

Chapter 2

Sources and Emissions of Air Pollutants

LEARNING OBJECTIVES

By the end of this chapter the reader will be able to:

- distinguish the “troposphere” from the “stratosphere”
- define “polluted air” in relation to various scientific disciplines
- describe “anthropogenic” sources of air pollutants and distinguish them from “natural” sources
- list 10 sources of indoor air contaminants
- identify three meteorological factors that affect the dispersal of air pollutants

CHAPTER OUTLINE

- I. Introduction
 - II. Measurement Basics
 - III. Unpolluted vs. Polluted Air
 - IV. Air Pollutant Sources and Their Emissions
 - V. Pollutant Transport
 - VI. Summary of Major Points
 - VII. Quiz and Problems
 - VIII. Discussion Topics
- References and Recommended Reading

I. INTRODUCTION

Structure of the Earth's Atmosphere

The Earth, along with Mercury, Venus, and Mars, is a terrestrial (as opposed to gaseous) planet with a permanent atmosphere. The Earth is an oblate (slightly flattened) sphere with a mean diameter of 12,700 km (about 8,000 statute miles). The highest surface feature, Mt. Everest, reaches about 8.87 km (5.5 miles) above sea

level. Mt. Everest is thus a minute bump on the globe that adds only 0.06 percent to the Earth's diameter.

The Earth's atmosphere consists of several defined layers (**Figure 2–1**). The *troposphere*, in which all life exists, and from which we breathe, reaches an altitude of about 7–8 km at the poles to just over 13 km at the equator: the mean thickness being 9.1 km (5.7 miles). Thus, the troposphere represents a very thin cover over the Earth, barely higher than Mt. Everest. If the Earth is represented by a ball with a diameter of 2 m, the thickness

