SECTION 12.3

Atmospheric Gases and Air Quality

Key Terms

criteria air contaminants

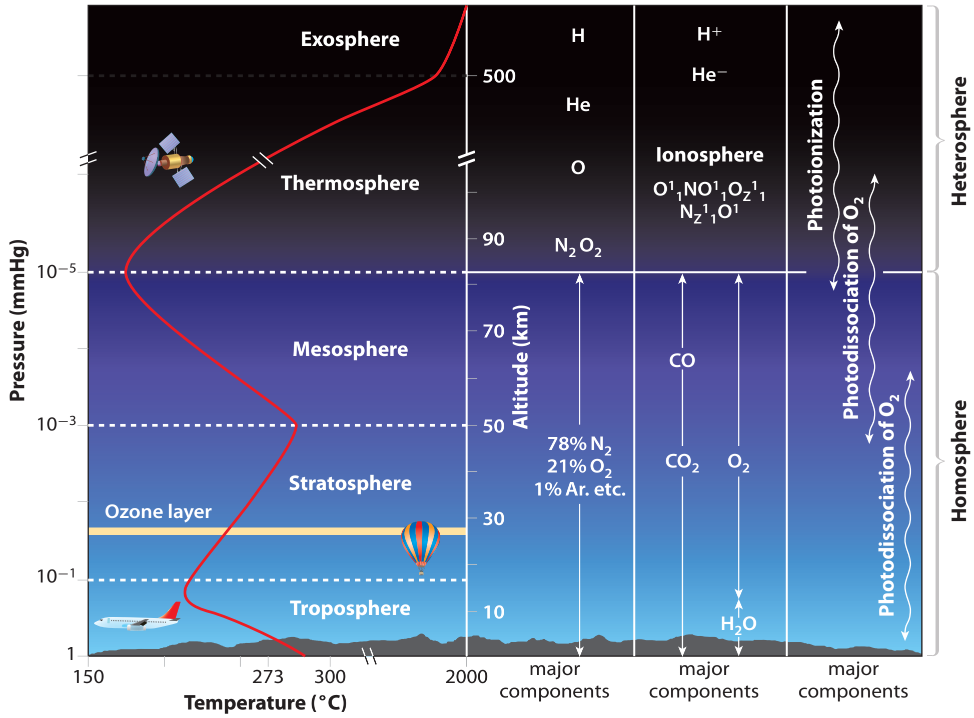

Figure 12.10 Variations in pressure, temperature, and the components that make up Earth's atmosphere are summarized here.

Infer *How can you explain the changes in temperature with altitude?*

Figure 12.10 summarizes information about the structure and composition of Earth's atmosphere. Much of this information is familiar to you from earlier in this unit or from your study of science or geography in earlier grades.

As you know from Boyle's law, gases are compressible. Thus, pressure in the atmosphere decreases with altitude, and this decrease is more rapid at lower altitudes than at higher altitudes. In fact, the vast majority of the mass of the atmosphere—about 99 percent—lies within 30 km of Earth's surface. About 90 percent of the mass of the atmosphere lies within 15 km of the surface, and about 75 percent lies within 11 km.

The atmosphere is divided into five distinct regions, based on temperature changes. You may recognize the names of some or perhaps all of these regions: the troposphere, stratosphere, mesosphere, thermosphere, and exosphere. In terms of composition, Earth's atmosphere is typically divided into two regions: the homosphere and the heterosphere.

The Homosphere Region of the Atmosphere

In the homosphere, gases are fairly evenly blended, giving the region a relatively uniform composition. This uniformity is due to mixing of the gases through a process called *convection*, which is a cyclical, up-and-down movement of air molecules caused by differences in the air density. Air near the land is warmer and less dense than the air above it. The cool, dense air above sinks, displacing the warmer, less-dense air below, causing the warm air to rise. Once away from the surface, the warm air cools and its density increases. This cooled air then sinks down to the surface and the convection process repeats itself and continues.

