in the hydrogen emission spectrum.
- The exercise continues with the red balls, which represent the energy between the second level (the chair) and the third level (the stool) and correspond to the red line in the hydrogen emission spectrum.
- If the student throws a yellow ball, the teacher ignores it, as yellow does not correspond to one of the energy-level transitions in hydrogen.
- Finally, the teacher catches a black ball (representing ultraviolet), jumps onto the counter, and runs free of the nucleus. This represents *ionization*.

Topic 2: Atomic Structure

SPECIFIC LEARNING OUTCOME

C12-2-04: Outline the historical development of the quantum mechanical model of the atom.

(continued)

This learning activity demonstrates a number of key points of Bohr's atomic theory and emission spectra. The coloured balls represent the different energy levels and the different energies correspond to jumps of different sizes. The emitted photon is typically ejected in a different direction than the incident photon. Electron jumps correspond to a small set of specific energy values.

SUGGESTIONS FOR ASSESSMENT

Research

1. Have students develop a timeline for the scientific research that resulted in modifications to the understanding of the structure of an atom.

2. Have students research the scientists whose work led to the establishment of the quantum mechanical model of the atom. Students' research findings could be presented in the form of
   - written reports
   - oral presentations
   - bulletin-board displays
   - multimedia presentations

   For assessment rubrics, refer to Appendix 11.

Note:
The historical development of the atom is an interesting account of experimental interpretations and theoretical explanations. It is not necessary for students to memorize this development, but they need to appreciate its complexity.

Paper-and-Pencil Task

Have students use a diagram to explain the structure of the atom in terms of the absorption of energy and the subsequent movement of electrons from one energy level to another.

SKILLS AND ATTITUDES OUTCOMES

C12-0-N1: Explain the roles of theory, evidence, and models in the development of scientific knowledge.

C12-0-N2: Describe, from a historical perspective, how the observations and experimental work of many individuals led to modern understandings of matter.

C12-0-N3: Describe how scientific knowledge changes as new evidence emerges and/or new ideas and interpretations are advanced.

LEARNING RESOURCES LINKS

Chemistry (Chang 264, 266, 279)

Chemistry (Zumdahl and Zumdahl 301, 306)

Chemistry: The Molecular Nature of Matter and Change (Silberberg 275)

Glencoe Chemistry: Matter and Change (Dingrando, et al. 127, 131)

Great Physicists: The Life and Times of Leading Physicists from Galileo to Hawking (Cropper)

Nelson Chemistry 11, Ontario Edition (Jenkins, et al. 37, 45)

Nelson Chemistry 12, College Preparation, Ontario Edition (Davies, et al. 21)

Nelson Chemistry 12, Ontario Edition (van Kessel, et al. 37, 45)

Prentice Hall Chemistry (Wilbraham, et al. 127, 130, 144)

World of Physics (McGrath)

Demonstration

Palmquist, Bruce C. "Interactive Spectra Demonstration." *The Physics Teacher* 40.3 (Mar. 2002): 140.

Websites

University of Colorado at Boulder. "Atomic Spectra." *Physics 2000: Science Trek.* <www.colorado.edu/physics/2000/quantumzone/lines2.html> (3 Aug. 2012).

Visionlearning, Inc. "Bohr's Atom: Quantum Behavior in Hydrogen." *Library*. <www.visionlearning.com/library/flash_viewer.php?oid=1347&mid=51> (3 Aug. 2012).

Selecting Learning Resources

For additional information on selecting learning resources for Grade 11 and Grade 12 Chemistry, see the Manitoba Education website at <www.edu.gov.mb.ca/k12/learnres/bibliographies.html>.

Topic 2: Atomic Structure

SPECIFIC LEARNING OUTCOMES

C12-2-05: Write electron configurations for elements of the periodic table.
Include: selected elements up to atomic number 36 (krypton)

C12-2-06: Relate the electron configuration of an element to its valence electron(s) and its position on the periodic table.

