# TOPIC 2:
# GASES AND THE ATMOSPHERE

## Topic 2: Gases and the Atmosphere

**C11-2-01** Identify the abundances of the naturally occurring gases in the atmosphere and examine how these abundances have changed over geologic time.

Include: oxygenation of Earth's atmosphere, the role of biota in oxygenation, changes in carbon dioxide content over time

**C11-2-02** Research Canadian and global initiatives to improve air quality.

**C11-2-03** Examine the historical development of the measurement of pressure.

*Examples: the contributions of Galileo Galilei, Evangelista Torricelli, Otto von Guericke, Blaise Pascal, Christiaan Huygens, John Dalton, Joseph Louis Gay-Lussac, Amadeo Avogadro…*

**C11-2-04** Describe the various units used to measure pressure.

Include: atmospheres (atm), kilopascals (kPa), millimetres of mercury (mmHg), millibars (mb)

**C11-2-05** Experiment to develop the relationship between the pressure and volume of a gas using visual, numeric, and graphical representations.

Include: historical contributions of Robert Boyle

**C11-2-06** Experiment to develop the relationship between the volume and temperature of a gas using visual, numeric, and graphical representations.

Include: historical contributions of Jacques Charles, the determination of absolute zero, the Kelvin temperature scale

**C11-2-07** Experiment to develop the relationship between the pressure and temperature of a gas using visual, numeric, and graphical representations.

Include: historical contributions of Joseph Louis Gay-Lussac

**C11-2-08** Solve quantitative problems involving the relationships among the pressure, temperature, and volume of a gas using dimensional analysis.

Include: symbolic relationships

**C11-2-09** Identify various industrial, environmental, and recreational applications of gases.

*Examples: self-contained underwater breathing apparatus (scuba), anaesthetics, air bags, acetylene welding, propane appliances, hyperbaric chambers…*

**Suggested Time: 10.5 hours**

SPECIFIC LEARNING OUTCOME

**C11-2-01:** Identify the abundances of the naturally occurring gases in the atmosphere and examine how these abundances have changed over geologic time.

Include: oxygenation of Earth's atmosphere, the role of biota in oxygenation, changes in carbon dioxide content over time

(1.5 hours)

SLO: C11-2-01

## SUGGESTIONS FOR INSTRUCTION

### Entry-Level Knowledge

The following learning outcomes were addressed in Grade 10 Science:

- S2-1-01: Illustrate and explain how carbon, nitrogen, and oxygen are cycled through an ecosystem.
- S2-4-01: Illustrate the composition and organization of the hydrosphere and atmosphere.

### Assessing Prior Knowledge

Check for student understanding of prior knowledge and review as necessary. Prior knowledge can be reviewed and/or assessed by using any of the KWL strategies (e.g., Concept Map, Knowledge Chart, Think-Pair-Share—see *SYSTH*, Chapter 9).

### TEACHER NOTES

Most chemistry texts provide a list of the components of the atmosphere, but few of them actually discuss how the composition has changed over geologic time.

It is generally believed that the composition of the atmosphere was dramatically different before life began on Earth than it is today, and was likely dominated by nitrogenous gases and significantly greater amounts of $CO_2$ than at present. Billions of years ago, the atmosphere consisted mainly of ammonia, methane, and water vapour. It is generally accepted that little free molecular oxygen existed. Ultraviolet radiation from the sun penetrated the relatively dense atmosphere and provided the energy for chemical reactions that eventually led to the emergence of key "biomolecules" (e.g., amino acids) consistent with the foundations of new life on Earth.

### General Learning Outcome Connections

**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 B4:** Demonstrate knowledge of and personal consideration for a range of possible science- and technology-related interests, hobbies, and careers.

**GLO D5:** Understand the composition of the Earth's atmosphere, hydrosphere, and lithosphere, as well as the processes involved within and among them.

**GLO E3:** Recognize that characteristics of materials and systems can remain constant or change over time, and describe the conditions and processes involved.

SKILLS AND ATTITUDES OUTCOMES

**C11-0-S5:** Collect, record, organize, and display data using an appropriate format.
*Examples: labelled diagrams, graphs, multimedia applications, software integration, probeware…*

**C11-0-R1:** Synthesize information obtained from a variety of sources.
Include: print and electronic sources, specialists, other resource people

**C11-0-R2:** Evaluate information obtained to determine its usefulness for information needs.
*Examples: scientific accuracy, reliability, currency, relevance, balance of perspectives, bias…*

**C11-0-R4:** Compare diverse perspectives and interpretations in the media and other information sources.

**C11-0-R5:** Communicate information in a variety of forms appropriate to the audience, purpose, and context.

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Origin-of-life models have generally proposed that about 1 billion years after the first primitive organisms emerged, blue-green algae appeared on Earth. These algae converted the existing carbon dioxide and water to free oxygen gas and glucose through the well-known process of *photosynthesis*. These photo-synthesizers were also responsible for helping to bind atmospheric hydrogen into carbonates and water.

Another important source of oxygen was the photo-decomposition of water vapour by ultraviolet light. As the amount of free oxygen increased, an ozone layer began to form high in the stratosphere due to the dissociation of molecular oxygen and subsequent recombination as $O_3$ (ozone). Ozone proved important in filtering out potentially damaging amounts of ultraviolet radiation and allowing for the development of more complex species. As further carbon was extracted from the atmosphere, early life forms provided a food supply that fuelled the progress of evolution. Through their death and decay, particularly in the world's oceans, early life forms not only laid down vast quantities of fossilized minerals, but also sequestered large quantities of carbon in the form of thick sequences of carbonate rocks. An estimate of the amount of atmospheric carbon that was extracted by this method has been proposed at $1 \times 10^{13}$ tonnes.

### Activities

A number of activities that involve graphing carbon dioxide levels over the last two centuries can be found in the appendices of *Senior 2 Science: A Foundation for Implementation* (see Appendix 4.35). A graphing activity from page A205 of this document follows.

SPECIFIC LEARNING OUTCOME

C11-2-01: Identify the abundances of the naturally occurring gases in the atmosphere and examine how these abundances have changed over geologic time.

Include: oxygenation of Earth's atmosphere, the role of biota in oxygenation, changes in carbon dioxide content over time

*(continued)*

**Carbon Dioxide $CO_2$ Concentrations in the Atmosphere and Temperature Changes (Anomaly) from 1840 to 2000**

| Year | $CO_2$ Concentration (parts per million of volume [ppmv]*) | Temperature Anomaly (°C above/below normal) |
|---|---|---|
| 1840 | 280 | –0.40 |
| 1955 | 310 | –0.05 |
| 1960 | 312 | 0.00 |
| 1965 | 316 | –0.10 |
| 1970 | 320 | –0.08 |
| 1975 | 327 | –0.08 |
| 1980 | 335 | –0.08 |
| 1985 | 345 | +0.10 |
| 1990 | 352 | +0.15 |
| 1995 | 355 | +0.25 |
| 2000 | 360 | +0.28 |

* 300 ppmv (300 parts per million by volume) is equivalent to 300 $CO_2$ molecules/1,000,000 molecules of dry air, or, expressed as a percent, 0.03%.

Data courtesy of Environment Canada <http://www.ec.gc.ca>. Copyright © 2001.

Students use the data from the table above to plot the year against the concentrations of carbon dioxide to show how the concentrations have changed from 1840 to 2000. The graphs could be drawn manually using graph paper. Another option would be for students to plot their graphs using a plotting program such as *Curve Expert*®, *Mathematica*®, or *Graphical Analysis 3*® by Vernier. Students should gain reinforcement in drawing the "best fit" curve that helps to determine a relationship, and discussing the results of the plot and any correlations that may be evident in the graph. The extent to which the analysis is treated would be determined by the mathematical experience of students in the class and the availability of class time and computer access.

## SUGGESTIONS FOR ASSESSMENT

### Rubrics/Checklists

See Appendix 10 for a selection of rubrics and checklists that can be used for self-assessment, peer assessment, and teacher assessment.

#### SKILLS AND ATTITUDES OUTCOMES

**C11-0-S5:** Collect, record, organize, and display data using an appropriate format.
*Examples: labelled diagrams, graphs, multimedia applications, software integration, probeware…*

**C11-0-R1:** Synthesize information obtained from a variety of sources.
Include: print and electronic sources, specialists, other resource people

**C11-0-R2:** Evaluate information obtained to determine its usefulness for information needs.
*Examples: scientific accuracy, reliability, currency, relevance, balance of perspectives, bias…*

**C11-0-R4:** Compare diverse perspectives and interpretations in the media and other information sources.

**C11-0-R5:** Communicate information in a variety of forms appropriate to the audience, purpose, and context.

### Research Reports

Have students conduct independent research towards achieving the specific learning outcome (C11-2-01) related to the composition of Earth's atmosphere over geologic time. Reporting can be done either individually or in cooperative groups. The information collected could be presented as

- written reports
- oral presentations
- bulletin board displays
- multimedia presentations
- a simulated scientific meeting
- a debate involving contested views on the history of Earth's atmospheric composition

### Visual Displays

Students could present the material they have collected using

- posters
- pamphlets
- bulletin boards
- models

Each of these presentation styles could be assessed using an appropriate rubric created with students prior to the assignment. A sample of a class presentation rubric is provided in Appendix 10 (also see *SYSTH* 14.15).

## LEARNING RESOURCES LINKS

*Chemistry* (Chang 732)

*Chemistry: The Molecular Nature of Matter and Change* (Silberberg 206)

*McGraw-Hill Ryerson Chemistry 11*, Ontario Edition (Mustoe, *et al*. 458)

SPECIFIC LEARNING OUTCOME

**C11-2-02:** Research Canadian and global initiatives to improve air quality.

(1.0 hour)

SLO: C11-2-02

## SUGGESTIONS FOR INSTRUCTION

### Entry-Level Knowledge

The following learning outcomes were addressed in Grade 10 Science:

- S2-4-07: Investigate and evaluate evidence that climate change occurs naturally and can be influenced by human activities.
- S2-4-08: Discuss potential consequences of climate change.

### Assessing Prior Knowledge

Check for understanding of prior knowledge and review as necessary. Prior knowledge can be reviewed and/or assessed by using any of the KWL strategies (e.g., Concept Map, Knowledge Chart, Think-Pair-Share—see *SYSTH*, Chapter 9).

### TEACHER NOTES

Numerous websites, such as those listed below, detail Canadian and global initiatives to mitigate the effects of global warming and its potential connections to overall climate instability.


World Health Organization. Protection of the Human Environment: <http://www.who.int/phe/en/>
This website provides a starting point to research global initiatives related to human health, the environment, and sustaining healthy living.

Natural Resources Canada. Climate Change in Canada. Teacher's Guide: <http://adaptation.nrcan.gc.ca/posters/teachers/resourc_e.asp>
This website offers a series of well-researched poster-style panels that detail the implications of changing climate in various regions of Canada. The posters can be ordered in hard copy for classroom use or viewed online. There are lesson

### General Learning Outcome Connections

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

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

**GLO D5:** Understand the composition of the Earth's atmosphere, hydrosphere, and lithosphere, as well as the processes involved within and among them.

**GLO E2:** Describe and appreciate how the natural and constructed world is made up of systems and how interactions take place within and among these systems.

**GLO E3:** Recognize that characteristics of materials and systems can remain constant or change over time, and describe the conditions and processes involved.