Gases in the homosphere behave like ideal gases. Therefore, in general, they obey the gas laws that you have studied in this unit. **Table 12.5** lists the major (green) and minor (yellow) components of the homosphere. Water vapour (not shown in the table) is also a major, variable component, making up 1 to 4 percent of the atmosphere.

Table 12.5 Percentage Composition of Clean, Dry Air in the Homosphere

Atmospheric Gas	Volume Percent
nitrogen, N_2	78.084
oxygen, O_2	20.946
argon, Ar	0.0340
carbon dioxide, CO_2	0.03845
neon, Ne	0.00182
helium, He	0.00052
methane, CH_4	0.00015
krypton, Kr	0.00011
hydrogen, H_2	0.00005
dinitrogen oxide, N_2O	0.00005
xenon, Xe	0.000009
ozone, O_3	0.000007

The Heterosphere Region of the Atmosphere

The mixing of atmospheric gases by convection does not occur in the heterosphere. Therefore, the gas composition in the heterosphere varies and is limited to a few gas types. Gas particles are layered by molecular mass. Nitrogen and oxygen molecules are in the lowest layers, along with ions such as O^+, NO^+, O_2^+, and N_2^+ that form by interactions of atoms and molecules and solar energy. Oxygen atoms are in the next highest layer; helium and free hydrogen atoms occur in the layers farther above.

Pollutants and Air Quality

The federal government, through Environment Canada, has identified several pollutants that are referred to as **criteria air contaminants**. These pollutants—carbon monoxide, nitrogen oxides, particulate materials, sulfur dioxide, and volatile organic compounds (VOCs)—are considered to be those that have the greatest impact on air quality and human health. **Figure 12.11** shows the anthropogenic (human-generated) sources of the criteria air contaminants.

criteria air contaminants air pollutants that are federally identified as those having the greatest impact on air quality and human health

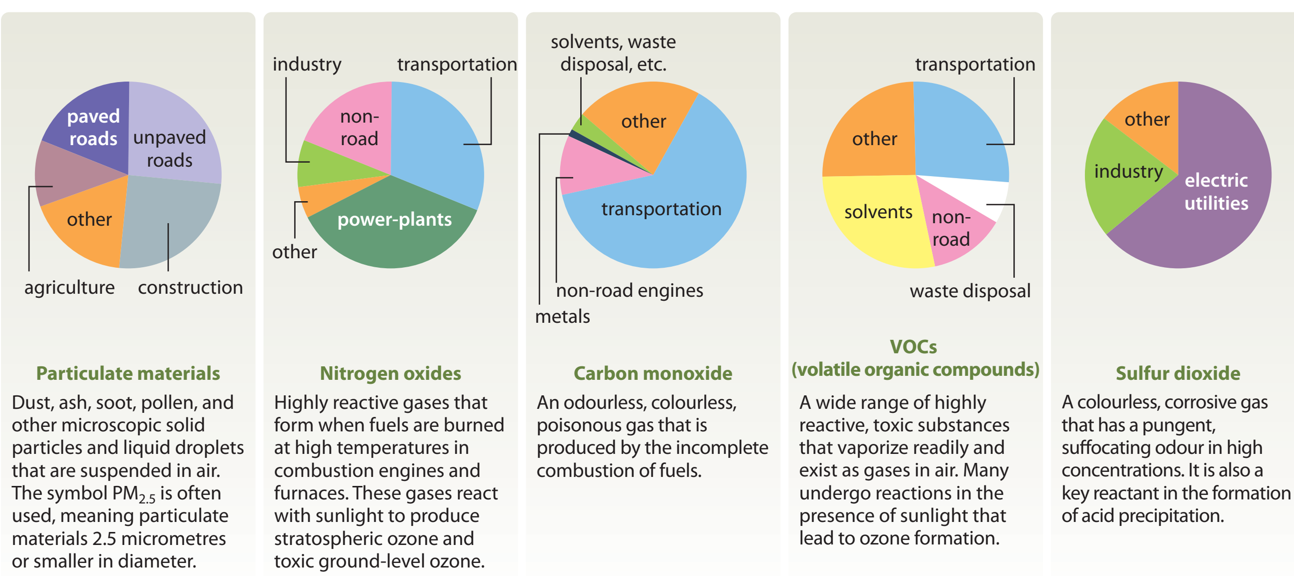

Figure 12.11 These pie graphs show the anthropogenic sources of the main criteria air contaminants.

