CHAPTER 16 AIR POLLUTION

Chapter Overview

This chapter explains the different types of air pollution. Sources of air pollution, both natural and anthropogenic, are discussed in this chapter. The effects of air pollution are also considered as well as remediation and prevention of air pollutants.

Topics and Key Concepts

Pollution

- Identify natural and anthropogenic sources of air pollution.
- Define and provide examples of primary and secondary air pollutants. Identify the six criteria air pollutants according to the EPA.
- Explain how topography and atmospheric processes affect air quality.
- Discuss the effects of air pollution on living organisms, and evaluate the efficacy of air pollution control methods.
- Explain how mercury from a coal burning power plant biomagnifies in organisms in higher trophic levels.

Global Change

- Outline the methods by which pollutants may be removed from the air.
- Explain the formation of ozone in the atmosphere, and how CFCs degrade the ozone layer.
- Summarize the effects of acid deposition on vegetation, aquatic animals, and human construction.

Key Terms

acid precipitation
aerosols
aesthetic degradation
ambient air
bronchitis
carbon monoxide
chlorofluorocarbons (CFCs)
fugitive emissions
hazardous air pollutants (HAPs)
*Montreal Protocol
nitric oxide
nitrogen dioxide
nitrogen oxides
nitrous oxide
primary pollutants
secondary pollutants
stratospheric ozone
sulfur dioxide
synergistic effects
temperature inversions
Toxic Release Inventory (TRI)

*Clean Air Act	ozone	volatile organic compounds (VOCs)
chronic obstructive lung disease	particulate matter	
conventional or criteria pollutants	photochemical oxidants	

Pacing Guide

Allow 5-7 days to discuss the effects of air pollution on materials and living things, in addition to the time spent on the previous chapter.

Approach and Tips

The discussion of air quality dovetails with the information covered in Chapter 15, on air circulation, the atmosphere, and climate change, and with information on toxicology covered in Chapter 8. Make sure that the students know that air pollution is the most widely spread form of global pollution, but because of new newer technology, air quality is improving. Emphasize the concept that air pollution is not just anthropogenic. Air pollution occurs naturally as plants decompose, volcanoes erupt, forest fires burn, by naturally released biogenic VOCs, and storms blow across loose soils.

Review the information students learned in the toxicology chapter and relate the information to toxins in the air. Make sure students understand how pollutants move through atmospheric currents. This is a good opportunity to review convection currents using an in class demo. This can be done by setting a large beaker on two hotplates and turning one on while leaving the other cold. You can place small chips of wood in the water to easily see the convection. Alternately, you can demonstrate thermal inversion using a small fish tank and water. Cool half of the water so that it is ice cold. Add blue food color so it is easier to see. Warm the other half of the water and add red food color. Place a partition in the fish tank and pour the two different temperatures on separate sides. When you remove the partition, the cold water will sink and the warm water will layer on top due to the difference in density. To assure success in this demonstration, you may want to add salt to the cold water to increase its density.

Students need to know the difference between primary and secondary pollutants as well as examples of each. Students should be familiar with NO_2, N_2O, SO_x, VOCs, lead, mercury, ozone, carbon monoxide, and particulates. Stress the importance of the concept of indoor air pollution and reinforce the concept of sick building syndrome.

Students need to know the difference between tropospheric and stratospheric ozone. Stratospheric ozone depletion is a fundamental concept of AP Environmental Science. Knowing the specific reactions and how the ozone is depleted is essential information. In addition, it is important for the students to know the environmental consequences of ozone depletion. The mechanism of ozone depletion is clearly illustrated in table 16.4 in the textbook. The Montreal Protocol of 1987 was instrumental in phasing out CFC production by the year 2000. Students should also be familiar with the ramifications of ozone depletion and that there are substitutes for CFCs. The substitutes still reduce ozone, but are not as harmful as CFCs.