(2.5 hours)

SLO: C12-2-05
SLO: C12-2-06

SUGGESTIONS FOR INSTRUCTION

Entry-Level Knowledge

In Grade 9 Science (S1-2-05), students drew Bohr atoms for the first 18 elements of the periodic table up to argon. Students should also have an understanding of the arrangement of the elements on the periodic table (S1-2-06, S2-2-01, S2-2-02). In Grade 10 Science (S2-2-01), students were introduced to Lewis dot diagrams.

TEACHER NOTES

Electron Configurations

The arrangement of electrons in an atom is called the *atom's electron configuration*. Chemists use a combination of numbers and letters to designate the energy levels of electrons within an atom.

- The *numbers* refer to the principal energy levels (1, 2, 3, 4, and so on).
- The *letters* refer to the energy levels (s, p, d, f, g, h, and so on), as shown in the following table.

General Learning Outcome Connections

GLO A2: Recognize that scientific knowledge is based on evidence, models, and explanations, and evolves as new evidence appears and new conceptualizations develop.

GLO D3: Understand the properties and structures of matter, as well as various common manifestations and applications of the actions and interactions of matter.

GLO D4: Understand how stability, motion, forces, and energy transfers and transformations play a role in a wide range of natural and constructed contexts.

GLO E1: Describe and appreciate the similarity and diversity of forms, functions, and patterns within the natural and constructed world.

SKILLS AND ATTITUDES OUTCOMES

C12-0-U1: Use appropriate strategies and skills to develop an understanding of chemical concepts.

Examples: analogies, concept frames, concept maps, manipulatives, particulate representations, role-plays, simulations, sort-and-predict frames, word cycles . . .

C12-0-U2: Demonstrate an understanding of chemical concepts.

Examples: use accurate scientific vocabulary, explain concepts to others, compare and contrast concepts, apply knowledge to new situations and/or contexts, create analogies, use manipulatives . . .

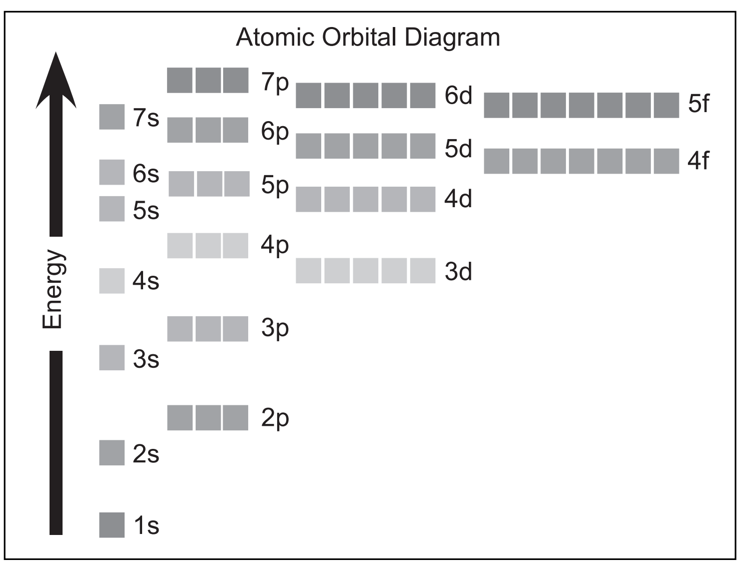
Summary of Energy Levels and Sublevels

Principal Quantum Number (*n*)	Sublevels Present (Types of Orbitals)	Number of Orbitals Related to Sublevel	Total Number of Orbitals Related to Principal Energy Level (n^2)
1	s	1	1
2	s p	1 3	4
3	s p d	1 3 5	9
4	s p d f	1 3 5 7	16

Three principles or rules define how electrons can be arranged in an atom's orbital.