SKILLS AND ATTITUDES OUTCOMES

**C11-0-R1:** Synthesize information obtained from a variety of sources.
Include: print and electronic sources, specialists, other resource people

**C11-0-R2:** Evaluate information obtained to determine its usefulness for information needs.
*Examples: scientific accuracy, reliability, currency, relevance, balance of perspectives, bias…*

**C11-0-R4**: Compare diverse perspectives and interpretations in the media and other information sources.

**C11-0-R5:** Communicate information in a variety of forms appropriate to the audience, purpose, and context.

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plans for the poster series developed from learning outcomes in the *Common Framework of Science Learning Outcomes K to 12: Pan-Canadian Protocol for Collaboration on School Curriculum* (Council of Ministers of Education, Canada). This Government of Canada website provides information on actions related to clean air.

Environment Canada. Clean Air Online: <http://www.ec.gc.ca/cleanair-airpur/>

This website describes and provides information on various pollutants, including smog, acid rain, ground-level ozone, particulate matter, persistent organic matter, and mercury. It describes sources and effects of pollution and provides an air quality forecast.

---. ---. Science and Research: <http://www.ec.gc.ca/cleanair-airpur/Science_and_Research-WS955E8065-1_En.htm>

This website provides a navigation bar that links to a variety of federal government initiatives, current research, and legislation related to air quality.

---. The CEPA Environmental Registry: <http://www.ec.gc.ca/CEPARegistry/>

In 1999, the Government of Canada introduced its 10-year Action Plan on Clean Air as a commitment to improve air quality. Through the efforts of the provinces, territories, and the private sector, the Government of Canada hopes to develop the awareness of and means to lessen industrial emissions and work toward a cleaner environment for Canadians.

Canada's 10-year Action Plan on Clean Air was intended to address these areas of science, standards, and public policy:

- *Canadian Environmental Protection Act* (CEPA) 1999
- science, reporting, and monitoring
- vehicles and fuels
- Canada-wide standards
- international agreements
- infrastructure
- acid rain

Information on international initiatives related to global climate change can be obtained by using search engine keywords such as "Clean Air Initiative," "CAI," and "Kyoto Protocol."

SPECIFIC LEARNING OUTCOME

**C11-2-02:** Research Canadian and global initiatives to improve air quality.

*(continued)*

The Kyoto Protocol has sharpened the focus of the role of forests in contributing to or mitigating climate change. Forested ecosystems, including both above and below soil-surface biomass, are large storehouses of carbon. Growing new forests can extract $CO_2$ from the atmosphere, and should, therefore, help in mitigating the potential warming effects from excess human production of $CO_2$.

### Activities

Have students access websites for information on current initiatives in engaging citizens to respond to the challenges presented by a future with greater abundances of atmospheric carbon dioxide. Encourage comparisons among Canadian projects and those supported by other countries around the world.

## SUGGESTIONS FOR ASSESSMENT

### Research Reports

Have students research and report their findings either individually or in small groups. The information collected could be presented as

- written reports
- oral presentations
- bulletin board displays
- multimedia presentations

### Visual Displays

Students could present the material they have collected using

- posters
- pamphlets
- bulletin boards
- models

Each of these presentation styles could be assessed using an appropriate rubric created with students prior to the assignment. A sample of a presentation rubric is provided in Appendix 10 of this document.

SKILLS AND ATTITUDES OUTCOMES

**C11-0-R1:** Synthesize information obtained from a variety of sources.
Include: print and electronic sources, specialists, other resource people

**C11-0-R2:** Evaluate information obtained to determine its usefulness for information needs.
*Examples: scientific accuracy, reliability, currency, relevance, balance of perspectives, bias…*

**C11-0-R4:** Compare diverse perspectives and interpretations in the media and other information sources.

**C11-0-R5:** Communicate information in a variety of forms appropriate to the audience, purpose, and context.

## Journal Writing

Specific learning outcome C11-2-02 (similar to C11-2-01) directly connects to the personal lifestyles of students and their future behaviour as energy consumers. In their journals, students can reflect on the causes and consequences of poor air quality and the difficulties with implementing global regulations or the tenets of signed agreements such as the Kyoto Protocol of 1997. Such international cooperation and the eventual implementation of agreements combine complex social, political, and scientific dimensions. As such, they present worthwhile STSE decision-making issues for classroom discussion.

## Paper-and-Pencil Tasks

Once students have completed the activities for this leaning outcome, they should be able to answer questions such as the following:

- What are some of the air pollutants about which we are most concerned?
- Why are these pollutants so much of a concern?
- What evidence is there that the concern is real?
- What is the Government of Canada doing to monitor air quality?
- How and where is air quality measured in Canada?
- What is the Kyoto Accord? When was it signed? Has Canada adopted specific targets for the reduction of $CO_2$ from industrial and domestic uses of fossil fuels?
- What governments have not yet signed the Kyoto Accord? (As of 2006, Australia, China, and the United States were non-signatories.)
- Are there justifiable reasons for delaying adoption of the Kyoto Accord based on sound scientific evidence?
- What other, non-scientific reasons would a government have for not signing such an environmental accord?
- What was the nature of the Montreal Declaration of 2005, signed by more than a hundred nations?

SPECIFIC LEARNING OUTCOME

**C11-2-02:** Research Canadian and global initiatives to improve air quality.

*(continued)*

### Climate Science Debate

The scientific community of atmospheric scientists and climatologists is far from reaching consensus on the implications of a planet with higher levels of $CO_2$. What is abundantly clear, however, is that the concentrations of carbon dioxide, methane, and certain other greenhouse-enhancing gases are rising steadily. Records of past atmospheric concentrations of these species (principally from ice core research) demonstrate that there have been episodes in the past 400 000 years when concentrations of $CO_2$ have been higher than present levels. What is different about the current epoch is the rate of change in the $CO_2$ levels. The global results of such a rapid increase in atmospheric $CO_2$ is a great unknown.

It is important for students to conduct research that is fair and representative of alternative, and viable, scientific viewpoints on such a vital issue. Students should research climate science, as articulated by organizations such as The Friends of Science—Providing Insight into Climate Science (see <http://www.friendsofscience.org/>). This large, international community of climate scientists, for instance, holds views quite contrary to what has been supported by Environment Canada and the United Nations' (UN) Intergovernmental Panel on Climate Change (IPCC) over the past decade.

Most Canadian climatologists take their research lead from the World Meteorological Organization (WMO), which is a UN-sponsored climate and weather science working group. The IPCC acts under the auspices of the UN and WMO. The IPCC website, located at <http://www.ipcc.ch/>, is a massive portal to the latest research in climate science, and contains pages for general consumption, as well as a significant body of technical publications. For instance, a number of presentation-quality graphics for classroom use are available at <http://www.ipcc.ch/present/presentations.htm>.

Students could role-play disparate points of view within the climate science community. Alternatively, local science faculty could bring expert interventions into the classroom. Staff of the Department of Geography at The University of Winnipeg and Environment Canada can be helpful in this outreach capacity. Insight into controversial issues, as discussed among scientific "experts," is one of the hallmarks of sound, rational scientific debate. Engage students in such debate, where appropriate.

### SKILLS AND ATTITUDES OUTCOMES

**C11-0-R1:** Synthesize information obtained from a variety of sources.
Include: print and electronic sources, specialists, other resource people

**C11-0-R2:** Evaluate information obtained to determine its usefulness for information needs.
*Examples: scientific accuracy, reliability, currency, relevance, balance of perspectives, bias…*

**C11-0-R4:** Compare diverse perspectives and interpretations in the media and other information sources.

**C11-0-R5:** Communicate information in a variety of forms appropriate to the audience, purpose, and context.

## LEARNING RESOURCES LINKS

*Chemistry* (Chang 732)

*Chemistry: The Molecular Nature of Matter and Change* (Silberberg 206)

*McGraw-Hill Ryerson Chemistry 11*, Ontario Edition (Mustoe, *et al.* 458)

*Nelson Chemistry 12: College Preparation*, Ontario Edition (Davies, *et al.* 343)

SPECIFIC LEARNING OUTCOMES

**C11-2-03:** Examine the historical development of the measurement of pressure.

*Examples: the contributions of Galileo Galilei, Evangelista Torricelli, Otto von Guericke, Blaise Pascal, Christiaan Huygens, John Dalton, Joseph Louis Gay-Lussac, Amadeo Avogadro…*

**C11-2-04:** Describe the various units used to measure pressure.

Include: atmospheres (atm), kilopascals (kPa), millimetres of mercury (mmHg), millibars (mb)

(1.0 hour)

SLO: C11-2-03
SLO: C11-2-04

## SUGGESTIONS FOR INSTRUCTION

### Entry-Level Knowledge

Students may be familiar with the barometer from discussions of barometric pressure in Grade 10 Science.

### TEACHER NOTES

A historical treatment of the development of devices to measure gas pressure is important for students to understand the progress of applications of scientific principles.

### Discrepant Event

Can you vacuum pack a student? A powerful domestic vacuum cleaner and a large heavy-gauge plastic garbage bag can be used to demonstrate a particularly interesting approach to changes in air pressure, as described in Appendix 2.1: Can You Vacuum Pack a Person? Have a student volunteer climb into the bag and sit down (this works best if the student is less than 170 cm tall). Gather the bag around the student's neck underneath the chin and insert the narrow tubular upholstery attachment into the gathered bag. Make sure the student can breathe easily! Have the student cup the end of the attachment to prevent the bag from getting sucked into the attachment. Turn on the vacuum cleaner. A significant enough vacuum will be created to immobilize the student. The student may fall over! **Use caution throughout.**

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

**GLO B1:** Describe scientific and technological developments—past and present—and appreciate their impact on individuals, societies, and the environment, both locally and globally.

**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.

Skills and Attitudes Outcomes

C11-0-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…*

C11-0-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…*

## Timeline Activity

The activity described in Appendix 2.2: A Historical Timeline of the Measurement of Pressure enables students to appreciate more clearly the historical timeline of the scientists identified in the following Teacher Notes. When creating the timeline, students could refer to the Peer-Assessment Rubric provided with Appendix 2.2.

## Teacher Notes

The information presented here is a summary of texts and other resources.

- **1564–1642: Galileo Galilei** developed the suction pump. He used air to draw underground water up a column, similar to how a syringe draws water. He was perplexed as to why there was a limit to the height water could be raised.
- **1643: Evangelista Torricelli** developed the first barometer. He carried on Galileo's work by determining that the limit to the height Galileo's pump could draw water was due to atmospheric pressure. He invented a closed-end tube filled with mercury that, in turn, was suspended in a shallow dish filled with liquid mercury. The height of the column of mercury in the tube (measured in mmHg) was equal to the atmospheric pressure acting on the mercury in the pan.
- **1643–1645: Otto von Guericke** made a pump that could create a vacuum so strong that a team of 16 horses could not pull two metal hemispheres apart. He reasoned that the hemispheres were held together by the mechanical force of the atmospheric pressure rather than the vacuum. (**Note:** Point out to students that vacuums don't "suck"—it is the force of the atmosphere that pushes. This demonstration can be reproduced by forcing two bathroom plungers together and having students attempt to pull them apart.)
- **1648: Blaise Pascal** used Torricelli's "barometer" and travelled up and down a mountain in southern France. He discovered that the pressure of the atmosphere increased as he moved down the mountain. Sometime later the SI unit of pressure, the Pascal, was named after him.
- **1661: Christiaan Huygens** developed the manometer to study the elastic forces in gases.
- **1801: John Dalton** stated that in a mixture of gases the total pressure is equal to the sum of the pressure of each gas, as if it were in a container alone. The pressure exerted by each gas is called its partial pressure.
- **1808: Joseph Louis Gay-Lussac** observed the law of combining volumes. He noticed that, for example, two volumes of hydrogen combined with one volume of oxygen to form two volumes of water.