Compare the chemical process of industrial versus photochemical smog. Students should know that industrial processes occur with the presence of nitrogen oxides and sulfur oxides, while photochemical smog forms when nitrogen oxides and volatile organic compounds react with sunlight. The location of each type of smog is determined by the presence of sunlight and/or industry. Please visit the website below for further examples of each type of smog.
http://education.nationalgeographic.com/education/encyclopedia/smog/?ar_a=1

Students should be able to discuss the goals of the Montreal Protocol, Kyoto Protocol, and the Clean Air Act and predict the effects amending the act would have on global air quality.

The importance of both temperature inversions and urban heat island effect are essential topics. Temperature inversions trap pollutants near the earth's surface as warmer air overlays cooler air. Air pollutants are heated by sunlight and other pollutants are added, concentrating and increasing contaminant levels. Concentrations of buildings and roads in urban areas create heat islands by blocking winds, preventing runoff, and decreasing vegetation. Students need to realize that air pollution is a global problem. Changing wind patterns move pollutants globally from warm areas to cooler ones, where they precipitate out as temperature changes.

Acid rain experiments with seeds and plants are commonly used to illustrate the damaging effects acid precipitation has on forested and other areas. Another way to illustrate the harmful effects atmospheric acids have on buildings is to have students carve a piece of chalk with their name or a design of some sort. Then have them mist the chalk with dilute solutions of vinegar and observe the reaction that takes place.

Students should be able to explain the process of scrubbing or precipitators for effluent gas emissions. This process should be introduced here and discussed again in the energy chapters. Students need to know how power plants burning fossil fuels can reduce emissions from smokestacks. In addition to electrostatic

precipitators, students should understand how smokestack wet and dry scrubbers work. Also, simply removing sulfur from coal or burning lower sulfur coal are both methods that will reduce the formation of sulfur oxides which lead to the formation of acid precipitation. Students should also be familiar with other common pre- and post-combustion methods to remove sulfur, as well as fluidized bed combustion.

Common Mistakes and Misconceptions

Quite frequently when students are asked to supply an environmental effect of burning fossil fuels, they will respond with air pollution. This is too vague as an AP answer. Students need to know specific air pollutants and their sources along with any remedial action that can be taken to alleviate the problem. Studetns should also be able to differentiate between human health effects and environmental effects.

A focus on differentiating between tropospheric ozone and stratospheric ozone is important. Students confuse the two concepts because of similar terminology used. Consider replacing the term tropospheric ozone with ground-level ozone so students become aware that the formation of ozone in our troposphere can be harmful. Students will also confuse the causes of the formation of the two processes. The teacher should clarify that ground-level ozone is caused by the release of nitrous oxides, VOCs, and hydrocarbons reacting with UV radiation, while stratospheric ozone is broken down by chlorofluocarbons reacting with UV radiation.

Activities

What's in your air?

There are several commercially available air sampling pumps and test strips, but these tend to be costly. This cost can be circumvented by creatively making your own testing materials.

If students live in an area with elevated ozone, you can make inexpensive test strips, called Schoenbein paper, which detects ozone using potassium iodide. More information on making and using Schoenbein paper can be found here: https://www.ucar.edu/learn/1_7_2_29t.htm

Particulate Collection Activity

Students can collect and analyze particulates in their local are using a homemade particulate sampler. Directions and procedures can be found here:

http://itsourair.org/sites/default/files/activities/IOA_1-7_Act_PM_Sample_042914.pdf

Ocean Acidification Activity

This activity will simulate the effects of increased concentration of CO_2 in the atmosphere on the pH of the ocean. If you do not have access to ocean water, you can make it using chemicals found in most chemistry labs. Recipes for ocean water can be found on the internet. Reinforce the concept of pH and ask the students why pH is important to living ecosystems. Students also need to realize that carbon dioxide in the air is sequestered in the oceans and changes the pH by forming a weak acid (carbonic acid). Buffering effects of the oceans may also be discussed. The procedure can be found on a worksheet at the end of this teacher's manual chapter.

Air Pollutant Vocabulary Mix-Up

Provide students with vocabulary terms found as a PDF file. Divide up the cards and place the cards in baggies in the following categories: primary pollutants, secondary pollutants, atmospheric layers/devices, and processes. The categories could also be divided into indoor and outdoor pollutants. Have students match the correct term with its source or definition.
The teacher can establish a QR code with the answers so student can scan the QR code to check their work. The vocabulary worksheet can be found at the end of this chapter.