1. **The Aufbau Principle**

   The *Aufbau principle* (derived from the German, *aufbauen*, which means to build up) was proposed by Danish physicist Neils Bohr (1885–1962). The Aufbau principle states that each electron occupies the lowest energy orbital available. The first step is for students to learn the sequence of atomic orbitals from lowest energy to highest energy, as shown in the following diagram.



Topic 2: Atomic Structure

SPECIFIC LEARNING OUTCOMES

C12-2-05: Write electron configurations for elements of the periodic table.

Include: selected elements up to atomic number 36 (krypton)

C12-2-06: Relate the electron configuration of an element to its valence electron(s) and its position on the periodic table.

(continued)

In the previous diagram, each box represents an atomic orbital. Each energy level (*n*1, *n*2, *n*3, *n*4) has one or more sublevels, referred to as s, p, d, f, g, h, and so on. All orbitals in the same sublevel have the same energy. For example, the electrons in the 2p sublevel have the same amount of energy in that sublevel. The energy sublevels within a principal energy level have different energies. The 2s orbital has a lower energy than 2p orbital. Orbitals related to energy sublevels within one principal energy level can overlap orbitals related to energy sublevels within another principal level. For example, the 4s orbital has a lower energy than the 3d orbitals.

2. **The Pauli Exclusion Principle**

   Proposed by Austrian physicist Wolfgang Pauli (1900–1958), the *Pauli exclusion principle* states that a maximum of two electrons may occupy a single atomic orbital, but only if the electrons have opposite spins. Pauli proposed this principle after observing atoms in excited states. The atomic orbital containing two electrons with opposite spins is written as ↑↓.

3. **Hund's Rule**

   Proposed by German physicist Friedrich Hund (1896–1997), *Hund's rule* states that single electrons with the same spin must occupy each equal-energy orbital before additional electrons with opposite spins can occupy the same orbitals. For example, the three 2p orbitals would be filled as shown below.

1 electron	↑		
2 electrons	↑	↑	
3 electrons	↑	↑	↑
4 electrons	↑↓	↑	↑

SKILLS AND ATTITUDES OUTCOMES

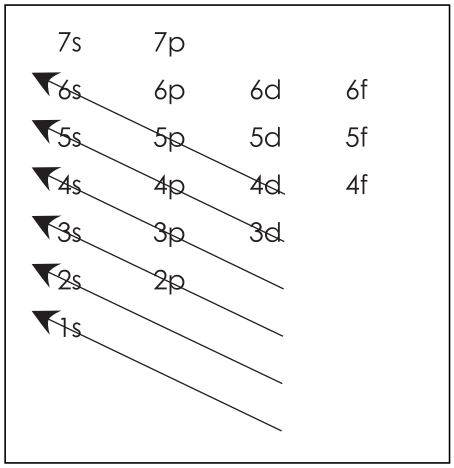
C12-0-U1: Use appropriate strategies and skills to develop an understanding of chemical concepts.

Examples: analogies, concept frames, concept maps, manipulatives, particulate representations, role-plays, simulations, sort-and-predict frames, word cycles . . .

C12-0-U2: Demonstrate an understanding of chemical concepts.

Examples: use accurate scientific vocabulary, explain concepts to others, compare and contrast concepts, apply knowledge to new situations and/or contexts, create analogies, use manipulatives . . .

A teaching aid that students can use to write the correct order for electron configurations can be to set up as a diagram, as shown below.



Starting at the base of the diagram, the orbitals are filled by following the direction of the arrows in this manner: 1s, 2s, 2p, 3s, 3p, 4s, 3d, 4p, 5s, 4d, 5p, 6s, and so on.

Learning Activities: Electron and Valence Configurations

1. Ask students to write the electronic configuration using noble gas notation. For example, the complete electron configuration for aluminum is $1s^22s^22p^63s^23p^1$. Using the noble gas notation, the electron configuration for aluminum would be written as [Ne] $3s^23p^1$.