SPECIFIC LEARNING OUTCOMES

C11-2-03: Examine the historical development of the measurement of pressure.

*Examples: the contributions of Galileo Galilei, Evangelista Torricelli, Otto von Guericke, Blaise Pascal, Christiaan Huygens, John Dalton, Joseph Louis Gay-Lussac, Amadeo Avogadro…*

C11-2-04: Describe the various units used to measure pressure.

Include: atmospheres (atm), kilopascals (kPa), millimetres of mercury (mmHg), millibars (mb)

*(continued)*

- **1811: Amadeo Avogadro** suggested, from Gay-Lussac's experiments conducted three years earlier, that the pressure in a container is directly proportional to the number of particles in that container (known as Avogadro's Hypothesis). This can be illustrated by blowing up a balloon, ball, or tire: the more air is added the larger the container becomes due to increased pressure. (**Note:** Avoid any mention of the mole or pressure-volume-temperature relationships at this time.)

Students were introduced to atmospheric pressure in Grade 10 Science. Recommended student learning resources often provide pressure measurements in units of kilopascals (kPa). If students used Environment Canada graphs as data sources for weather and climate in Grade 10, they would have been introduced to millibar units.

The *millibar* is a meteorological unit of atmospheric pressure. One bar is equal to standard atmospheric pressure or 1 atm. For purposes of unit conversions, use the conversion 1 kPa = 10 mb.

The unit *atmosphere* (atm) was derived from standard atmospheric pressure at sea level. One atmosphere is equal to 760 mmHg, or 101.325 kPa. Two atmospheres is twice the standard atmospheric pressure, and so on. The unit mm of mercury is not commonly used today. However, it is used extensively in the science laboratory. Some aneroid barometers found in the home use both mm of mercury and another unit, such as kilopascals.

It is not necessary at this time to have students convert from one pressure unit to another. This can be done during the section on gas law problems (later in Topic 2).

Most students will have experienced the increase in pressure when diving into a swimming pool. Relate the pressure of the atmosphere to the relative pressure of salt water and fresh water.

Chemistry textbooks often present a discussion of pressure as force per unit area. They use, as an example, the pressure exerted by high-heeled shoes compared to the pressure exerted by regular shoes.

SKILLS AND ATTITUDES OUTCOMES

**C11-0-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…*

**C11-0-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…*

### Demonstration

Use a clean, metallic solvent container or can that has a small threaded cap to demonstrate the force of the atmosphere. Boil a small amount of water in the bottom of the container, and then quickly close the cap and cool the closed container. For more impressive results, select a student to come up and gently touch the exterior top of the container as soon as it is sealed, wait a moment, and, as if by "magic," the container is crushed. Discuss the results in terms of *interior* and *exterior pressure* on the container.

### TEACHER NOTES

Many certifying agencies for scuba diving can be contacted for information on the physics and physiology of diving. The following table shows the comparison between depths of water and the corresponding pressure of air and water.

**Water Pressure Comparison Chart**

| Depth | | | | Pressure | | |
|---|---|---|---|---|---|---|
| Fresh (ft.) | Fresh (m) | Salt (ft.) | Salt (m) | psi | atm | kPa (approx.) |
| 0 | 0 | 0 | 0 | 14.7 | 1.0 | 100 |
| 34 | 10 | 33 | 10 | 29.4 | 2.0 | 200 |
| 68 | 21 | 66 | 20 | 44.1 | 3.0 | 300 |
| 102 | 31 | 99 | 30 | 58.8 | 4.0 | 400 |
| 136 | 41 | 132 | 40 | 73.5 | 5.0 | 500 |

**Extension:** Show students how to read an open-ended and a closed-ended manometer, if available.

SPECIFIC LEARNING OUTCOMES

**C11-2-03:** Examine the historical development of the measurement of pressure.

*Examples: the contributions of Galileo Galilei, Evangelista Torricelli, Otto von Guericke, Blaise Pascal, Christiaan Huygens, John Dalton, Joseph Louis Gay-Lussac, Amadeo Avogadro…*

**C11-2-04:** Describe the various units used to measure pressure.

Include: atmospheres (atm), kilopascals (kPa), millimetres of mercury (mmHg), millibars (mb)

*(continued)*

## SUGGESTIONS FOR ASSESSMENT

### Rubrics/Checklists

See Appendix 10 for a variety of rubrics and checklists that can be used for self-assessment, peer assessment, and teacher assessment.

### Research Projects

Students can research the contributions of each of the scientists noted in learning outcome C11-2-03, either individually or as a small group, and present their findings in the form of

- written reports
- oral presentations
- posters
- pamphlets
- bulletin board displays
- multimedia presentations
- website presentations

### Discussion Questions

Discuss the following questions:

- Scuba divers using compressed air must be very careful not to hold their breath when ascending from a depth, as life-threatening damage to the respiratory system can result. Why might this happen? Explain.
- What is the record for the deepest “free” dive without the use of scuba tanks? How is a free dive possible without damage to the respiratory system?
- What would be another name for a vacuum cleaner?

SKILLS AND ATTITUDES OUTCOMES

**C11-0-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…*

**C11-0-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…*

### Pencil-and-Paper Tasks

Once students have completed the learning activities suggested for learning outcomes C11-2-03 and C11-2-04, they should be able to answer questions such as the following:

- Of the scientists discussed, who in your opinion made the greatest contribution to the understanding of gases? Provide reasons for your choice.
- Why would salt water cause greater pressure for a diver than fresh water?
- What pressure units are generally used most in everyday life?
- How does a barometer differ from a manometer?
- How does an aneroid barometer differ from a mercury barometer? Which one is more accurate? Explain why.
- **Enrichment:** How could we measure the buoyant force of air?

### Journal Entry

Journal topics for discussion could include the following:

- where the various pressure units are used in everyday life
- the "vacuum pack" demonstration
- self-contained underwater breathing apparatus (scuba) diving
- "free" scuba diving
- STSE issues associated with diving

## LEARNING RESOURCES LINKS

*Chemistry* (Chang 166)

*Chemistry: The Central Science* (Brown, *et al.* 367)

*Chemistry: Concepts and Applications* (Phillips, Strozak, and Wistrom 378)

*Chemistry: The Molecular Nature of Matter and Change* (Silberberg 176)

*Glencoe Chemistry: Matter and Change* (Dingrando, *et al.* 390)

*Introductory Chemistry: A Foundation* (Zumdahl 361)

*McGraw-Hill Ryerson Chemistry 11*, Ontario Edition (Mustoe, *et al.* 425)

*Nelson Chemistry 11*, Ontario Edition (Jenkins, *et al.* 424)

*Nelson Chemistry 12: College Preparation*, Ontario Edition (Davies, *et al.* 331)

*Prentice Hall Chemistry: Connections to Our Changing World* (LeMay, *et al.* 425)

SPECIFIC LEARNING OUTCOME

**C11-2-05:** Experiment to develop the relationship between the pressure and volume of a gas using visual, numerical, and graphical representations.

Include: historical contributions of Robert Boyle

(1.0 hour)

SLO: C11-2-05

## SUGGESTIONS FOR INSTRUCTION

### Entry-Level Knowledge

Students may have no entry-level knowledge other than a mathematical understanding of an inverse proportion relationship and the ability to draw a graph with two variables.

### TEACHER NOTES

The intent of specific learning outcome C11-2-05 (as well as C11-2-06, C11-2-07, and C11-2-08) is not simply to provide the relationship formulas, but also to have students develop the relationships using visual, numerical, graphical, symbolic, and particulate representations. (For a discussion of these five modes of representation, see Section 2: Implementation of Grade 11 Chemistry.)

### Discrepant Events

1. An effective way to introduce the gas law, and to illustrate it visually, is with the use of a "drinking bird" apparatus (see Appendix 2.3: The Drinking Bird). This apparatus demonstrates 36 physical properties and laws. Leave the explanation for this event until the end of this sequence of learning outcomes (C11-2-05 to C11-2-08). Once students have been introduced to the remaining learning outcomes, many of them will be able to provide their own explanations. The complete explanation can be found in Appendix 2.3.
2. This event requires either a manual or an electric vacuum pump. When using the pump, ensure that there is sufficient oil in the pump and that a drying tube is attached to the suction side of it. Place marshmallows in the chamber and turn on the pump. When the demonstration is finished, allow air to enter the chamber *before* turning off the pump, or oil may get drawn out of the pump.

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

**GLO C7:** Work cooperatively and value the ideas and contributions of others while carrying out scientific and technological activities.

**GLO C8:** Evaluate, from a scientific perspective, information and ideas encountered during investigations and in daily life.

SKILLS AND ATTITUDES OUTCOMES

**C11-0-S5:** Collect, record, organize, and display data using an appropriate format.
*Examples: labelled diagrams, graphs, multimedia applications, software integration, probeware…*

**C11-0-S7:** Interpret patterns and trends in data, and infer and explain relationships.

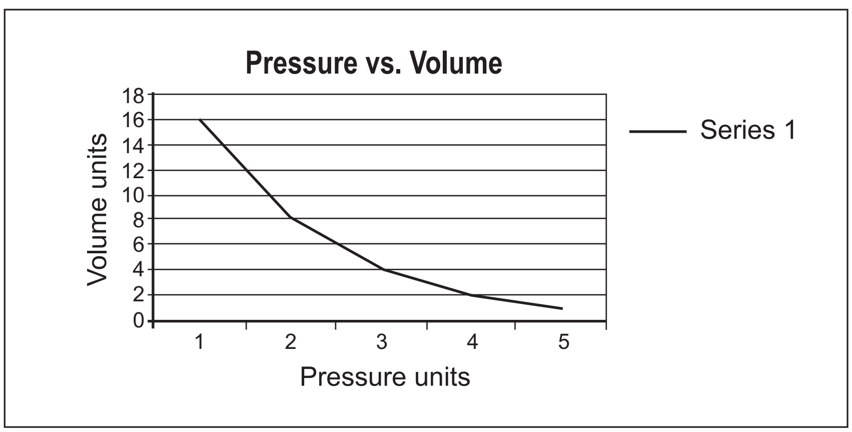
**C11-0-S8:** Evaluate data and data-collection methods for accuracy and precision.
Include: discrepancies in data, sources of error, percent error

**C11-0-S9:** Draw a conclusion based on the analysis and interpretation of data.
Include: cause-and-effect relationships, alternative explanations, supporting or rejecting a hypothesis or prediction

## Laboratory Activity

Students can work toward the development of the relationship between volume and pressure by performing a lab with these two variables in mind. Numerous procedures for conducting such a lab are available in standard chemistry resources. One variation making use of a syringe apparatus is described in *McGraw-Hill Ryerson Chemistry 11* (Mustoe, *et al.* 430).