Air Pollutant Criteria (National Ambient Air Quality Standards)

Provide students with the Criteria Air Pollutants handout. Students can visit www.epa.gov to determine the part per million/billion of each pollutant generated in order to calculate for the percent change of each pollutant. It is significant for students to be able to identify the six major air pollutants (as defined by the United States) with set standards established by the NAAQS. The handout can be found at the end of this chapter.

Air Pollutants Cheat Charts

Students have a difficult time differentiating between primary and secondary pollutants, indoor versus outdoor pollutants, and the criteria pollutants. For the AP exam, students should be able to compare and contrast each of the various pollutants, their sources, and effects. Due to the quantity of information necessary to understand, cheat charts are provided which include the most pertinent information required for students to understand for the exam. The teacher can

have students build their own charts or use the formatted charts to study after in class discussions. Charts should include the source(s) of the pollutant, environmental impact, human health effects, preventative measures, remediation strategies, and other important facts (such as acceptable levels, whether or not it bioaccumulates, etc).

Stratospheric Ozone Destruction Demonstration

Students frequently confuse the concepts of global climate change, ground-level ozone formation and the destruction of ozone. Consider quizzing over this section separately, so students do not overlap the concepts with Air Pollution and Global Climate Change. It is significant that students understand the molecular process of the breakdown of stratospheric ozone by chlorofluocarbons. Students should also understand that UV radiation is not involved in climate change, it does not become infrared radiation.

Create several O_3 molecules, CFC molecules, and UV rays with paper materials. Place a string around each paper model. Hand out each element and ask students to form the molecules and role play how O_3 molecules are destroyed by CFCs. The activity is elementary in nature, but significant for visual or kinesthetic learners.

Questions for Review

1. What are secondary pollutants and how are they formed from chemical reactions with primary pollutants?
   Primary pollutants are those released directly from the source into the air in a harmful form. Secondary pollutants are converted to a hazardous form after they enter the air or are formed by chemical reactions as components of the air mix and interact.

2. What are natural sources of air quality degradation? What are anthropogenic sources of air pollution?
   Natural sources of air pollution occur naturally as plants decompose, volcanoes erupt, forest fires burn, and storms blow across loose soils. Anthropogenic sources are a result of burning fossil fuels, different types of industrial processes, and transportation.

3. What is the difference between stratospheric ozone and tropospheric ozone?
   Stratospheric ozone protects Earth's inhabitants from harmful UV rays, whereas tropospheric ozone results from industrial processes and is harmful to the human respiratory system. Tropospheric ozone also damages vegetation and is a component of photochemical smog.

4. Why is indoor air pollution more dangerous than outdoor air pollution? What is an example of one such pollutant in your house and what could you do to eliminate this pollutant from your indoor air?
   Indoor air pollution is much more concentrated, thus making risk due to exposure greater than that of outdoor air pollution. An example of an indoor air pollutant is cigarette smoke. This can be eliminated by not letting people smoke in your home.

Practice Questions

Multiple Choice:

Directions for questions 1-5: The lettered choices below correspond to the descriptions given in questions 1-5. Select the one lettered choice that best fits each statement. Each choice may be used once, more than once, or not at all.