2. Show students how the modern periodic table has been designed according to the structure of the atom with respect to valence electrons and the chemical reactivity of elements.

   Provide students with Appendix 2.5: Blank Periodic Table of the Elements and have them write in the valence electrons and the orbital that is being completed. Once the table is complete, the organization of the table should be apparent.

$2s^1$	$2s^2$	$2s^2$ $2p^1$	$2s^2$ $2p^2$	$2s^2$ $2p^3$	etc.

   Periodic tables indicating the electron configurations of elements are available online (see Websites in Learning Resources Links).

Topic 2: Atomic Structure

SPECIFIC LEARNING OUTCOMES

C12-2-05: Write electron configurations for elements of the periodic table.

Include: selected elements up to atomic number 36 (krypton)

C12-2-06: Relate the electron configuration of an element to its valence electron(s) and its position on the periodic table.

(continued)

3. Students can play Electron Configuration Bingo. Hand out the symbols of the elements on a bingo card and call out electron configurations. For example, call out $1s^2$, and have students cover up He.

Laboratory Activity

Have students perform a small-scale experiment on electron configurations of atoms and ions (see Waterman and Thompson 73–76).

SUGGESTIONS FOR ASSESSMENT

Paper-and-Pencil Tasks

1. Ask students to write the complete electronic configuration and the valence configuration for elements up to and including krypton.
2. Have students identify the valence configuration from an element's position on the periodic table.

Concept Development

Have students "think about and explain the analogy between Hund's rule and the behaviour of total strangers as they board an empty bus" (Dingrando, et al., *Glencoe Chemistry: Matter and Change, Teacher Wraparound Edition* 137).

Journal Writing

Ask students to write a report

> . . . in which they speculate about flying a spacecraft to a planet in a different solar system. In the new solar system, they discover that each atomic orbital of the planet's solid, liquid, and gaseous matter may contain up to three electrons rather than just two. Their speculation should focus on the characteristics of the elements on this new planet. (Dingrando, et al., *Glencoe Chemistry: Matter and Change, Teacher Wraparound Edition* 140)

SKILLS AND ATTITUDES OUTCOMES

C12-0-U1: Use appropriate strategies and skills to develop an understanding of chemical concepts.

Examples: analogies, concept frames, concept maps, manipulatives, particulate representations, role-plays, simulations, sort-and-predict frames, word cycles . . .

C12-0-U2: Demonstrate an understanding of chemical concepts.

Examples: use accurate scientific vocabulary, explain concepts to others, compare and contrast concepts, apply knowledge to new situations and/or contexts, create analogies, use manipulatives . . .

LEARNING RESOURCES LINKS

Chemistry (Chang 285, 292)

Chemistry (Zumdahl and Zumdahl 309, 319)

Chemistry: The Molecular Nature of Matter and Change (Silberberg 296, 301)

Glencoe Chemistry: Concepts and Applications (Phillips, Strozak, and Wistrom 235, 238, 244)

Glencoe Chemistry: Matter and Change (Dingrando, et al. 135, 140, 160)

Glencoe Chemistry: Matter and Change, Teacher Wraparound Edition (Dingrando, et al. 137, 140)

Prentice Hall Chemistry (Wilbraham, et al. 131, 133, 164)

Investigation

Prentice Hall Chemistry: Small-Scale Chemistry Laboratory Manual (Waterman and Thompson)
Experiment 10: Electron Configurations of Atoms and Ions, 73–76

Websites

The ChemCollective. "Periodic Table." *Applets.* <www.chemcollective.org/applets/pertable.php> (1 Feb. 2012).

ScienceGeek.net. "Printable Periodic Tables." *Other Resources.* <www.sciencegeek.net/tables/tables.shtml> (1 Feb. 2012).

Appendix

Appendix 2.5: Blank Periodic Table of the Elements

Selecting Learning Resources

For additional information on selecting learning resources for Grade 11 and Grade 12 Chemistry, see the Manitoba Education website at <www.edu.gov.mb.ca/k12/learnres/bibliographies.html>.