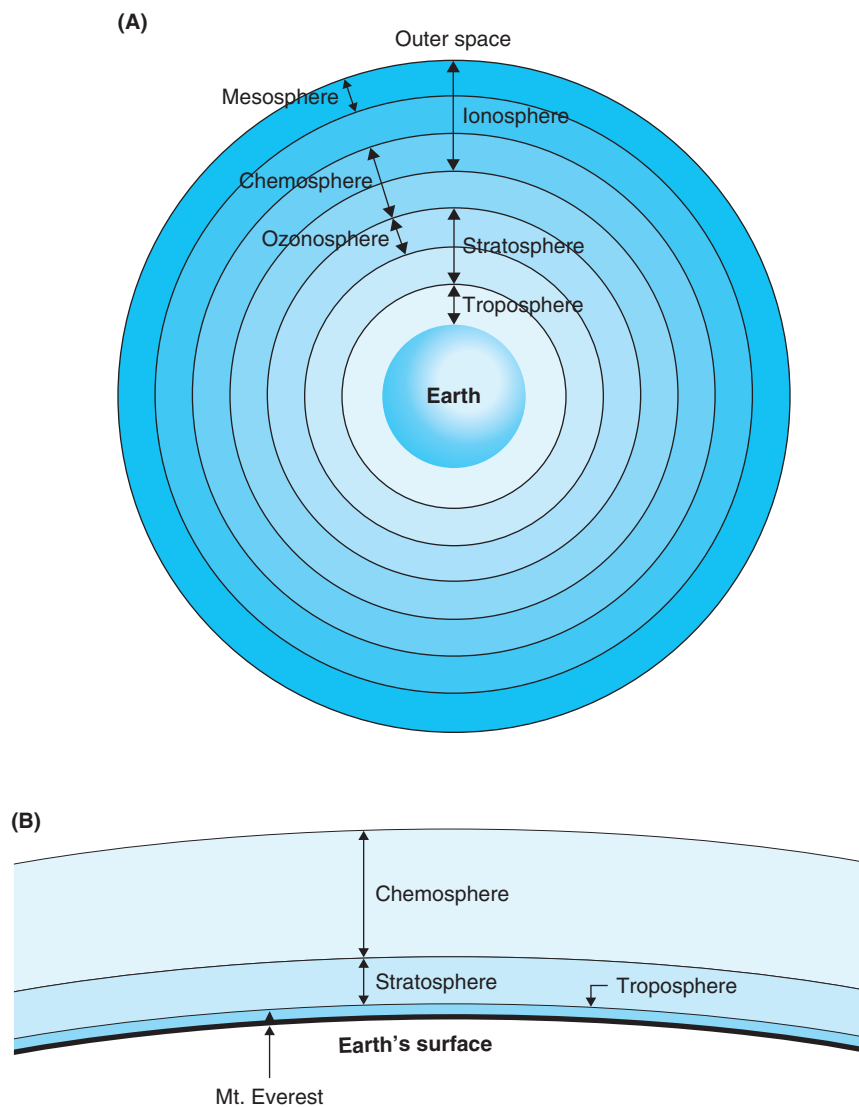


Figure 2–1 A: Layers of the earth's atmosphere (not drawn to scale); B: To-scale depiction of layers of earth's atmosphere.

Source: The University of California Air Pollution Health Effects Laboratory, with kind permission.

of the troposphere would be about 1.3 mm (**Figure 2–1**). The main point is that surface air pollutants are released into a thin atmospheric skin.

Gravitational attraction binds the atmosphere to the Earth. The outermost traces of the atmosphere reach to over 100 km (60 miles) above the surface. The protective ozone layer is above the troposphere at a variable altitude of about 20 to 30 km.

Vertical Mixing and Inversions

From our knowledge of thermodynamics and hot air balloon observations, we know that heating the air causes it to expand and rise. Because the temperature of the air in the troposphere normally decreases with increasing altitude, warmer surface air rises vertically until it cools sufficiently. This vertical air movement and subsequent mixing dilutes air contaminants generated near the surface, thus preventing their accumulation in the air we normally breathe. However, the situation is changed by *air temperature inversions*, in which vertical air movement is impeded. Inversions are characterized by local parcels of *warm* air over *cooler* air, which prevents the normal vertical mixing. Inversions can trap air pollutants very close to the Earth's surface. Inversions may be low, less than 100 m high, in some cases. In such cases, clear air may be seen above a sharply defined smoggy yellow-brown air layer that extends down to the surface.

Inversions are caused by many phenomena, including (1) movement of a warm front into a region; (2) solar heating of the air above a shaded valley; (3) downward flow of cold mountain air into a warm valley; and (4) nighttime cooling of the Earth's surface by the radiation of surface heat to space. Several types of air contaminants (e.g., black carbon particles) absorb solar energy and heat the surrounding air, thus it is also possible that the trapping of solar heat in the upper layers of a heavily polluted air mass can produce or sustain an air inversion (i.e., a *smog inversion*). When a low-level inversion is coupled with stagnant winds and heavy local emissions of air contaminants, the conditions are right for an air pollution episode. The major historical air pollution episodes all occurred during stagnant inversions in regions that had significant sources of combustion-related air pollutants (see Chapter 1). Although local differences in air temperature and the Earth's rotation normally drive winds that transport and dilute air pollutants, air stagnation and low wind-speed conditions are common in many regions.

Tropospheric vs. Stratospheric Pollutant Effects

Just above the troposphere, the stratosphere reaches to an altitude of about 50 km (30 miles). The boundary between the troposphere and the *stratosphere* is called the *tropopause*. Above the tropopause the temperature rises, creating a natural global inversion that traps pollutants in the troposphere. Large meteorologic events, such as major storms, volcanic eruptions, and nuclear bomb detonations, can penetrate the tropopause and locally mix tropospheric and stratospheric air. Also, the tropopause does not represent an absolute barrier to gaseous molecules that rise through it, which is a factor in the stratospheric *ozone depletion* caused from the rise of chlorofluorocarbons (CFCs) and other reactive substances from the troposphere.