(A) NO_x
(B) SO_x
(C) O_3
(D) CFCs
(E) VOCs

1. responsible for ozone depletion

2. shields Earth from UV rays

3. produced primarily by burning coal

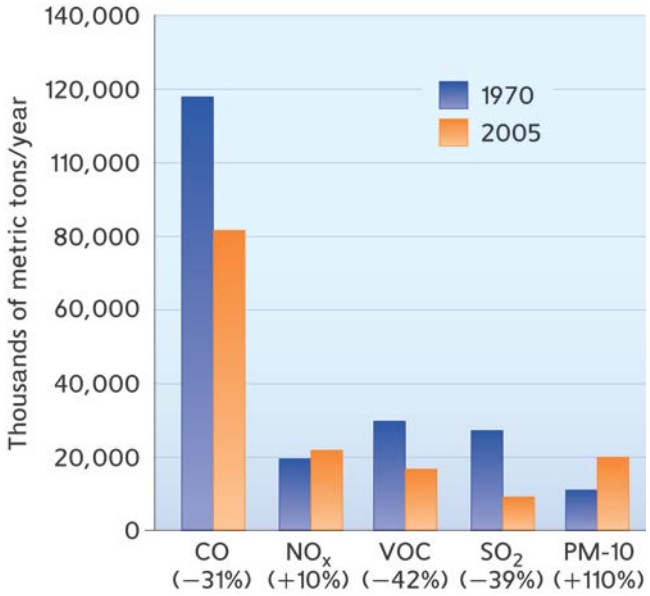
4. produced primarily by fuel combustion in transportation

5. methane is one that is produced in rice paddies by bacteria

6. About 70% of airborne mercury is derived from all of the following EXCEPT
   (A) burning coal
   (B) smelting of metal ores
   (C) mining
   (D) waste incineration
   (E) flooding behind a dam

7. In order for precipitation to be considered acidic, the pH of acid precipitation must be _____.
   (A) below 7
   (B) below 5.6
   (C) between 4-6
   (D) below 6.5
   (E) between 6-7

Use the following graph to answer questions 8-10



8. What is one likely reason that all pollutants decreased with the exceptions of nitrogen oxides and particulates?
   (A) Population has decreased.
   (B) All pollution has increased.
   (C) Emissions criteria for all pollutants EXCEPT NO_x and particulates have decreased.
   (D) Economic activity has increased.
   (E) Economic activity has decreased.

9. The primary reason for the decrease in CO is
   (A) increased biofuel production
   (B) increased fuel efficiency in cars
   (C) electrostatic precipitators required at all power plants
   (D) catalytic converters required on all cars
   (E) smokestack scrubbers

10. With reference to the graphs, what is the significance of the date 1970?
   (A) The Clean Air Act was ratified by Congress and signed into law by the President.
   (B) The hippie generation started their war to save the environment.
   (C) President Kennedy signed NEPA into law.
   (D) Rachel Carson's book told of the dangers of air pollutants.
   (E) There was a general awareness of the dangers of pesticides.

Free-Response Question:

Directions: Answer all parts of the following question. Where explanation or discussion is required, support your answers with relevant information and/or specific examples. When a calculation is required, be sure to show how you arrived at your answer.

1. Heavy metals and other pollutants are products of our industrialized society.

   (a) Identify TWO heavy metals.

      (i) For one of the heavy metals identified in part (a), explain how that substance finds its way into the human body.
      (ii) For one of the heavy metals identified in part (a), describe a possible health effect that results from exposure to that substance.

   (b) Identify TWO pollutants that result from burning fossil fuels. You may not use any of the heavy metals you gave in part (a).

      (i) For one of the pollutants identified in part (b), identify an environmental effect that results from that pollutant.
      (ii) For one of the pollutants identified in part (b), explain a method to reduce the production of that pollutant.

   (c) Identify and describe ONE federal law that may help regulate the pollutants described in the previous sections.

Answers to Practice Questions

Multiple Choice:

1. D
2. C
3. A
4. B
5. A
6. E
7. A
8. B
9. C
10. A

Free-Response Question:

This question is based on 10 points.

1. (a) 2 points total. One point for each heavy metal. Only the first two will be scored. Heavy metals include: mercury, lead, cadmium

   (i) 1 point for a source of one of the heavy metals named. Mercury: ingesting fish, lead: inhaling lead dust from sanded lead based paint, cadmium: leachate from landfills into groundwater supplies

   (ii) 1 points for correctly naming a health effect. Mercury-affects the central nervous system, lead can be fatal and may lead to learning disabilities, cadmium can cause kidney damage.

   (b) 2 points total. 1 point for each pollutant. Possible answers include: SO_x, CO_2, CO, arsenic

   (i) 1 point for a correct environmental effect of the pollutant. SO_x combines with water to form acid precipitation, CO_2 contributes to global warming, CO is a fatal gas, arsenic (acute and chronic effects) inhibits growth, photosynthesis and reproduction.