Topic 2: Atomic Structure

SPECIFIC LEARNING OUTCOME

C12-2-07: Identify and account for periodic trends among the properties of elements, and relate the properties to electron configuration.

Include: atomic radii, ionic radii, ionization energy, and electronegativity

(3 hours)

SLO: C12-2-07

SUGGESTIONS FOR INSTRUCTION

Prior Knowledge

Electronegativity was briefly discussed in Grade 11 Chemistry (C11-4-02). Students learned about this concept in order to explain the polarity and subsequent function of the water molecule in the solution process. In Grade 10 Science (S2-2-02), students were introduced to Lewis dot diagrams as a method of illustrating atomic structure in both ionic and simple covalent compounds.

Activating Activity

Have students identify the first ionization energies of the first 36 elements of the periodic table (H to Kr). Students should then graph the atomic number versus ionization energy for each element. The points for each element of a period should be connected with a straight line so that there are four curves on the graph. Students will use this graph to determine the periodic and group trends of the first ionization energies (Jenkins, et al. 54–56). Also see Appendix C2: The Elements (Jenkins, et al. 632–633), or Appendix C, Table C–6: Properties of Elements (Dingrando, et al. 914–916).

Students could repeat this activating activity using atomic radii and ionic radii data for the first 36 elements to help them determine the respective trends.

TEACHER NOTES

Most chemistry texts provide an explanation of period and group trends for atomic radii, ionization energies, and ionic radii. Encourage students to use their understanding of nuclear charge and electron configurations to explain the trends, rather than simply memorizing them.

General Learning Outcome Connections

GLO C2: Demonstrate appropriate scientific skills when seeking answers to questions.

GLO C5: Demonstrate curiosity, skepticism, creativity, open-mindedness, accuracy, precision, honesty, and persistence, and appreciate their importance as scientific and technological habits of mind.

GLO D3: Understand the properties and structures of matter, as well as various common manifestations and applications of the actions and interactions of matter.

GLO D4: Understand how stability, motion, forces, and energy transfers and transformations play a role in a wide range of natural and constructed contexts.

GLO E1: Describe and appreciate the similarity and diversity of forms, functions, and patterns within the natural and constructed world.

SKILLS AND ATTITUDES OUTCOMES

C12-0-U1: Use appropriate strategies and skills to develop an understanding of chemical concepts.

Examples: analogies, concept frames, concept maps, manipulatives, particulate representations, role-plays, simulations, sort-and-predict frames, word cycles . . .

C12-0-S5: Collect, record, organize, and display data using an appropriate format.

Examples: labelled diagrams, graphs, multimedia applications, software integration, probeware . . .

C12-0-S7: Interpret patterns and trends in data, and infer and explain relationships.

Trends in Atomic Radii

- **Periodic Trends in Atomic Radii**

  The atomic radii generally decrease across a period from left to right. Since each additional electron is added to the same principal energy level, the additional electrons are not shielded from the increasingly positive nucleus. The increased nuclear charge pulls the valence electrons closer to the nucleus, reducing the atomic radius.

- **Group Trends in Atomic Radii**

  The atomic radii generally increase as you move down a group. The outermost orbital increases in size, shielding the valence electrons from the pull of the nucleus. These factors overpower the increased pull of the more positive nucleus on the valence electrons, causing the atomic radius to increase.

Trends in Ionization Energy

Ionization energy is the energy required to remove an electron from an atom in its gaseous state. These values indicate how strongly an atom's nucleus holds onto its valence electrons. High ionization energy values indicate the atom has a strong hold on the electrons. Low ionization energy values indicate the atom has a weak hold on the electrons. Atoms with high ionization values are unlikely to lose electrons and form positive ions.