Air Quality Effects on the Environment and Human Health

The environmental and human health effects of poor air quality are numerous and widespread. Ground-level ozone retards plant growth, and thus reduces the productivity of crops and causes damage to forests. In addition, ground-level ozone damages plastics, breaks down rubber, and corrodes metals. In terms of the human health effects, breathing ozone can trigger a variety of human health problems, including chest pain, coughing, throat irritation, and congestion. In addition, it can worsen existing chronic lung conditions such as asthma and emphysema.

Humans have some ability to resist the effects of poor air quality. However, Canada's national health agency, Health Canada, cautions that such resistance can be overwhelmed with higher levels of and prolonged exposure to air pollution. Children, people who are sick, and seniors are the most susceptible to pollution-related illness and disease. Many human health problems are linked to poor air quality, including asthma, allergies, lung cancer, and cardiovascular disease.

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To help Canadians better understand and assess the potential effects of air quality on human health, the federal departments of health and environment, with the participation of the provinces and territories, have created the Air Quality Health Index (AQHI). As you can see in **Figure 12.12**, the AQHI uses numbers from 1 to 10+, and a rating system of "low" to "very high," to indicate the air quality and its associated health risks. Each report for a selected location indicates who may be at risk given the current air quality conditions, provides health messages, and includes a short-term forecast to help in planning outdoor activities.

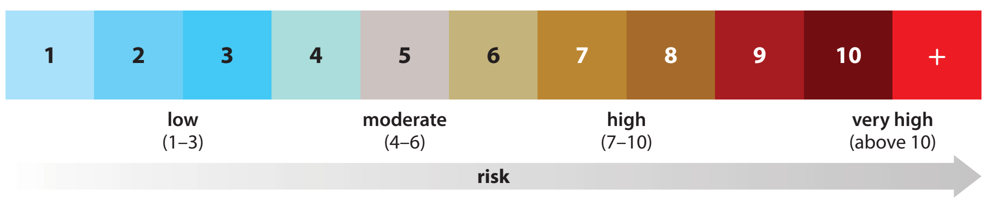

Figure 12.12 The AQHI is based on the known health risks associated with a combination of common air pollutants that include ground-level ozone, particulate matter, and nitrogen dioxide.

Pollution Prevention, Emissions Limits, and Air Quality Standards

In Canada, air quality management is the responsibility of mainly the provincial and territorial governments and is overseen by the federal government. The main federal environmental law, the *Canadian Environmental Protection Act, 1999*, reinforces this role. The law addresses the government's responsibility to work with the provinces and territories on pollution prevention and on the creation of national environmental standards. One such standard focusses on particulate matter and ground-level ozone. It commits governments to meet defined pollution reduction targets. Governments have passed regulations and set up mandatory programs to reduce harmful gas emissions from all sectors of the economy, and are encouraging individuals, businesses, and industries to join voluntary programs to achieve this goal.

Learning Check

13. Describe several key features of the homosphere and the heterosphere.

14. Which gases are the main components, by volume, of Earth's atmosphere?

15. What are criteria air contaminants?

16. Why does mixing of atmospheric gases by convection occur in the homosphere but not the heterosphere?

17. What does AQHI stand for, and what is its purpose?

18. In Ontario, under what conditions would you expect AQHI values of 7 to 10?

Activity 12.2 Biofuel: A Greenhouse Gas Solution or An Air Quality Problem?