In this lab activity, a plastic pipette is calibrated to show a change in volume as pressure is applied. The data would then be graphed and a relationship established. Numerical and graphical analyses should be built into the lab activity, in addition to developing an algorithmic relationship based on the non-linear inverse relationship (it is actually a "power law" mathematically and has an analogue in Isaac Newton's Law of Cooling). A typical graph for an inverse relationship is shown below.




As an alternative activity, students could gain experience with an inverse relationship using syringes and books. This could be done as a demonstration, with students conducting the activity, or as a full lab if enough syringes are available. The syringes usually have a short lifetime because of excessive wear and, over time, produce poor results. The syringes are plugged and held in place by small blocks of wood. When books are placed on a syringe, the plunger is depressed and a reading of the volume can be made that corresponds to the pressure caused by the books.

SPECIFIC LEARNING OUTCOME

**C11-2-05:** Experiment to develop the relationship between the pressure and volume of a gas using visual, numerical, and graphical representations.

Include: historical contributions of Robert Boyle

*(continued)*

### Working with Robert Boyle's Original Data

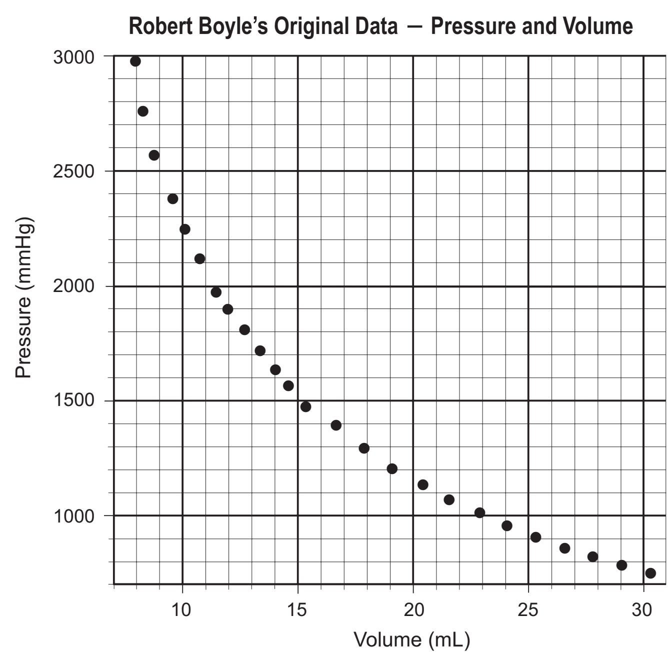
Students may find it interesting to model the pressure-volume (P-V) relationship through a comparison of their own experimental data with that recorded in the laboratory notes of Robert Boyle. Here are his results for such a comparison:

### Robert Boyle's Data

| Volume (mL) | Pressure (mmHg) |
|---|---|
| 30.48 | 739.775 |
| 29.21 | 776.275 |
| 27.94 | 811.2 |
| 26.67 | 850.9 |
| 25.4 | 896.925 |
| 24.13 | 939.8 |
| 22.86 | 998.525 |
| 21.59 | 1057.28 |
| 20.32 | 1122.35 |
| 19.05 | 1195.37 |
| 17.78 | 1277.92 |
| 16.51 | 1379.52 |
| 15.24 | 1493.82 |
| 14.605 | 1557.32 |
| 13.97 | 1627.17 |
| 13.335 | 1703.37 |
| 12.7 | 1795.45 |
| 12.065 | 1882.78 |
| 11.43 | 1978.03 |
| 10.795 | 2101.85 |
| 10.16 | 2232.03 |
| 9.525 | 2363.77 |
| 8.89 | 2551.1 |
| 8.255 | 2738.42 |
| 7.62 | 2986.07 |

### Graphical Representation

A graphical representation of Boyle's data follows:



### SKILLS AND ATTITUDES OUTCOMES

**C11-0-S5:** Collect, record, organize, and display data using an appropriate format.
*Examples: labelled diagrams, graphs, multimedia applications, software integration, probeware…*

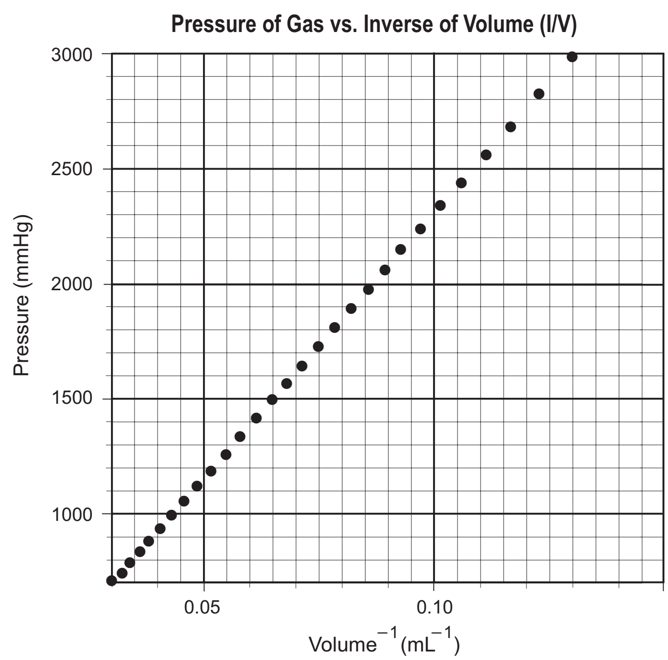
**C11-0-S7:** Interpret patterns and trends in data, and infer and explain relationships.

**C11-0-S8:** Evaluate data and data-collection methods for accuracy and precision.
Include: discrepancies in data, sources of error, percent error

**C11-0-S9:** Draw a conclusion based on the analysis and interpretation of data.
Include: cause-and-effect relationships, alternative explanations, supporting or rejecting a hypothesis or prediction

The plot below demonstrates how to "straighten" the curve of the data by recognizing that the original relationship observed was an *inverse* one (i.e., as pressure goes up, volume of the gas sample goes down).

We then test to see whether P x V = constant by re-plotting the data as pressure versus the *inverse* of volume. The straight line indicates that there is indeed a linear relationship between P and 1/V, and hence we can conclude that $P_nV_n$ = constant.




## TEACHER NOTES

Students often have difficulty with inverse mathematical relationships. (Review the discussion of the *modes of representation* in Section 2 of this document.) Have students establish a ratio of the initial and final volumes and ask them to predict what effect this ratio will have on the initial pressure. Will the ratio make the resultant pressure larger or smaller?

SPECIFIC LEARNING OUTCOME

**C11-2-05:** Experiment to develop the relationship between the pressure and volume of a gas using visual, numerical, and graphical representations.

Include: historical contributions of Robert Boyle

*(continued)*

### Sample Problem

If 3 L of gas is initially at a pressure of 1 atm, what would be the new pressure to cause the volume of the gas to become 0.5 L?

Two ratios are possible to make the units cancel:

a) $\dfrac{3\ \text{L}}{0.5\ \text{L}}$ or b) $\dfrac{0.5\ \text{L}}{3\ \text{L}}$

According to the experimental results that students would have obtained from the lab activity V $\alpha$ 1/P, if the volume decreases, then the pressure must have increased. In this example, the pressure must have increased, causing the volume to decrease. Therefore, we must multiply by the ratio that would make the answer larger than the initial pressure of 1 atm. Clearly, ratio (a) is the correct one. Therefore:

$$\frac{3\ \cancel{\text{L}}}{0.5\ \cancel{\text{L}}} \times 1\ \text{atm} = 6\ \text{atm}$$

After each problem, students should "test" or check their prediction by using logic and the experimental inverse relationship.

*Units of Standard Temperature/Pressure:*

STP (Standard Temperature and Pressure) =
273 K (0°C), 1 atm (101.3 kPa or 760 mmHg)

*"Room" Conditions:*

298 K (25°C), 1 atm (101.3 kPa or 760 mmHg)

### On a Particulate Level

Suggest that students use a drawing of a syringe or a bicycle pump filled with dots to represent particles. Have students illustrate what the particles would look like before pressure was applied, and then after. With a smaller volume, the same number of particles will be closer together. This should be related back to the Kinetic Molecular Theory. Have students illustrate their discussions using a Concept Relationship Frame (see *SYSTH* 11.35).

If probeware is available at school, use lab activities to develop the relationship between pressure and volume. Microscale labs are also excellent means of demonstrating Boyle's Law and other gas laws.

Skills and Attitudes Outcomes

**C11-0-S5:** Collect, record, organize, and display data using an appropriate format.
*Examples: labelled diagrams, graphs, multimedia applications, software integration, probeware…*

**C11-0-S7:** Interpret patterns and trends in data, and infer and explain relationships.

**C11-0-S8:** Evaluate data and data-collection methods for accuracy and precision.
Include: discrepancies in data, sources of error, percent error

**C11-0-S9:** Draw a conclusion based on the analysis and interpretation of data.
Include: cause-and-effect relationships, alternative explanations, supporting or rejecting a hypothesis or prediction

Robert Boyle (1627-1691) used a J-shaped glass tube with a sealed end to measure the height of air trapped by mercury that was added to the open end of the tube. After more mercury was added, the height of the trapped air became less. This helped Boyle deduce the relationship between pressure and volume. Robert Boyle and Robert Hooke constructed an air pump to use in their experiments.

### Did You Know?

Edme Mariotte of France discovered the inverse correlation between volume and pressure independent of Robert Boyle of Ireland. In Australia and the West Indies, Boyle's Law is called Mariotte's Law.

### Teacher Resources


University of Waterloo. *CHEM 13 NEWS*:
<http://www.chemistry.uwaterloo.ca/about/outreach/chem13news/index.html>
Articles in *CHEM 13 NEWS*, an online teacher resource maintained by the University of Waterloo, are useful for discussing the historical development of the gas laws, together with demonstrations and lab activities.

The Physics Hypertext. Thermal Physics. Gas Laws:
<http://hypertextbook.com/physics/thermal/gas-laws/>
Maintained by Glenn Elert, this website contains a detailed review of the gas laws, along with additional research material.

### Activity/Demonstration

1. A Cartesian diver not only illustrates Boyle's Law, but can also be a vehicle for students to demonstrate their ingenuity and creativity. The design for these divers can be simple or complex. Students can have fun with science by making divers and testing them. A number of designs are suggested in Appendix 2.4: Make Your Own Cartesian Diver. This activity provides additional challenges and problems for students to solve, including the creation of variations:
   - the sunken diver
   - Cartesian retrievers
   - Cartesian counters and messages
   - diving whirligigs
   - closed-system divers

SPECIFIC LEARNING OUTCOME

**C11-2-05:** Experiment to develop the relationship between the pressure and volume of a gas using visual, numerical, and graphical representations.

Include: historical contributions of Robert Boyle

*(continued)*

- density-column divers
- remote-controlled divers
- the Cartesian see-saw
- concentric divers
- the electric diver

2. If the rubber bulb of a glass eyedropper is partially filled with water, it will become a Cartesian diver when placed into a plastic 2 L pop bottle filled with water. The buoyancy of the "diver" is adjusted until it just floats. When the bottle is squeezed, the volume of the bulb decreases, the density of the diver decreases, and the diver descends.
3. Large wooden matchsticks can also be used as divers in a similar way. The buoyancy is regulated by cutting off part of a matchstick until it just floats.

## SUGGESTIONS FOR ASSESSMENT

### Rubrics/Checklists

See Appendix 10 for a variety of rubrics and checklists that can be used for self-assessment, peer assessment, and teacher assessment.