   (ii) 1 point for a viable remedy. Remedies may include but are not limited to the following: switch to a renewable, non-polluting source of energy, conservation methods, educate people as to the hazards of these substances so they can make informed decisions.

(c) 2 points total. 1 point for naming the Clean Air Act and 1 point for explaining the provisions. The Clean Air Act initiated regulation of pollutants coming from smokestacks. Amendments followed which addressed a variety of issues, including acid rain, urban air pollution, and toxic air emissions. These amendments also restricted ozone-depleting chemicals in accordance with the Montreal Protocol.

Answers to questions in the Student Edition:

Case Study AP Document-Based Question (p. 351)

(A) Air pollution decreases air quality far outside of the cities that produce it. Extreme air pollution can contaminate soil and water, making drinking water and growing crops near cities unsafe. It can also make it harder for plants to absorb sunlight. The damaging health effects of extreme pollution can even travel with winds to areas far outside the city.

(B) Environmental impacts of air pollution include soil and water contamination and increased acid rain. Human health impacts include respiratory issues, sickness from consuming contaminated foods or water, cancer or nerve damage, and decreased access to resources and care due to having to periodically shut down the city due to smog.

(C) Answers will vary and could include the following: decreasing the use of coal, encouraging the use of public transportation and carpools to decrease vehicle emissions, outlawing the use of vehicles that produce high emissions, the use of air purifiers in schools to decrease children's exposure to smog, free dust masks for residents to protect them from air pollution, and increasing the use of clean energy sources.

AP Connections Review Answers (pages 375)

Multiple-Choice Questions

1. b. Mercury is not a criteria air pollutant.

2. a. Ozone does not rise from the troposphere to the stratosphere.

3. e. Fluidized bed combustion reduces SO_2 emissions.

4. c. Mercury is converted into its most toxic form by bacteria. Mercury bioaccumulates in fat and is released into the atmosphere by coal combustion.

Data Analysis & Free-Response Questions

1a Texas has the greatest range in precipitation pH, ranging from 4.5 to ≥ 5.3. The modal precipitation pH is ≥ 5.3 since it covers the greatest area.

1b The precipitation pH on the southern tip of Florida is 5-6 times more acidic than in Nevada: (5.3 – 4.7) * 10 = 6; (5.3 – 4.8) * 10 = 5.

1c Answers will vary. The more acidic areas of the United States could be correlated to air pollution from coal plants (Ohio and Texas) and use of vehicles for transportation.

2a Answers will vary. The six conventional or criteria pollutants are particulate matter, lead, nitrogen oxides, carbon monoxide, volatile organic compounds, and sulfur dioxide. Other compounds, termed unconventional pollutants because the are uncommon or have no natural sources, are asbestos, benzene, mercury, polychlorinated biphenyls, and vinyl chloride. These pollutants can have a variety of impacts on human health including respiratory illness and various forms of illness as a result of the toxicity of many of these pollutants.

2b Answers will vary but could include using less toxic paints and fabrics, having living plants in the indoor areas, and opening windows.

2c Answers will vary.

Ocean Acidification Activity

*Student:*_____

Procedure:

1. Put 50 mL of ocean water in a beaker.
2. Place a few drops of bromothymol blue into the ocean water. Record the color.
3. Obtain a pH meter and record the initial pH of the ocean. If you don't have access to a pH meter, the indicator will give you approximate pH values.
4. Using a straw, blow into the ocean water until the indicator changes colors. It should change two times.
5. As the color changes, record the pH at each different color.

Data Table:

Color	pH

Questions to Consider:

1. What was the initial color of the ocean water containing the indicator? What is the corresponding pH? Is that acidic, basic, or neutral?

2. What happened to the color as you blew through the straw?

3. What happened to the pH as you blew through the straw?

4. What is the identity of the gas being disseminated into the ocean water?

Conclusions:

1. Why did the pH change as you blew through the straw?

2. What are the implications of burning fossil fuels to the pH of the oceans? Why are these ideas a problem for ocean ecosystems?

3. Do you see any connection(s) between global warming and this activity?