A biofuel is any fuel made from sustainable, biological materials such as plant matter. Burning gasoline releases large amounts of the greenhouse gas, carbon dioxide, into the atmosphere. Burning biofuel is an alternative to burning gasoline. In this activity, you will compare the CO_2 emission factors of several components of biofuels and gasoline, and assess the effects of biofuel, including its impact on air quality.

Procedure

1. Read the following text and sample calculation. A carbon footprint measures the total amount of greenhouse gas emitted by an activity or process over time. Typically, carbon dioxide is the source of carbon for calculating a carbon footprint. One method of calculation involves calculating a CO_2 emission factor for a given activity:

$$CO_2 \text{ emission factor} = \frac{\text{mass of } CO_2 \text{ emitted}}{\text{quantity of activity}}$$

The "quantity of activity" can be expressed in different ways. For example, calculating the mass of CO_2 emitted per litre of a fuel being burned yields the emission factor. In this case, the litre of fuel is the quantity of activity. The example below shows how to calculate the CO_2 emission factor for the combustion of a liquid fuel, butane, $C_4H_{10}(\ell)$.

a. Liquid butane burns according to the following balanced chemical equation:

$$2C_4H_{10}(\ell) + 13O_2(g) \longrightarrow 8CO_2(g) + 10H_2O(g)$$

b. Calculate the molar mass of liquid butane.

$$M_{C_4H_{10}} = 4M_C + 10M_H$$
$$= 4(12.01 \text{ g/mol}) + 10(1.01 \text{ g/mol})$$
$$= 58.14 \text{ g/mol}$$

c. Determine the amount (in moles) in 1.000 L of liquid butane. Liquid butane has a density of 573.0 g/L at 25°C.

$$D = \frac{m}{V}$$
$$m = DV = 573.0\text{g}/\cancel{\text{L}} \times 1.00\cancel{\text{L}} = 573.0 \text{ g}$$
$$n = \frac{m}{M} = \frac{573.0\ \cancel{\text{g}}}{58.14\ \cancel{\text{g}}/\text{mol}} = 9.85552 \text{ mol}$$

d. From the chemical equation, the mole ratio is 2 mol $C_4H_{10}(\ell)$: 8 mol $CO_2(g)$. Determine the amount of carbon dioxide in moles.

$$n_{CO_2} = 9.85552\ \cancel{\text{mol } C_4H_{10}} \times \frac{8 \text{ mol } CO_2}{2\ \cancel{\text{mol } C_4H_{10}}}$$
$$= 39.4221 \text{ mol } CO_2$$

e. Calculate the molar mass of carbon dioxide.

$$M_{CO_2} = M_C + 2M_O$$
$$= 12.01 \text{ g/mol} + 2(16.00 \text{ g/mol})$$
$$= 44.01 \text{ g/mol}$$

f. Determine the mass of carbon dioxide.

$$m = n \times M$$
$$= 39.4221\ \cancel{\text{mol}} \times 44.01 \text{ g}/\cancel{\text{mol}}$$
$$= 1734.9666 \text{ g}$$

g. Determine the carbon dioxide emission factor for burning liquid butane.

$$CO_2 \text{ emission factor} = \frac{\text{mass of } CO_2 \text{ emitted}}{\text{quantity of activity}}$$
$$= \frac{1734.9666 \text{ g } CO_2}{1.000 \text{ L } C_4H_{10}}$$

Thus, using correct significant figures, the CO_2 emission factor is 1735 g of carbon dioxide per 1.000 L of combusted liquid butane.

2. Use the data below to calculate the carbon footprints of the two biofuel and two gasoline components in terms of the CO_2 emission factor for each compound. Begin each calculation by writing a balanced combustion reaction.