Pollutants in the troposphere can have *direct effects* on living things and physical objects on the surface of the Earth. The physical and chemical properties of the pollutants, the time of contact, and other factors will determine the types and magnitudes of these direct effects. In contrast, pollutants in the stratosphere do not usually contact the surface or interact with life, but they can produce *indirect effects*. These indirect effects relate primarily to absorption and scattering of solar radiation (visible light, infrared, and ultraviolet rays) and cosmic ionizing radiation. The stratosphere provides important protection for life by shielding the surface from such damaging radiations. It also influences and stabilizes the temperature of the Earth, which has significant implications for the sustainability of life on Earth (see Chapter 5). Similarly, tropospheric pollutants can affect surface temperatures by scattering and by absorbing thermal energy from the sun and by trapping nighttime heat that radiates from the surface.

II. MEASUREMENT BASICS

Quantitation and Scale

Quantitative measurements are among the indispensable tools of science. Without such measurements one only has generalities and personal statements, such as “it's too cold”; “the air is clean”; and “visibility is poor.” Such generalities convey some information, but they are imprecise and of little use in air pollution science. Quantitative measurements are based on accepted *units of measurement* that are precisely defined. Such units do not vary from time-to-time, place-to-place, or

observer-to-observer. They quantify time, size, location, temperature, pressure, altitude, mass (or weight, which is mass times the acceleration due to gravity), humidity, particle count, and many other measurable factors. Ratios such as parts per million (ppm) or milligrams per cubic meter (mg/m^3) are quantitative, and also frequently used in air pollution science.

To demonstrate the use of measurement units, consider sulfur. The total mass of 10 billion, trillion sulfur atoms is only about 0.5 grams. In contrast, the mass of sulfur released in a volcanic eruption can be several billion grams. In order to express such wide ranges of scale, powers of 10 (i.e., exponents) are used. **Table 2–1** provides the scientific nomenclature associated with powers of 10. Such exponents are commonplace in air pollution science.

Powers of 10 are also used for expressing ratios. For example, 1 cubic cm (cm^3) of a gas dispersed in 1 million cubic cm of air is 1 part per million (ppm_v , volume-to-volume ratio). The concentrations of gaseous contaminants in the air are typically reported as ppm_v values (usually without the subscript, v). To avoid confusion, think of ppm as similar to a percentage. Instead of a ratio of 1/100 as with a percent, ppm is a ratio of 1/1,000,000. The scale is different by several powers of 10.

One could also express ratios on a weight-to-volume basis. For example, 1 cubic cm of sulfur dioxide gas (SO_2) at standard laboratory conditions has a mass of 2.6 mg, thus the measure of mass of sulfur dioxide to a 1 m^3 volume of air would be 2.6 mg per 1 million cubic cm (or $2.6\text{ mg}/\text{m}^3$). Such weight per unit volume measures are commonly reported for solid or liquid contaminants suspended in the air. However, this measure can still be used with gaseous components in air. In some cases the air contaminant may exist in both the gaseous and solid or liquid phases within the air. The weight per volume measure is often used in these instances.

Additional ratios of measure can also be used. For example, as a m^3 of air has a mass of about 1.2 kg, the weight-to-weight ratio for the sulfur dioxide example above would be about 2.2 ppm_w . One could also express the ratio of the *number* of sulfur dioxide molecules to air molecules, but this is seldom done in air pollution science. The weight of an air contaminant in a cubic meter of air (mg/m^3) and the volume ratio (ppm_v , or just ppm) are normally used. **Table 2–2** shows some useful conversion factors for changing mg/m^3 to ppm_v .

Variations in Units of Measurement

Air pollution science involves several disciplines including meteorology, chemistry, physics, ecology, biology, physiology, toxicology, and medicine. Each discipline uses its own measures for pollutant particles, gases, or vapors. Meteorologists are interested in emissions measured in mass or weight units, so concentrations are measured in units such as mg/m^3 of air or parts per million ppm_v . Chemists tend to use units such as moles per cubic meter and atoms or molecules per unit volume. Physicists may use the number, mass, or surface area of particles per cubic centimeter and the partial pressure of a gas. Biologists and physiologists, who are interested in the effects of air pollutants on living systems, use measures such as mass per unit volume of air and *partial pressure* for gases and vapors. Physicians are frequently interested in doses, so the concentrations in organs and tissues (e.g., micrograms per gram of tissue or mass of pollutant delivered to an individual subject) are of interest. Although many more examples could be given, the important points can be made: (1) a number of measures of pollutants are in common use; (2) converting units from one measure to another is often required. This introductory text will use those specific units that best suit the topic at hand.