### Paper-and Pencil-Tasks

Students should be able to solve quantitative problems involving pressure and volume using dimensional analysis.

Students should solve pressure versus volume problems using inspection of ratios in order to determine which ratio will give them a plausible answer. Encourage oral expression in class.

### Laboratory Reports

The activities developed for specific learning outcome C11-2-05 could be assessed either as formal lab reports using the Laboratory Report Format (see *SYSTH* 14.12) or by using questions and answers from the data collected from the various activities.

SKILLS AND ATTITUDES OUTCOMES

**C11-0-S5:** Collect, record, organize, and display data using an appropriate format.
*Examples: labelled diagrams, graphs, multimedia applications, software integration, probeware…*

**C11-0-S7:** Interpret patterns and trends in data, and infer and explain relationships.

**C11-0-S8:** Evaluate data and data-collection methods for accuracy and precision.
Include: discrepancies in data, sources of error, percent error

**C11-0-S9:** Draw a conclusion based on the analysis and interpretation of data.
Include: cause-and-effect relationships, alternative explanations, supporting or rejecting a hypothesis or prediction

### Journal Writing

Teachers may wish to demonstrate some interesting discrepant events and activities that connect with pressure and volume relationships, thereby providing students with opportunities to reflect on and to construct personalized explanations of the phenomena observed. Students may also have questions whose explanations will come later in Topic 2 of Grade 11 Chemistry.

If students observed The Drinking Bird activity (Appendix 2.3), have them propose explanations as to why it works.

## LEARNING RESOURCES LINKS

*Chemistry: The Central Science* (Brown, *et al.* 371)

*Chemistry: Concepts and Applications* (Phillips, Strozak, and Wistrom 383)

*Chemistry with Calculators* (Holmquist and Volz)—Available from Vernier: <http://www.vernier.com/chemistry/>

*Chemistry with Computers* (Holmquist and Volz, Boyle's Law: Pressure-Volume Relationship in Gases)—Available from Vernier: <http://www.vernier.com/chemistry/>

*Glencoe Chemistry: Matter and Change* (Dingrando, *et al.* 421)

*Glencoe Chemistry: Matter and Change: CBL Laboratory Manual—Teacher Edition* (LAB 4: Boyle's Law, 13)

*Introductory Chemistry: A Foundation* (Zumdahl 363)

*McGraw-Hill Ryerson Chemistry 11*, Ontario Edition (Mustoe, *et al.* 430)

*Microscale Chemistry Laboratory Manual* (Slater and Rayner-Canham 8)

*Nelson Chemistry 11*, Ontario Edition (Jenkins, *et al.* 424)

*Nelson Chemistry 12: College Preparation*, Ontario Edition (Davies, *et al.* 332)

*PASPort Explorations in Chemistry Lab Manual* (PASCO Scientific)—Available from PASCO: <http://www.pasco.com/hsmanuals/ps2808.html>

PASCO Scientific. Online Science Experiments. Boyle's Law: <http://www.pasco.com/experiments/chemistry/november _2001/home.html>

*Prentice Hall Chemistry: Connections to Our Changing World* (LeMay, *et al.* 431)

SPECIFIC LEARNING OUTCOME

C11-2-06: Experiment to develop the relationship between the volume and temperature of a gas using visual, numerical, and graphical representations.

Include: historical contributions of Jacques Charles, the determination of absolute zero, the Kelvin temperature scale

(2.0 hours)

SLO: C11-2-06

## SUGGESTIONS FOR INSTRUCTION

### Entry-Level Knowledge

Students may be familiar with the barometer from discussions of barometric pressure in Grade 10 Science (Cluster 4: Weather Dynamics).

### TEACHER NOTES

It is recommended that the relationship between temperature and volume be developed experimentally or by a demonstration in which students collect data and draw their own conclusions. It is not intended that all suggested activities be done. Select the appropriate ones for the class.

### Demonstrations/Laboratory Activities

Any of the following activities should first be done by the teacher to ensure safety and accuracy of results. Many of these activities are explained in detail as formal lab experiments in various resources.

1. A simple demonstration is to place a balloon over the mouth of an Erlenmeyer flask containing water at room temperature. Place the flask on a hot plate. The balloon will fill as the air in the flask expands. If the flask is cooled with ice, the balloon will be drawn into the flask.
2. Another simple demonstration is to put about 20 mL of water into an empty 255 mL pop can. Place the can on a hot plate or burner. When the water in the can boils, quickly invert the can into a shallow pan of ice-cold water with beaker tongs.

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

GLO C7: Work cooperatively and value the ideas and contributions of others while carrying out scientific and technological activities.

GLO C8: Evaluate, from a scientific perspective, information and ideas encountered during investigations and in daily life.

SKILLS AND ATTITUDES OUTCOMES

**C11-0-S7:** Interpret patterns and trends in data, and infer and explain relationships.

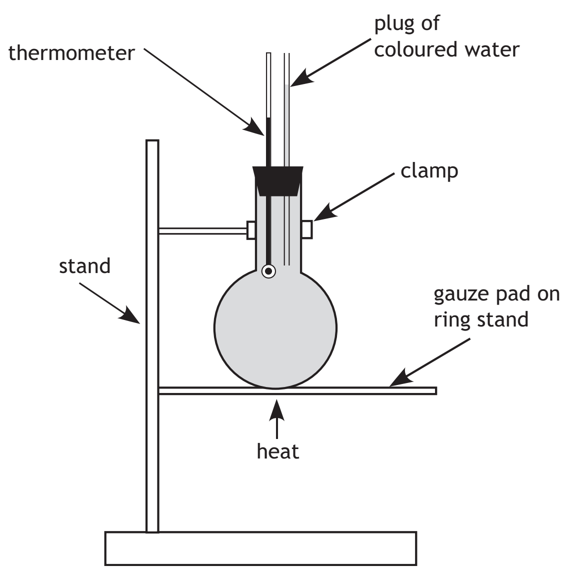
**C11-0-S8:** Evaluate data and data-collection methods for accuracy and precision.
Include: discrepancies in data, sources of error, percent error

**C11-0-S9:** Draw a conclusion based on the analysis and interpretation of data.
Include: cause-and-effect relationships, alternative explanations, supporting or rejecting a hypothesis or prediction

**C11-0-R1:** Synthesize information obtained from a variety of sources.
Include: print and electronic sources, specialists, other resource people

**C11-0-R5:** Communicate information in a variety of forms appropriate to the audience, purpose, and context.

3. A more quantitative approach can be taken by inserting both a thermometer and a 20 cm length of glass tubing into a double-holed stopper, as shown in the following diagram. Insert the stopper assembly tightly into a flat- or round-bottomed flask filled to the top with coloured water. As the stopper is inserted, the fluid rises in the glass tubing. Mark the level of the fluid and record the temperature. Then place the flask in a temperature bath, or slowly heat it with a Bunsen burner, and allow the system to equilibrate. By recording the change in volume at a number of temperatures, data can be collected and given to students to graph. A mixture of acetone and dry ice will produce a temperature of approximately –78°C. Students should plot temperature on the horizontal axis and volume on the vertical axis. By extending the *x*-axis to negative values for temperature, students can extrapolate the plotted points down to the temperature axis to obtain an approximate value for 0 K.




4. The procedure for a lab using syringes can be found in Appendix 2.5: Charles's Law: The Temperature-Volume Relationship in Gases.

SPECIFIC LEARNING OUTCOME

**C11-2-06:** Experiment to develop the relationship between the volume and temperature of a gas using visual, numerical, and graphical representations.

Include: historical contributions of Jacques Charles, the determination of absolute zero, the Kelvin temperature scale

*(continued)*

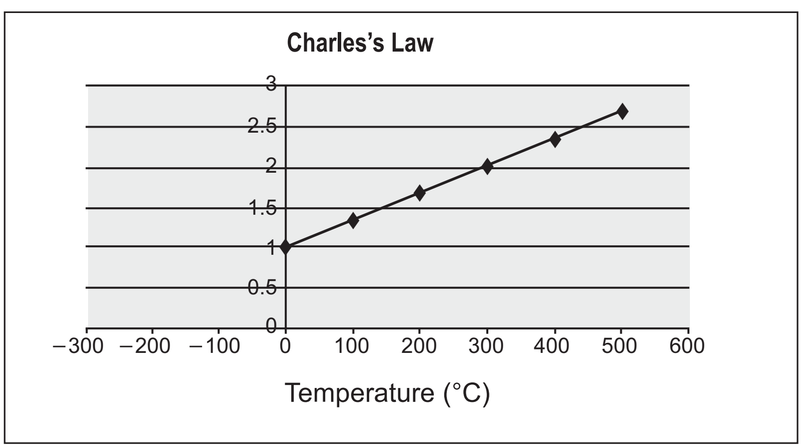
5. The syringes used in the Boyle's Law activity can be immersed in water at varying temperatures and the volumes measured to give straight-line data for V $\alpha$ T.
6. Probeware can also be used for this activity if the equipment is available.
7. The procedure for a lab using animations on the Internet can be found in Appendix 2.7: Charles's Law Lab.

### Did You Know?

Since the dawn of civilization, billions of bakers have known about the relationship between temperature and pressure. The precise mathematical relationship of V $\alpha$ P was not described until 1699, however, when it was discovered by French physicist Guillaume Amontons. The experiment was later repeated by Jacque Alexander César Charles in 1787, and much later by Joseph Louis Gay-Lussac in 1802. Charles did not publish his findings, but Gay-Lussac did. The relationship is most frequently called Charles's Law in the British sphere of influence, and Gay-Lussac's Law in the French sphere, but it was never called Amontons's Law.

### TEACHER NOTES

With the popularity of hot-air balloons in his time, Jacques Charles (1746–1823) investigated the expansion rates of different gases due to temperature changes. Regardless of the gas tested, he found that for every 1°C change, the volume changed 1/273. When the temperature was increased by 273°C, the volume increased by 546/273 times the original volume, or in this case, it doubled.



SKILLS AND ATTITUDES OUTCOMES

**C11-0-S7:** Interpret patterns and trends in data, and infer and explain relationships.

**C11-0-S8:** Evaluate data and data-collection methods for accuracy and precision.
Include: discrepancies in data, sources of error, percent error

**C11-0-S9:** Draw a conclusion based on the analysis and interpretation of data.
Include: cause-and-effect relationships, alternative explanations, supporting or rejecting a hypothesis or prediction

**C11-0-R1:** Synthesize information obtained from a variety of sources.
Include: print and electronic sources, specialists, other resource people

**C11-0-R5:** Communicate information in a variety of forms appropriate to the audience, purpose, and context.

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It was not until 61 years later that William Thomson (later elevated to the peerage as Lord Kelvin) recognized the significance of the 273 and created the Kelvin scale where –273°C is the lowest temperature possible, or absolute zero. Based on this, the *x*-intercept on a graph of volume versus temperature for any gas would always be –273°C. Students could extrapolate the Charles's Law graph and determine a good value for 0 K—that is, the temperature at which the volume becomes zero. For a full-size graph, see Appendix 2.6: Charles's Law.