Components of Biofuel

Compound	Density (g/L) at 20°C
Methanol, $CH_4O(\ell)$	791.4
Ethanol, $C_2H_6O(\ell)$	789.3

Components of Gasoline

Compound	Density (g/L) at 20°C
Pentane, $C_5H_{12}(\ell)$	626.2
Nonane, $C_9H_{20}(\ell)$	719.2

3. Biofuel combustion has negative effects on air quality. For example, burning a biofuel generates up to 15 percent more nitrogen dioxide, $NO_2(g)$, than burning gasoline does. Conduct research to

a. learn the role of nitrogen dioxide in producing ground-level ozone, $O_3(g)$, which is a chief component of smog.

b. investigate biofuel production and use in terms of the negative effects on human health and the environment. Assess the use of biofuel as a suitable replacement for gasoline.

Questions

1. **a.** Some people argue that biofuel has a larger carbon footprint than gasoline. Based on your calculations for methanol and ethanol, what would be true about the relationship between the CO_2 emission factor and the carbon footprint of biofuel, if this argument were correct?

b. Identify at least one other factor that might affect the carbon footprint of biofuel. Explain your reasoning.

2. When determining the impact of a certain fuel upon the environment, what information, other than its carbon footprint, should to be taken into consideration?

3. You are trying to reduce your carbon footprint.

a. Is driving a car that runs on biofuel an effective way to reduce your carbon footprint? Explain your reasoning.

b. List three other transportation choices to reduce your carbon footprint. Rank them by effectiveness. Provide your reasoning for each ranking.

STSE FEATURE

QUIRKS & QUARKS

with BOB MCDONALD

CBC

THIS WEEK ON QUIRKS & QUARKS

PFOA—Here Today, Here Forever?

Even though we cannot see them, chemical compounds such as perfluorooctanic acid (PFOA) are in our homes, in our bodies, and even in the blood of polar bears in the Arctic. Dr. Scott Mabury, professor and chair of the Chemistry Department at the University of Toronto, believes he has found an explanation for how persistent, bioaccumulative, and potentially toxic fluorochemicals have gotten there. Bob McDonald interviewed Dr. Mabury to find out the source of PFOA and how emissions can be reduced.

Stain Repellant and Water Resistant

One of the main sources of PFOA comes from the manufacturing of stain-resistant carpets, water-resistant clothing, and even microwave popcorn bags. Due to inefficient production methods, unreacted starting materials end up on the final product. Dr. Mabury and other scientists hypothesize that these materials, referred to as precursor alcohols, off-gas into the atmosphere. Once there, the gases travel thousands of kilometres and eventually degrade. When the precursor alcohols degrade, PFOA and other compounds like it form and enter the food chain.

PFOA is both persistent (does not break down easily so it stays for a long time in the environment) and bioaccumulative (builds up in the tissues of organisms in the food chain). Dr. Mabury notes that PFOA has been identified as a likely human carcinogen. Because of these properties, scientists at Environment Canada and the United States Environmental Protection Agency (USEPA) are concerned about the amount of PFOA being released into the environment.

Reducing Emissions

Environment Canada banned the import of four new fluorinated polymers because they are recognized as a source of fluorochemicals in the Arctic. After reviewing Dr. Mabury's research, the USEPA has asked manufacturers of PFOA to voluntarily reduce or eliminate emissions during the manufacturing process. This would mean producing a final product that did not have residual precursor alcohols on it. Dr. Mabury feels that if the manufacturing process can be cleaned up, it could significantly reduce the release of the precursors of PFOA. Scientists are also developing chemical substitutes for PFOA that, due to their chemical structure, are no longer bioaccumulative.

Related Career

Dr. Scott Mabury is an environmental chemist. As a university professor, he teaches and conducts research. He asks questions about and studies the fate of fluorochemicals in the environment, such as how they degrade after being released into the atmosphere. Dr. Mabury communicates the results of his research by publishing articles in scientific journals.

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The PFOA coating on the inside of microwave popcorn bags keeps oil from soaking through the bag.

Polar bears and other arctic animals, such as seals, have high concentrations of PFOA in their bloodstream due to the bioaccumulative property of the chemical.