Table 2–1 Powers of ten, using the International System of Units (SI) nomenclature.

	Numerical Equivalent	Prefix/Name	Symbol
10^{-12}	0.000000000001	pico/trillionth	p
10^{-9}	0.000000001	nano/billionth	n
10^{-6}	0.000001	micro/millionth	μ
10^{-3}	0.001	milli/thousandth	m
10^{-2}	0.01	centi/hundredth	c
10^{-1}	0.1	deci/tenth	d
10^0	1	unity	none
10^1	10	deca/ten	da
10^2	100	hecto/hundred	h
10^3	1,000	kilo/thousand	k
10^6	1,000,000	mega/million	M
10^9	1,000,000,000	giga/billion	G
10^{12}	1,000,000,000,000	tera/trillion	T

Note: In the United Kingdom, 1 billion = 10^{12} (i.e. a million million), and 1 trillion = 10^{18} (i.e. a billion billion).

Table 2–2 When converting mg/m³ (mass of gas/volume of air) to ppm (volume gas/volume of air) multiply by k. Valid for 25°C and 760 mm Hg pressure.

Pollutant Gas	Chemical Formula	Gas Mol.Wt. (g/mole)	$k = 24.45/MW$ (ppm/[mg/m ³])
Ammonia	NH ₃	17.03	1.44
Carbon dioxide	CO ₂	44.01	0.556
Carbon monoxide	CO	28.01	0.873
Chlorine	Cl ₂	70.91	0.345
Formaldehyde	HCHO	30.03	0.814
Hydrogen sulfide	H ₂ S	34.08	0.717
Methane	CH ₄	16.04	1.52
Nitric oxide	NO	30.01	0.815
Nitrogen	N ₂	28.02	0.873
Nitrogen dioxide	NO ₂	46.01	0.531
Nitrous oxide	N ₂ O	44.02	0.555
Oxygen	O ₂	32.00	0.764
Ozone	O ₃	48.00	0.509
Sulfur dioxide	SO ₂	64.07	0.382

III. UNPOLLUTED VS. POLLUTED AIR

Clean Air, Can it be Harmful?

Unpolluted (clean) tropospheric air is defined in **Table 2–3**. Of the two major atmospheric gases, N₂ and O₂, one is considered to be *chemically inert* (N₂), and the other *oxidizing* (O₂). However, N₂ is not always *biologically inert*. In deep-sea diving, where the pressure

is several atmospheres, divers breathing compressed air can become disoriented due to the narcotic effects of N₂ dissolved in the fatty tissue of the brain. So N₂ is biologically inert at atmospheric pressure, but toxic at elevated pressures. The use of 80 percent helium gas plus 20 percent O₂ in diving air prevents gas toxicity problems at elevated pressures. Similarly, O₂ is beneficial at normal partial pressure (20.9 percent of 1 atmosphere), but toxic when breathed for a prolonged time at

Table 2–3 The gaseous composition of dry and wet (100% RH) unpolluted air.

Substance	ppm by Volume, Dry Air	μg per m ³ , Dry Air	ppm by Volume, Wet Air
Nitrogen	781,000	9×10^8	757,000
Oxygen	209,000	2.7×10^8	203,000
Water	0	0	31,200
Argon	9,300	1.5×10^7	9,000
Carbon dioxide	315	5.7×10^5	305
Neon	18	1.5×10^4	17
Helium	5.2	8.5×10^2	5.0
Methane	1.0–1.2	7.0×10^2	1.0
Krypton	1.0	3.4×10^3	1.0
Nitrous oxide	trace	trace	trace
Hydrogen	trace	trace	trace
Xenon	trace	trace	trace
Organic vapors	trace	trace	trace

100 percent concentration at a pressure of 1 atmosphere. In toxicology (the study of adverse effects of chemicals), not only must gas concentrations be considered, but also the gas pressures (or partial pressures of each gas in a mixture) must be taken into account. Thus, the toxicology of a gas or vapor in a spacecraft (low ambient pressure) or a submarine (high ambient pressure) may not apply to other environments with different atmospheric pressures.