Lord Kelvin (1824–1907) further reasoned that at this temperature all molecular motion would cease, the kinetic energy would be zero, and the volume of a gas, hypothetically, would also be zero. The actual 0 K is equal to –273.15°C (taken to five significant figures). The advantage of this scale is that there are no negative numbers. We now solve Charles's Law by converting to kelvins and use the same ratio argument we used in Boyle's Law problems. (**Note:** For most student problem sets, the use of 273 K is sufficient.)

kelvin = centigrade + 273.15 or K = °C + 273.15

*Example:*

| | **Kelvin Scale** | **Celsius Scale** |
|---|---|---|
| Absolute zero | 0 K | –273.15°C |
| Freezing point of water | 273.15 K | 0°C |
| Boiling point of water | 373.15 K | 100°C |

## Sample Problems

**Problem 1:**

If the temperature of 6.00 L of a gas at 25.0°C is increased to 227°C, determine the volume at the new temperature.

SPECIFIC LEARNING OUTCOME

C11-2-06: Experiment to develop the relationship between the volume and temperature of a gas using visual, numerical, and graphical representations.

Include: historical contributions of Jacques Charles, the determination of absolute zero, the Kelvin temperature scale

*(continued)*

*Solution:*

First change the temperatures to kelvins.

25.0°C + 273 = 298 K
227°C + 273 = 500 K

There are only two possible ratios for the units to cancel:

a) $\frac{298\ \text{K}}{500\ \text{K}}$ or b) $\frac{500\ \text{K}}{298\ \text{K}}$

From Charles's Law we know that V $\alpha$ T(K). So the volume must get larger since the temperature is increasing. Multiplying the second ratio (b) by the original volumes of 6.00 L would make the values increase, and so (b) is the ratio we need to use.

$$6.00\ \text{L} \times \frac{500\ \cancel{\text{K}}}{298\ \cancel{\text{K}}} = 10.1\ \text{L}$$

**Problem 2:**

If the volume of a gas at –73.0°C is doubled to 48.0 L, calculate the final temperature in Celsius.

*Solution:*

First change the initial temperature to kelvin.

–73.0°C + 273 = 200 K

The possible ratios to solve the problem according to Charles's Law are:

a) $\frac{48.0\ \text{L}}{24.0\ \text{L}}$ or b) $\frac{24.0\ \text{L}}{48.0\ \text{L}}$

Since the volume doubled, the temperature must have increased, and the ratio that increases the temperature values when multiplied by the ratio is (a). Therefore:

$$200\ \text{K} \times \frac{48.0\ \cancel{\text{L}}}{24.0\ \cancel{\text{L}}} = 400\ \text{K}$$

400 K – 273 = 127°C

SKILLS AND ATTITUDES OUTCOMES

**C11-0-S7:** Interpret patterns and trends in data, and infer and explain relationships.

**C11-0-S8:** Evaluate data and data-collection methods for accuracy and precision.
Include: discrepancies in data, sources of error, percent error

**C11-0-S9:** Draw a conclusion based on the analysis and interpretation of data.
Include: cause-and-effect relationships, alternative explanations, supporting or rejecting a hypothesis or prediction

**C11-0-R1:** Synthesize information obtained from a variety of sources.
Include: print and electronic sources, specialists, other resource people

**C11-0-R5:** Communicate information in a variety of forms appropriate to the audience, purpose, and context.

## SUGGESTIONS FOR ASSESSMENT

### Laboratory Activities

The activities outlined for learning outcome C11-2-06 could be assessed either as formal lab reports using the Laboratory Report Format (see *SYSTH* 14.12) or by using questions and answers from the data collected from the various activities. Labs can be adapted from existing materials for CBLs, probes, or computers. A microscale lab is also available. (See Learning Resources Links for references.)

### Research

The stories behind the lives and research of scientists are interesting to read. Have students research the Internet (e.g., Google) for information on the following prominent scientists:

- Guillaume Amontons
- Jacques Alexandre César Charles
- Joseph Louis Gay-Lussac
- William Thomson (Lord Kelvin)

The information gathered could be presented and assessed by a number of methods, including

- letters written to another scientist claiming credit for a discovery
- debates between scientists claiming credit
- posters or pamphlets
- short *PowerPoint* presentations
- written reports

### Paper-and-Pencil Task

The texts cited in the Learning Resources Links provide samples of problems with Charles's Law relationships.

### Did You Know?

Guillaume Amontons developed the air thermometer. It relied on an increase in volume of a gas with temperature, rather than the increase in volume of a liquid.

SPECIFIC LEARNING OUTCOME

**C11-2-06:** Experiment to develop the relationship between the volume and temperature of a gas using visual, numerical, and graphical representations.

Include: historical contributions of Jacques Charles, the determination of absolute zero, the Kelvin temperature scale

*(continued)*

## LEARNING RESOURCES LINKS

*Chemistry* (Chang 172)

*Chemistry* (Zumdahl and Zumdahl 195)

*Chemistry: The Central Science* (Brown, *et al.* 372)

*Chemistry: Concepts and Applications* (Phillips, Strozak, and Wistrom 391)

*Chemistry: The Molecular Nature of Matter and Change* (Silberberg 181)

*Chemistry with Calculators* (Holmquist and Volz)—Available from Vernier: <http://www.vernier.com/chemistry/>

*Glencoe Chemistry: Matter and Change* (Dingrando, *et al.* 423)

*Glencoe Chemistry: Matter and Change: CBL Laboratory Manual – Teacher Edition* (LAB 5: Gay-Lussac's Law, 17)

*Introductory Chemistry: A Foundation* (Zumdahl 367)

*McGraw-Hill Ryerson Chemistry 11*, Ontario Edition (Mustoe, *et al.* 436, 440)

*Microscale Chemistry Laboratory Manual* (Slater and Rayner-Canham 9)

*Nelson Chemistry 11*, Ontario Edition (Jenkins, *et al.* 429)

*Nelson Chemistry 12: College Preparation*, Ontario Edition (Davies, *et al.* 335)

PASCO Scientific. Physics Experiment Kits. Ideal Gas Law Experiment #9954—Available from PASCO: <http://www.pasco.com/products/groups/55-372-2.html>

*Prentice Hall Chemistry: Connections to Our Changing World* (LeMay, *et al.* 435)

### SKILLS AND ATTITUDES OUTCOMES

**C11-0-S7:** Interpret patterns and trends in data, and infer and explain relationships.

**C11-0-S8:** Evaluate data and data-collection methods for accuracy and precision.
Include: discrepancies in data, sources of error, percent error

**C11-0-S9:** Draw a conclusion based on the analysis and interpretation of data.
Include: cause-and-effect relationships, alternative explanations, supporting or rejecting a hypothesis or prediction

**C11-0-R1:** Synthesize information obtained from a variety of sources.
Include: print and electronic sources, specialists, other resource people

**C11-0-R5:** Communicate information in a variety of forms appropriate to the audience, purpose, and context.

## NOTES

SPECIFIC LEARNING OUTCOME

C11-2-07: Experiment to develop the relationship between the pressure and temperature of a gas using visual, numerical, and graphical representations.

Include: historical contributions of Joseph Louis Gay-Lussac

(1.0 hour)

SLO: C11-2-07

## SUGGESTIONS FOR INSTRUCTION

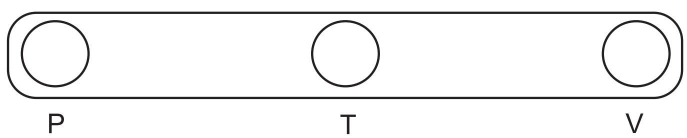
### Entry-Level Knowledge

No prior entry-level knowledge is expected, other than what was indicated for previous learning outcomes in Topic 2: Gases and the Atmosphere.

### Assessing Prior Knowledge

Check for understanding of prior knowledge and review as necessary. Prior knowledge can be reviewed and/or assessed by using any of the KWLstrategies (e.g., Concept Map, Knowledge Chart, Think-Pair-Share—see *SYSTH*, Chapter 9).

If students have not yet visualized the relationship between pressure, volume, and temperature, show them the following visual. Imagine that three holes (labelled P, T, and V) are made in a length of wood such as a wooden ruler, as shown below.




- If P is constant, and held in a fixed position, as T moves down so does V (i.e., T $\alpha$ V).
- If T is constant, and held in a fixed position, the stick acts like a see-saw and shows the inverse relationship for Boyle, P $\alpha$ 1/V.
- Similarly, if V is constant, P $\alpha$ T, and so on.

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

**GLO C7:** Work cooperatively and value the ideas and contributions of others while carrying out scientific and technological activities.

**GLO C8:** Evaluate, from a scientific perspective, information and ideas encountered during investigations and in daily life.

SKILLS AND ATTITUDES OUTCOMES

**C11-0-S5:** Collect, record, organize, and display data using an appropriate format.
*Examples: labelled diagrams, graphs, multimedia applications, software integration, probeware…*

**C11-0-S7:** Interpret patterns and trends in data, and infer and explain relationships.

**C11-0-S9:** Draw a conclusion based on the analysis and interpretation of data.
Include: cause-and-effect relationships, alternative explanations, supporting or rejecting a hypothesis or prediction

## TEACHER NOTES

The presentation of the gas laws is generally *sequential* and *developmental* in its approach. Therefore, the next gas law addressed in this topic follows from the work done by Jacques Charles and Robert Boyle. Recall that in the treatment of specific learning outcome C11-1-02, the Kinetic Molecular Theory was used as a model to explain the properties of gases. An increase in the temperature of a gas increases the kinetic energy of the gas, and thus the frequency of collisions among gaseous particulates. It is not surprising, then, to expect that an increase in temperature would cause an increase in the pressure of a gas at constant volume due to kinetics and energy involved. Joseph Gay-Lussac explored this relationship and found that a direct relationship exists between the kelvin temperature and the pressure of the gas (i.e., $P \alpha T$ [K]).

### Activities/Demonstrations

1. It is recommended that the relationship between the temperature and pressure of a gas be developed experimentally or by a demonstration in which students collect data and draw their own conclusions.
2. If probeware is available, use lab activities designed to determine the relationship between pressure and temperature.
3. A piece of equipment designed specifically to demonstrate the relationship between pressure and temperature can be purchased from most science supply locations. It consists of a metal bulb connected to a pressure gauge and a valve through which air can be added. If the equipment is used correctly, students can achieve a very good experimental value for Gay-Lussac's relationship.
4. If a eudiometer, two-thirds filled with water, is inverted in a 1 L glass graduated cylinder filled with water, the volume of air in the tube can be seen to change as the hydrostatic head changes by lowering and raising the tube in the cylinder. This demonstration can also be quantitative by measuring the volume and calculating the water pressure. The pressure of the air in the tube would be the same as atmospheric pressure when the water levels are aligned opposite each other. **Note:** The partial pressure contribution from the water vapour could be left out of the discussion to make the calculations less complex. Including the partial pressure contribution due to water vapour would be considered enrichment. Dalton's Law of partial pressures is not included in Grade 11 Chemistry, but can certainly be included where circumstances and the interests of students warrant its treatment.

SPECIFIC LEARNING OUTCOME

**C11-2-07:** Experiment to develop the relationship between the pressure and temperature of a gas using visual, numerical, and graphical representations.

Include: historical contributions of Joseph Louis Gay-Lussac

*(continued)*

5. Another method of illustrating the relationship between pressure and temperature is to use a scuba tank (with half its maximum pressure) connected to a regulator and pressure gauge. Measure the initial pressure at below room temperature (as in a cool area of the school), and then measure the pressure as the temperature slowly rises to above room temperature (as in a hot water bath). Students graph the results to obtain Gay-Lussac's discovery of the relationship between pressure and temperature. (See Teacher Notes.)