- **Periodic Trends in First Ionization Energies**

  The first ionization energy generally increases across a period from left to right. For example, lithium has a low first ionization energy, indicating it will easily lose an electron to form the Li^{+} ion. The lithium atom has one valence electron, and this electron is easily removed from its atom. As you move across the period, it becomes increasingly harder to remove a valence electron from the atom. The reason for this is that the increased nuclear charge of each successive element produces an increased hold on the valence electrons, thereby increasing the ionization energies. The stronger nuclear charge makes it harder to remove a valence electron, as the electrons are pulled closer to the positively charged nucleus. Therefore, neon, which is located at the end of the period, has a high first ionization energy, indicating it will be unlikely to lose an electron to form Ne^{+} ion. Neon has a stable outer energy level (8 electrons), so it does not want to give up an electron readily.

Topic 2: Atomic Structure

SPECIFIC LEARNING OUTCOME

C12-2-07: Identify and account for periodic trends among the properties of elements, and relate the properties to electron configuration.

Include: atomic radii, ionic radii, ionization energy, and electronegativity

(continued)

- **Periodic Trends in Successive Ionization Energies**

The energy required for each successive ionization energy increases across a period from left to right, as shown in Table 6–2: Successive Ionization Energies for the Period 2 Elements (Dingrando, et al., *Chemistry: Matter and Change* 168). The primary reason for this is that the increase in positive charge binds the electrons more strongly.

The table also shows that for each element, the energy required for a specific ionization displays a significant increase. The reason for this is that atoms tend to lose or gain electrons in order to acquire a full energy level because this is the most stable state. The energy jump occurs when a core electron, as opposed to a valence electron, is being removed.

Example:

Sodium atom (with 1 valence electron) | Sodium ion (no valence electrons)

500 kJ/mol energy needed to remove the 1 valence electron

4560 kJ/mol energy needed to remove the 1 electron from the stable energy level $2s^22p^6$

- **Group Trends in Ionization Energies**

The ionization energies decrease as you move down a group. The increasing atomic size pushes the valence electrons further away from the nucleus. Consequently, it takes less energy to remove the electron because the strength of attraction is less.

SKILLS AND ATTITUDES OUTCOMES

C12-0-U1: Use appropriate strategies and skills to develop an understanding of chemical concepts.

Examples: analogies, concept frames, concept maps, manipulatives, particulate representations, role-plays, simulations, sort-and-predict frames, word cycles . . .

C12-0-S5: Collect, record, organize, and display data using an appropriate format.

Examples: labelled diagrams, graphs, multimedia applications, software integration, probeware . . .

C12-0-S7: Interpret patterns and trends in data, and infer and explain relationships.

Trends in Ionic Radii

When atoms lose electrons to form positive ions (cations) they always get smaller. Two factors lead to the reduction in size. First, the lost valence electron may lead to a completely empty orbital. Second, the electron shielding is reduced, allowing the nucleus to pull the electrons closer to the nucleus.

When atoms gain electrons to form negative ions (anions) they always get larger. The electron shielding increases, pushing the electrons farther from the nucleus.

- **Periodic Trends in Ionic Radii**

  The size of positive ions decrease as you move across a period from left to right, and the size of negative ions decrease as you move across a period from left to right.

- **Group Trends in Ionic Radii**

  The ionic radii of both positive and negative ions increase as you move down a group.

Trends in Electronegativity

Electronegativity is the ability of an atom in a molecule to attract electrons to itself. The first and most widely used electronegativity scale was developed by Linus Pauling, who based his scale on thermochemical data. Many chemistry texts contain Pauling's values. Robert Mulliken, in 1936, developed an approach to electronegativity that is based on atomic properties only. The Allred-Rochow scale, proposed by A. L. Allred and E. G. Rochow, is based upon the electrostatic force of attraction between the nucleus and the valence electrons. This scale is included in Appendix 2.6: Table of Electronegativity Values. Other tables could also be used and are available online.