Defining Air Pollutants

Air contaminants (also *air pollutants*) are difficult to concisely define. They exist in several forms including solids, liquids, vapors (vapors are gases formed by volatile liquids/solids), gases, ions, and mixtures of these primary states of matter. Pollutants may persist in the air only briefly (e.g., short-lived reactive chemical species with lifetimes less than 1 second), or for several years (e.g., very small particles and nonreactive gases).

What makes something an air pollutant? From a *regulatory perspective*, an air pollutant is a substance that is, or may be, present at a concentration that exceeds its *safe* concentration. Also, from a regulatory point of view the air is not necessarily polluted if none of its constituents are out of *compliance* with an air quality standard. Note that the air may quickly go from “unpolluted” to “polluted” if an air standard is tightened. Regulatory agencies may refer to *criteria pollutants*, *air toxics*, or *hazardous air pollutants* (HAPs) that have published standards that are intended to protect susceptible populations or the general public. Criteria air standards are reviewed by the U.S. Environmental Protection Agency (U.S. EPA) about every five years. HAPs are reviewed only when deemed necessary. Workers are usually permitted exposure to higher levels of air pollutants than the public, as workers are healthier (as a group). For the protection of workers from airborne hazards, essentially any substance may be added at any time to lists that provide recommended (e.g., ACGIH[®], 2010) air concentrations.

From a *practical perspective*, an air pollutant can be defined as any substance, regulated or not, that interferes with a person, process, or an object that has value. Thus, for an analytical chemist a trace of water vapor in the air may be an interfering pollutant. For a deep sea diver, N₂ gas in tank air may be a pollutant. And for a manufacturer of computer chips, very tiny amounts of particles in the air are serious pollutants that may affect product quality. As the practical perspective can

include essentially any known substance as a pollutant, it is impractical to consider it in the context of this textbook: specialty publications should be consulted as needed.

An air pollutant is a substance that, at realistic environmental concentrations, is known to have adverse effects on humans, other animals, vegetation, visibility, the climate, or other assets (such as objects of art, machinery, or buildings).

Because regulated pollutants have been subjected to the most intensive research, they are a primary focus in this textbook. If the U.S. EPA, the Occupational Safety and Health Administration (OSHA), or another major regulatory body deems something to be an air pollutant, so will the authors of this book. However, the main point is that both the *substance* and its *concentration*, along with a subject’s *exposure* and *sensitivity*, are what actually produce a health problem.

IV. AIR POLLUTANT SOURCES AND THEIR EMISSIONS

Terminology and Pollutant Source Categories

The sources of air pollutants are numerous and varied. Three categories of sources may be defined: (1) *natural* (i.e., those that are not associated with human activities); (2) *anthropogenic* (i.e., those produced by human activities); and (3) *secondary* (i.e., those formed in the atmosphere from natural and anthropogenic air pollutants). Each of these three categories of air pollutants can be further subdivided. For example, anthropogenic pollutant sources can be classified as *stationary*, (e.g., factories, farms, homes, etc.) vs. *mobile* (e.g., cars, trucks, boats, aircraft, etc.). Other subcategories, such as *indoor* vs. *outdoor*, *organic* vs. *inorganic*, or *local* vs. *regional*, are also used. The following sections will provide an overview of the sources and emissions associated with these and other categories and classes of air pollutants.

Natural vs. Anthropogenic

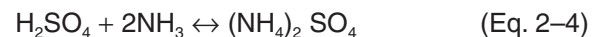
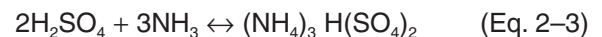
Table 2–4 lists some major sources and annual national emission estimates (in thousands of tons) for some of the air pollutants that are regulated by the U.S. EPA. The natural sources of selected air pollutants are shown in **Table 2–5**. Several points can be made related to these tables. Natural sources are difficult, if not impossible to

Table 2–4 Some major anthropogenic sources and emissions of ambient air pollutants in the United States in 1993, including primary particle sources and sources of precursor gases (sulfur and nitrogen oxides) and volatile organic compounds (VOCs) (EPA, 1996). PM_{10} refers to particles with diameters under 10 micrometers. SO_x and NO_x are oxides of sulfur and nitrogen, respectively. One ton equals 907 kg.