QUESTIONS

1. Summarize the key issues associated with the use of perfluorooctanic acid (PFOA).
2. Research what position Health Canada and Environment Canada are taking regarding the PFOA issue.
3. Research more information about being an environmental chemist. What are some of the different job positions an environmental chemist would be qualified for?

Section 12.3 REVIEW

Section Summary

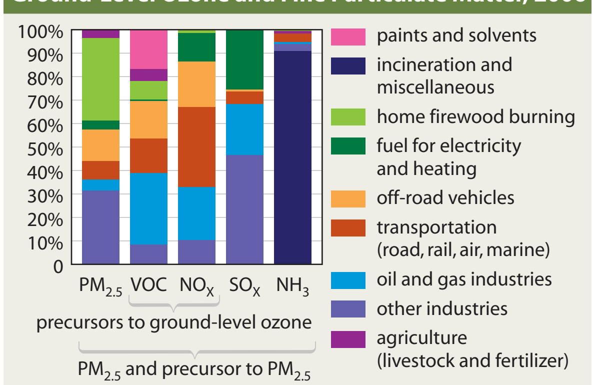
- The major components of Earth's atmosphere are nitrogen, oxygen, argon, and carbon dioxide gases, as well as water vapour. Minor components of Earth's atmosphere include very small amounts of other gases. Both major and minor components are concentrated mostly in the lowest region of the atmosphere, within 11 km of Earth's surface.
- Criteria air contaminants are carbon monoxide, nitrogen oxides, particulate materials, sulfur dioxide, and volatile organic compounds (VOCs).
- The Air Quality Health Index (AQHI) is a rating and advisory scale developed by the federal government, in consultation with provincial and territorial governments, to help Canadians understand the possible effects of air quality on any given day, and to make personal choices based on that information.

Review Questions

1. **C** Use a graphic organizer such as a Venn diagram to compare the homosphere and the heterosphere of Earth's atmosphere.
2. **K/U** List and describe the criteria air contaminants.
3. **K/U** Describe the role of the federal and provincial government in determining and implementing environmental policy.
4. **A** When making government policy on atmospheric pollution, target goals are often set over long periods of time. Why is it not practical for governments to set hard and fast standards in the short-term?

Use the graph below to answer questions 5–9. (Note: NO_X refers to nitrogen dioxide and nitrogen dioxide.)

Emission Sources of Air Pollutants Leading to Ground-Level Ozone and Fine Particulate Matter, 2006



5. **K/U** Which industry contributes the most pollution in terms of:
   a. nitrogen oxides
   b. VOCs
   c. particulate material
6. **T/I** By what percentage do paints and solvents contribute to VOC release?
7. **T/I** Does home firewood burning contribute significantly to VOC's or NO_X? Explain.
8. **A** Given the industries that contribute NO_X and VOC's to the atmosphere, make a list of concrete recommendations that could be implemented that would reduce these emissions.
9. **A** Examine the contributors to particulate matter. Make a list of recommendations that could be implemented to reduce these emissions
10. **T/I** Some provinces use an Air Quality Index (AQI) that is different from the federal Air Quality Health Index (AQHI). Conduct research to find out about the AQI system currently in use in Ontario, explain how the AQI differs from the AQHI, and use a PMI chart to assess the "pros and cons" of each system.
11. **K/U** Earth's atmosphere is classified into distinct regions based on different criteria. Identify these criteria and use each criterion to name the atmospheric regions based on it.
12. **A** The Environmental Protection Agency (EPA) of the United States has a listing of criteria air contaminants, just as Canada does. Do research to compare the EPA and Environment Canada sets of criteria air contaminants. Which pollutants are common to both, which are not, and why is there a difference?
13. **C** Carbon dioxide and methane are classified as greenhouse gases and are considered key contributors to global warming. And yet neither of these gases is identified as a criteria air contaminant. Does this surprise you? Write a short supported opinion piece to present your ideas.
14. **C** Conduct research to present, in the form of a poster or computer slide show, the link between air pollution and acid precipitation.