### TEACHER NOTES

Have someone from a local diving supply shop, or a responsible local diver, come into the school to assist with the demonstration using a scuba tank. North American pressure gauges will read pressure in pounds per square inch (psi). Teachers or students can easily convert this to kilopascals (kPa) or atmospheres (atm).

$$1500\ \cancel{\text{psi}} \times \frac{6.89476\ \text{kPa}}{\cancel{\text{psi}}} = \text{kPa}$$

$$15000\ \cancel{\text{psi}} \times \frac{0.0680460\ \text{atm}}{\cancel{\text{psi}}} = \text{atm}$$

#### Safety Precautions

- Even though safeguards against excessive pressure are built into the scuba tank, it is recommended that teachers use a tank that allows only half the maximum pressure. A "burst" plug of lead is built into the tank valve that will deform and allow the gas from the tank to escape if the pressure in the tank exceeds a set maximum amount.
- Each certified tank must be hydrostatically tested (required every five years) to withstand five-thirds (5/3) of the maximum pressure. School administration should be notified well in advance of this demonstration being done.

SKILLS AND ATTITUDES OUTCOMES

**C11-0-S5:** Collect, record, organize, and display data using an appropriate format.
*Examples: labelled diagrams, graphs, multimedia applications, software integration, probeware…*

**C11-0-S7:** Interpret patterns and trends in data, and infer and explain relationships.

**C11-0-S9:** Draw a conclusion based on the analysis and interpretation of data.
Include: cause-and-effect relationships, alternative explanations, supporting or rejecting a hypothesis or prediction

## SUGGESTIONS FOR ASSESSMENT

### Sample Problems

Most chemistry textbooks provide problems based on P $\alpha$ T (K). Try to avoid having students solve problems using the gas law formulas. Have students use the ratio method whenever possible.

**Problem 1:**

If a sample of gas is found to have a volume of 12.0 L at 0.0°C, calculate the new pressure at 128°C if the volume is constant.

*Solution:*

Initial values: 12.0 L 0.0°C

Final values: _____ 128°C

0.0°C = 273 K and 128°C = 401 K

Two possible ratios would produce the correct unit in the answer.

a) $\frac{273\text{ K}}{401\text{ K}}$ or b) $\frac{401\text{ K}}{273\text{ K}}$

According to the Kinetic Molecular Theory, an increase in the temperature of a gas increases the kinetic energy of the gas and thus the frequency of collisions. Therefore, we can expect that an increase in temperature should cause an increase in the pressure of a gas at constant volume. If P $\alpha$ T (K), then the ratio (b) should cause an increase in the volume to get the correct answer to the problem. Therefore:

$$101.3\text{ kPa} \times \frac{401\ \cancel{\text{K}}}{273\ \cancel{\text{K}}} = 149\text{ kPa}$$

### Laboratory Reports

Students will either have done the lab activity or seen a demonstration of Gay-Lussac's Law. Assessment could include a formal lab report using the Laboratory Report Format (see *SYSTH* 14.12) or questions and answers about the activity or the results.

SPECIFIC LEARNING OUTCOME

**C11-2-07:** Experiment to develop the relationship between the pressure and temperature of a gas using visual, numerical, and graphical representations.

Include: historical contributions of Joseph Louis Gay-Lussac

*(continued)*

### Rubrics/Checklists

See Appendix 10 for a variety of rubrics and checklists that can be used for self-assessment, peer assessment, and teacher assessment.

### Paper-and-Pencil Tasks

Provide students with an opportunity to explain and differentiate between each gas law before going on to the combined laws. This can be done effectively using a Concept Relationship frame (see *SYSTH* 11.21).

### Journal Writing

Students may want to reflect on the results of the activities connected to learning outcome C11-2-07 with, for instance, a description of procedures involved in handling compressed gases in cylinders.

## LEARNING RESOURCES LINKS

*Chemistry* (Chang 172)

*Chemistry* (Zumdahl and Zumdahl 195)

*Chemistry: The Central Science* (Brown, *et al.* 372)

*Chemistry: Concepts and Applications* (Phillips, Strozak, and Wistrom 391)

*Chemistry: The Molecular Nature of Matter and Change* (Silberberg 181)

*Chemistry with Calculators* (Holmquist and Volz, Pressure-Temperature Relationship in Gases)—Available from Vernier: <http://www.vernier.com/chemistry/>

*Chemistry with Computers* (Holmquist and Volz)—Available from Vernier: <http://www.vernier.com/chemistry/>

*Glencoe Chemistry: Matter and Change* (Dingrando, *et al.* 423)

*Glencoe Chemistry: Matter and Change: CBL Laboratory Manual—Teacher Edition* (LAB 5: Gay-Lussac's Law, 17)

*McGraw-Hill Ryerson Chemistry 11*, Ontario Edition (Mustoe, *et al.* 440)

*Nelson Chemistry 11*, Ontario Edition (Jenkins, *et al.* 429)

*Prentice Hall Chemistry: Connections to Our Changing World* (LeMay, *et al.* 435)

### SKILLS AND ATTITUDES OUTCOMES

**C11-0-S5:** Collect, record, organize, and display data using an appropriate format.

*Examples: labelled diagrams, graphs, multimedia applications, software integration, probeware…*

**C11-0-S7:** Interpret patterns and trends in data, and infer and explain relationships.

**C11-0-S9:** Draw a conclusion based on the analysis and interpretation of data.

Include: cause-and-effect relationships, alternative explanations, supporting or rejecting a hypothesis or prediction

## NOTES

SPECIFIC LEARNING OUTCOME

**C11-2-08:** Solve quantitative problems involving the relationships among the pressure, temperature, and volume of a gas using dimensional analysis.

Include: symbolic relationships

(1.0 hour)

SLO: C11-2-08

## SUGGESTIONS FOR INSTRUCTION

### Entry-Level Knowledge

At this point, students should be able to solve gas law problems using the ratio method and dimensional analysis.

### TEACHER NOTES

The ratio method for solving problems can now be applied to more than one variable where several gas laws are used.

So far, students know:

$$V \,\alpha\, 1/P\,, \quad V \,\alpha\, T\,(K)\,, \quad P \,\alpha\, T\,(K)$$

### Sample Problems

**Problem 1:**

If a gas occupies a volume of 25.0 L at 25.0°C and 1.25 atm, *calculate the volume* at 128°C and 0.750 atm.

25.0 L at 298 K and 1.25 atm

___ L at 401 K and 0.75 atm

*Solution:*

Two sets of ratios are possible to give the correct units in the answer.

For V and P:

$$\text{a)}\ \frac{1.25\text{ atm}}{0.750\text{ atm}} \quad \text{or} \quad \text{b)}\ \frac{0.750\text{ atm}}{1.25\text{ atm}}$$

For an inverse proportion, as P decreases, V increases; therefore, ratio (a) should be used.

**General Learning Outcome Connections**

GLO C3: Demonstrate appropriate problem-solving skills when seeking solutions to technological challenge.

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

C11-0-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…*

C11-0-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…*

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For V and T:

a) $\dfrac{401\text{ K}}{298\text{ K}}$ or b) $\dfrac{298\text{ K}}{401\text{ K}}$

For a direct proportion, as T increases, V increases; therefore, ratio (a) should be used.

$$25.0\text{ L} \times \frac{1.25\ \cancel{\text{atm}}}{0.750\ \cancel{\text{atm}}} \times \frac{401\ \cancel{\text{K}}}{298\ \cancel{\text{K}}} = 56.1\text{ L}$$

The atm and K units cancel, leaving L for the answer.

**Problem 2:**

If a gas has a volume of 125 L at 325 kPa and 58.0°C, *calculate the temperature* in Celsius to produce a volume of 22.4 L at 101.3 kPa.

*Solution:*

58.0°C becomes 331 K

125 L at 325 kPa and 331 K

22.4 L at 101.3 kPa and ___ K

331 K x volume ratio x pressure ratio = answer

Since V $\alpha$ T (K), if V decreases, then T should decrease, and the ratio would be:

$$331\text{ K x } \frac{22.4\text{ L}}{125\text{ L}}$$

Since P $\alpha$ T (K), if P decreases, then T decreases, and the ratio would be:

$$331\text{ K} \times \frac{22.4\ \cancel{\text{L}}}{125\ \cancel{\text{L}}} \times \frac{101.3\ \cancel{\text{kPa}}}{325\ \cancel{\text{kPa}}} = 18.5\text{ K or } -254^{\circ}\text{C}$$

SPECIFIC LEARNING OUTCOME

C11-2-08: Solve quantitative problems involving the relationships among the pressure, temperature, and volume of a gas using dimensional analysis.

Include: symbolic relationships

*(continued)*

### Solving Problems by Symbolic Relationships

- Boyle's Law: $P_1V_1 = P_2V_2$
- Charles's Law: $V_1/T_1 = V_2/T_2$
- Gay-Lussac's Law: $P_1/T_1 = P_2/T_2$

Pressure and volume are directly related to temperature, whereas P and V are inversely related to each other. Therefore, we can derive the "combined gas law":

$$P_1V_1/T_1 = P_2V_2/T_2$$

### Solving Problems Numerically

Using the equation $P_1V_1/T_1 = P_2V_2/T_2$, solve problems involving pressure, volume, and temperature.

### TEACHER NOTES

The following is a method for explaining the combined relationship:

$$(P_1V_1) \times (V_1/T_1) \times (P_1/T_1) = (P_2V_2) \times (V_2/T_2) \times (P_2/T_2)$$

Multiplying each part:

$$\frac{P_1^2V_1^2}{T_1^2} = \frac{P_2^2V_2^2}{T_2^2}$$

Taking the square root of both sides:

$$\sqrt{\frac{P_1^2V_1^2}{T_1^2}} = \sqrt{\frac{P_2^2V_2^2}{T_2^2}}$$

We get:

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$$

There are two schools of thought with regard to the solution of problems involving literal equations. One method is to solve the literal equation for the required variable first before substituting in values, while the other method is to substitute values into the equation first and then solve for the required value.

SKILLS AND ATTITUDES OUTCOMES

**C11-0-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…*

**C11-0-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…*

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### Sample Problems *(continued)*

**Problem 3:**

Salvage divers often use lift bags to lift objects to the surface. Divers are required to make a pre-dive calculation of the forces involved, to ensure the safety of the divers during the recovery. A lift bag contains 145 L of air at the bottom of a lake, at a temperature of 5.20°C and a pressure of 6.00 atm. As the bag is released, it ascends to the surface, where the pressure is 1.00 atm and 16.0°C. Calculate what volume the gas would occupy at the surface of the lake. If the maximum volume of the lift bag is 750 L, will the bag burst at the surface?

*Solution:*

145 L at 278.2°C and 6.00 atm

$V_2$ at 289°C and 1.00 atm

Solving for $V_2$ first:

$$V_2 = \frac{P_1V_1T_2}{P_2T_1}$$

$$V_2 = 904 \text{ L}$$

The new volume of 904 L exceeds the limit of the lift bag, which will burst, causing the object to drop to the bottom of the lake again.