Sample Website:

Chemistry@Davidson. "Electronegativity: Pauling, Allred-Rochow, and Mulliken-Jaffé." *Dr. Nutt's CHE 115 Course*. <www.chm.davidson.edu/ronutt/che115/electroneg.htm> (8 Feb. 2012).

This website presents the three different electronegativity scales: Pauling, Allred-Rochow, and Mulliken-Jaffé.

Topic 2: Atomic Structure

SPECIFIC LEARNING OUTCOME

C12-2-07: Identify and account for periodic trends among the properties of elements, and relate the properties to electron configuration.

Include: atomic radii, ionic radii, ionization energy, and electronegativity

(continued)

Electronegativity and Bond Type

Learning outcome C12-2-07 restricts the examples to binary compounds. Most chemistry texts will have a periodic table that contains electronegativity values for each element. By taking the difference between the values for each element, students will be able to predict the type of bonding that occurs between the atoms. Ask students to identify only whether the bonds are non-polar covalent, moderately polar covalent, very polar covalent, or ionic, according to the following table. It is not necessary for students to specify the percent character, even though some texts provide percent values.

Electronegativity Differences and Predicted Bond Character		
Electronegativity Difference	**Predicted Bond Type**	**Examples**
0.0 – 0.4	Non-polar covalent	O–O (0.0)
0.4 – 1.0	Moderately polar covalent	SCl_2 (3.16–2.58)
1.0 – 2.0	Very polar covalent	CaS (2.58–1.00)
≥ 2.0	Ionic	KCl (3.16–0.82)

Predicting Type of Bonding That Occurs in Atoms

Give students both a periodic table that contains the electronegativity values (see Appendix 2.6: Table of Electronegativity Values) and the above table without the examples. Then provide them with the formulae of various binary compounds and have them predict the bond type.

Example:

What type of bond would occur in a molecule of LiF?

Solution:

From the electronegativity values, Li has a value of 0.97 and F has a value of 4.10. The difference between 4.10 and 0.97 is 3.13. This would indicate that the bond between Li and F is ionic in character.

See Appendix 2.7A: Electronegativities (BLM) for sample problems. A teacher key is provided in Appendix 2.7B.

SKILLS AND ATTITUDES OUTCOMES

C12-0-U1: Use appropriate strategies and skills to develop an understanding of chemical concepts.

Examples: analogies, concept frames, concept maps, manipulatives, particulate representations, role-plays, simulations, sort-and-predict frames, word cycles . . .

C12-0-S5: Collect, record, organize, and display data using an appropriate format.

Examples: labelled diagrams, graphs, multimedia applications, software integration, probeware . . .

C12-0-S7: Interpret patterns and trends in data, and infer and explain relationships.

Multimedia Presentation

For a PowerPoint presentation that provides an overview of electrons and their periodic trends, visit the following website.

Sample Website:

ScienceGeek.net. "AP Chemistry Powerpoints." *AP Chemistry.* <www.sciencegeek.net/APchemistry/Powerpoints.shtml> (1 Feb. 2012).

Laboratory Activity

Students can perform a lab activity identifying an element's place in the periodic table based on the element's properties (see Waterman and Thompson 69).

SUGGESTIONS FOR ASSESSMENT

Visual Displays

Students could present the periodic and group trends for atomic radii, ionic radii, ionization energy, and electronegativity in a visual display, such as a poster, pamphlet, or bulletin board exhibit. Each presentation style could be assessed by a predetermined rubric (samples of presentation rubrics are provided in Appendix 11). Students can also fill in the period and group trends on a blank periodic table (see Appendix 2.5).

Paper-and-Pencil Tasks

1. Ask students to rank the atomic radii, ionic radii, ionization energy, and electronegativity for a set of elements. Students should also be able to explain their rankings by relating them to electron configuration.