## SUGGESTIONS FOR ASSESSMENT

Assess students' achievement of learning outcome C11-2-08 using problems obtained from chemistry textbooks or from teacher reference material. An obvious caution is for the teacher to solve the problems before giving them to students to make sure they are at the appropriate level of difficulty and can be solved using the information presented in this document.

Many publishers provide CDs that contain banks of test questions. There are usually a variety of types of questions for each major topic: multiple choice, matching, true and false, short answer, long answer, essay questions, and so on. The test-maker program will often allow the teacher to: access an existing test bank, create a test with an answer key, create Internet-published tests and study guides, and prepare tests that can be displayed on a local school network system.

SPECIFIC LEARNING OUTCOME

**C11-2-08:** Solve quantitative problems involving the relationships among the pressure, temperature, and volume of a gas using dimensional analysis.

Include: symbolic relationships

*(continued)*

## LEARNING RESOURCES LINKS

*Chemistry: Concepts and Applications* (Phillips, Strozak, and Wistrom 394)

*Glencoe Chemistry: Matter and Change* (Dingrando, *et al.* 428)

*McGraw-Hill Ryerson Chemistry 11*, Ontario Edition (Mustoe, *et al.* 452)

*Nelson Chemistry 11*, Ontario Edition (Jenkins, *et al.* 436)

### Skills and Attitudes Outcomes

C11-0-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…*

C11-0-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…*

## Notes

### SPECIFIC LEARNING OUTCOME

**C11-2-09:** Identify various industrial, environmental, and recreational applications of gases.

*Examples: self-contained underwater breathing apparatus (scuba), anaesthetics, air bags, acetylene welding, propane appliances, hyperbaric chambers…*

(2.0 hours)

SLO: C11-2-09

## SUGGESTIONS FOR INSTRUCTION

### Entry-Level Knowledge

No entry-level knowledge is expected.

### TEACHER NOTES

The following examples provide an introduction to what could be considered in achieving specific learning outcome C11-2-09. Teachers will likely select examples that relate to student and teacher interests and experiences. Supplement this material with additional research using a variety of resources (e.g., the Internet, texts, encyclopedias, journals, local experts).

- **Acetylene welding** or **oxy-fuel gas welding:** a group of welding processes that produce coalescence by heating materials with an oxygen-fuel gas flame or flames. There are four distinct processes within this group:
  - oxyacetylene welding
  - oxyhydrogen welding
  - air acetylene welding
  - pressure gas welding
- **Air bags:** a supplementary restraint system found in vehicles. An air bag slows a passenger's speed to zero with generally little or no damage. In the air bag's inflation system, sodium azide, $NaN_3$, reacts with potassium nitrate, $KNO_3$, to produce a rapid blast of nitrogen gas.

### General Learning Outcome Connections

GLO B1: Describe scientific and technological developments—past and present—and appreciate their impact on individuals, societies, and the environment, both locally and globally.

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 B4: Demonstrate knowledge of and personal consideration for a range of possible science- and technology-related interests, hobbies, and careers.

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

### Skills and Attitudes Outcomes

**C11-0-R1:** Synthesize information obtained from a variety of sources.
Include: print and electronic sources, specialists, other resource people

**C11-0-R3:** Quote from or refer to sources as required and reference information sources according to an accepted practice.

**C11-0-R5:** Communicate information in a variety of forms appropriate to the audience, purpose, and context.

**C11-0-C1:** Collaborate with others to achieve group goals and responsibilities.

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- **Airships:** powered balloons that can be steered. At one time, airships or dirigibles (like the famous Hindenburg) were filled with flammable hydrogen gas. Today such balloons or "blimps" are filled with hydrogen gas that is inert and safer but less buoyant than helium due to its larger atomic mass. Helium is also used in weather balloons. These balloons differ greatly from the hot-air balloons used for recreational purposes.

- **Anaesthetics:** the use of drugs (in this case inhalation anaesthetics) to reduce pain.

- **Hyperbaric chambers:** strong-walled metal chambers in which atmospheric pressure can be adjusted for research into therapeutic treatment or human environment extremes. Hyperbaric oxygen chambers have been used since the 1940s. They were originally used by the navy to treat divers who were suffering from decompression sickness commonly known as *the bends* (nitrogen narcosis). The person who required treatment was placed in the chamber and the pressure inside was increased to many atmospheres that would equilibrate with what the ambient pressures were at depth. This re-compressed (i.e., rendered soluble) the micro-bubbles of nitrogen gas in the blood and tissues in order to remove or reduce the symptoms of the illness. Even today, many treatments are often necessary, depending on the severity of exposure to excess pressure.

  Two "baric" chambers are located in Winnipeg. Both chambers are associated with the Canadian Forces School of Survival and Aeromedical Training (CFSSAT) at Canadian Forces Base (CFB) Westwin. One chamber is *hyperbaric* and the other is *hypobaric*.
  - The *hyperbaric* chamber is used to treat medical conditions of barotrauma.
  - The *hypobaric* chamber is used to train pilots and air crew personnel with the symptoms of hypoxia. The chamber simulates going from ground level to an altitude of approximately 10,000 m.

  Information on the CFB Westwin pressure chambers is available online at:
  National Defence. Canadian Forces School of Survival and Aeromedical Training (CFSSAT): <http://www.airforce.forces.ca/17wing/squadron/cfssat_e.asp>.

  Today, hyperbaric chambers are still used to treat decompression sickness but they are now also used to treat other medical conditions, such as cancer and carbon monoxide poisoning. However, they jury is still out as to how successful these treatments have been. In some cases, athletes have been placed in chambers owned by athletic clubs, reportedly to improve the recovery of injuries by oxygenation of the blood.

SPECIFIC LEARNING OUTCOME

C11-2-09: Identify various industrial, environmental, and recreational applications of gases.

*Examples: self-contained underwater breathing apparatus (scuba), anaesthetics, air bags, acetylene welding, propane appliances, hyperbaric chambers…*

*(continued)*

- **Propane appliances:** appliances using propane as a fuel source. Propane often serves as a fuel for home heating systems. It is also used for a variety of applications, including cooking, clothes drying, pool/sauna heating, fireplaces, and grilling.

  The propane refrigerator found in many recreation vehicles is an application of propane in an appliance. These refrigerators have no moving parts and use heat, in the form of burning propane, to produce the cold inside the refrigerator.

  The cycle works like this:

  1. Heat is applied to the generator. The heat comes from burning propane, kerosene, or some other combustible fuel.
  2. In the generator is a solution of ammonia and water. The heat raises the temperature of the solution to the boiling point of the ammonia.
  3. The boiling solution flows to the separator. In the separator, the water separates from the ammonia gas.
  4. The ammonia gas flows upward to the condenser. The condenser is composed of metal coils and fins that allow the ammonia gas to dissipate its heat and condense into a liquid.
  5. The liquid ammonia makes its way to the evaporator, where it mixes with hydrogen gas and evaporates, producing cold temperatures inside the refrigerator.
  6. The ammonia and hydrogen gases flow to the absorber. Here, the water that has collected in the separator is mixed with the ammonia and hydrogen gases.
  7. The ammonia forms a solution with the water and releases the hydrogen gas, which flows back to the evaporator. The ammonia-and-water solution flows toward the generator to repeat the cycle.

- **Self-contained underwater breathing apparatus (scuba):** an apparatus that divers use to provide air or other breathable gases at ambient pressure while they are submerged.

  All three gas laws have an effect on underwater divers who must take into consideration all their combined effects when planning a dive. The modern regulator provides air on demand at ambient pressure. This means that at 99 ft. (30 m) or 4 atm, a regulator will adjust the pressure from the cylinder to 4.0 atm. The danger for a diver on ascent is that the gases within the body expand, and if adequate venting is not permitted, air bubbles can be forced into the tissues and bloodstream, with life-threatening consequences.

**SKILLS AND ATTITUDES OUTCOMES**

**C11-0-R1:** Synthesize information obtained from a variety of sources.
Include: print and electronic sources, specialists, other resource people

**C11-0-R3:** Quote from or refer to sources as required and reference information sources according to an accepted practice.

**C11-0-R5:** Communicate information in a variety of forms appropriate to the audience, purpose, and context.

**C11-0-C1:** Collaborate with others to achieve group goals and responsibilities.

The modern diver also wears a buoyancy-compensating device (BCD). This device holds the compressed air tank in place and controls buoyancy. The addition of too much air can cause a diver to accelerate toward the surface as the air inside the BCD expands with the reduced pressure. If the dissolved gas in the bloodstream cannot escape quickly enough, physical damage may result for the diver. Too little air in the BCD or too much weight on the weight belt can cause a descent that is too fast for the body to adjust safely, which again may cause injury.

## SUGGESTIONS FOR ASSESSMENT

### Rubrics/Checklists

See Appendix 10 for a variety of rubrics and checklists that can be used for self-assessment, peer assessment, and teacher assessment.

### Research Reports

Have students research and report on various industrial, environmental, and recreational applications of gases (see Appendix 2.8: Applications of Gases in Our Lives). Some groups could present findings at this point, while others could report on a different topic at another time (e.g., in Topic 3: Chemical Reactions).

The information collected could be presented as

- written reports
- oral presentations
- bulletin board displays
- multimedia presentations

### Visual Displays

Students could present the material they have collected using

- posters
- pamphlets
- bulletin boards
- models

Each presentation style could be assessed using an appropriate rubric created with students prior to the assignment. Samples of presentation rubrics are provided in Appendix 10 of this document.

SPECIFIC LEARNING OUTCOME

C11-2-09: Identify various industrial, environmental, and recreational applications of gases.

*Examples: self-contained underwater breathing apparatus (scuba), anaesthetics, air bags, acetylene welding, propane appliances, hyperbaric chambers…*

*(continued)*

**Journal Writing**

There are many uses of gas in our lives. Students may wish to reflect on how our lives would be different if industrial gases were not present.

**Topic-Review Activity**

An activity game has been designed to review the material in Topic 2: Gases and the Atmosphere. For details, see Appendix 2.9: Review Game. Teachers can create their own set of questions to relate more specifically to their emphases, presentations, findings, and so on.

## LEARNING RESOURCES LINKS

*Chemistry* (Chang 184)

*Chemistry* (Zumdahl and Zumdahl 210)

*Chemistry: The Central Science* (Brown, *et al.* 381, 382)

*Chemistry: Concepts and Applications* (Phillips, Strozak, and Wistrom 387, 390, 417)

*Glencoe Chemistry: Matter and Change* (Dingrando, *et al.* 180, 376, 446)

*McGraw-Hill Ryerson Chemistry 11*, Ontario Edition (Mustoe, *et al.* 450, 506)

*Nelson Chemistry 11*, Ontario Edition (Jenkins, *et al.* 416, 441, 442)

*Nelson Chemistry 12: College Preparation*, Ontario Edition (Davies, *et al.* 331)

*Prentice Hall Chemistry: Connections to Our Changing World* (LeMay, *et al.* 359, 432, 447)

### SKILLS AND ATTITUDES OUTCOMES

**C11-0-R1:** Synthesize information obtained from a variety of sources.
Include: print and electronic sources, specialists, other resource people

**C11-0-R3:** Quote from or refer to sources as required and reference information sources according to an accepted practice.

**C11-0-R5:** Communicate information in a variety of forms appropriate to the audience, purpose, and context.

**C11-0-C1:** Collaborate with others to achieve group goals and responsibilities.

## NOTES