2. Have students draw the periodic and group trends, using directional arrows, on a blank periodic table for atomic radii, ionic radii, ionization energy, and electronegativity. See Appendix 2.5: Blank Periodic Table of the Elements.

3. Provide students with examples of binary compounds and ask them to predict the bond character of the molecule.

Journal Writing

Have students summarize the periodic and group trends of atomic radii, ionic radii, ionization energy, and electronegativity.

Topic 2: Atomic Structure

SPECIFIC LEARNING OUTCOME

C12-2-07: Identify and account for periodic trends among the properties of elements, and relate the properties to electron configuration.

Include: atomic radii, ionic radii, ionization energy, and electronegativity

(continued)

LEARNING RESOURCES LINKS

Chemistry (Chang 312, 315, 319, 357)

Chemistry (Zumdahl and Zumdahl 327, 332, 353)

Chemistry: The Molecular Nature of Matter and Change (Silberberg 294, 305, 309, 320, 351)

Glencoe Chemistry: Concepts and Applications (Phillips, Strozak, and Wistrom 258, 260, 303)

Glencoe Chemistry: Matter and Change (Dingrando, et al. 163, 165, 167, 168, 914–916)

McGraw-Hill Ryerson Chemistry, Combined Atlantic Edition (Mustoe, et al. 174)

McGraw-Hill Ryerson Inquiry into Chemistry (Chastko, et al. 36)

Nelson Chemistry 11, Ontario Edition (Jenkins, et al., 51, 54–56, 57, 632–633)

Nelson Chemistry 12, Ontario Edition (van Kessel, et al. 251)

Nelson Chemistry 12: College Preparation, Ontario Edition (Davies, et al. 40)

Prentice Hall Chemistry (Wilbraham, et al. 170, 173, 176, 177)

Investigations

Glencoe Chemistry: Concepts and Applications (Phillips, Strozak, and Wistrom)
MiniLAB 8.1: What's periodic about atomic radii? 262

Nelson Chemistry 11, Ontario Edition (Jenkins, et al.)
Activity 1.5.1: Graphing First Ionization Energy, 54
Activity 1.5.2: Graphing Electronegativity, 57

Prentice Hall Chemistry (Wilbraham, et al.)
Small-Scale LAB 6: Periodicity in Three Dimensions, 179
Quick LAB 6: Periodic Trends in Ionic Radii, 175

Prentice Hall Chemistry: Small-Scale Chemistry Laboratory Manual (Waterman and Thompson)
Experiment 9: A Periodic Table Logic Problem, 69

SKILLS AND ATTITUDES OUTCOMES

C12-0-U1: Use appropriate strategies and skills to develop an understanding of chemical concepts.

Examples: analogies, concept frames, concept maps, manipulatives, particulate representations, role-plays, simulations, sort-and-predict frames, word cycles . . .

C12-0-S5: Collect, record, organize, and display data using an appropriate format.

Examples: labelled diagrams, graphs, multimedia applications, software integration, probeware . . .

C12-0-S7: Interpret patterns and trends in data, and infer and explain relationships.

Websites

Chemistry@Davidson. "Electronegativity: Pauling, Allred-Rochow, and Mulliken-Jaffé." *Dr. Nutt's CHE 115 Course.* <www.chm.davidson.edu/ronutt/che115/electroneg.htm> (8 Feb. 2012).

ScienceGeek.net. "AP Chemistry Powerpoints." *AP Chemistry.* <www.sciencegeek.net/APchemistry/Powerpoints.shtml> (1 Feb. 2012).

Appendices

Appendix 2.5: Blank Periodic Table of the Elements

Appendix 2.6: Table of Electronegativity Values

Appendix 2.7A: Electronegativities (BLM)

Appendix 2.7B: Electronegativities (Teacher Key)

Selecting Learning Resources

For additional information on selecting learning resources for Grade 11 and Grade 12 Chemistry, see the Manitoba Education website at <www.edu.gov.mb.ca/k12/learnres/bibliographies.html>.