Source	Thousands of Tons/Year			
	PM_{10}	SO_x	NO_x	VOCs
Fuel Combustion				
Utilities	270	15,836	7,782	36
Industrial	219	2,830	3,176	271
Other sources	723	600	732	341
Industrial Processes	553	1,862	905	3,091
Solvent Utilization	305	43	90	10,381
On-road Vehicles	197	438	7,437	6,094
Off-road Vehicles	395	278	2,996	2,207
Fugitive Dust				
Roads	22,568			
Construction/Mining	11,368			
Agriculture	7,236			

control. Natural emissions are often generated at locations that are unpopulated, or sparsely populated by people. For these and other reasons, the primary focus of regulators is on studying and controlling anthropogenic sources. However, a problem arises when secondary pollutants (formed in the air) are considered. For example, anthro-

pogenic (or natural) SO_2 is a precursor of H_2SO_4 (sulfuric acid) and other acidic sulfates. But the natural (and anthropogenic) pollutant, NH_3 (ammonia) reacts with H_2SO_4 , and neutralizes its strong acidity. Proposed net reactions include:



Equations 2–1 to 2–4 represent the formation (and back reactions) of gases/vapors to solid or liquid products, in this case sulfate salts. These salts are typically secondary pollutants formed by the reactions of anthropogenic and natural emissions. Sometimes, it is difficult to isolate the roles of human activities in producing poor air quality.

The foregoing example, which represents only a few of essentially countless atmospheric reactions, demonstrates the importance of air chemistry modeling to support regulations. Air chemistry is covered more completely in Chapter 3.

Table 2–5 Some major global natural sources and emissions of air pollutants.

Source	Millions Tons/Year			
	Particles	Sulfur	NO_x	CO
Dust & Soil	90–450		24	
Sea Spray	800	48		
Biological Action	70–180	108	3–30	40–400
Volcanic Eruptions	*	5.5		
Lightning			24	
Fires & Other Oxidation	*		35	100–5,700

Note: * = extremely large amounts are released.

Data, in short tons (2,000 lbs, 907 kg), are from various sources including: Finlayson–Pitts and Pitts (1986); U.S. EPA (2000).

Stationary vs. Mobile and Point vs. Distributed Sources

Anthropogenic pollutant sources are classified as *stationary* or *mobile*. The major stationary sources as defined by the U.S. EPA (2000) include:

- electric utilities that burn organic fuels (note that nuclear, hydroelectric, and wind-powered utilities usually do not produce air pollutants);
- industrial plants that burn organic fuels;
- chemical manufacturing;
- metals processing;
- petroleum industries;
- other industries (agriculture, textile, wood, rubber, electronic, construction, etc.);
- solvent users (degreasing, graphic arts, dry cleaning, etc.);
- storage (terminals, service stations, chemical storage, etc.);
- waste handling (incinerators, open burning, landfills, etc.); and
- miscellaneous sources (forestry, health services, accidental releases, repair shops, cooling towers, etc.).

Mobile sources, which are vehicles, include:

- on-road gasoline powered trucks, automobiles, and motorcycles;
- on-road diesels; and
- off-road vehicles (gasoline and diesel powered automobiles and trucks, aircraft, marine vehicles, and railroad engines).

For each source, data are gathered on pollutants such as carbon monoxide; sulfur dioxide; ammonia; volatile organic compounds; nitrogen oxides; lead; particulate matter; and hazardous air pollutants. **Figures 2–2 through 2–9** depict 2008 U.S. emissions for several air pollutants. The major source of carbon monoxide is on-road vehicles (about 60 percent of the total). Non-road vehicles emit another 20 percent, and other sources emit the remainder. Vehicles are also major emission sources for nitrogen oxides and volatile organic compounds. Electric utilities are major emitters of sulfur dioxide. Most of the lead emissions are from metals processing, followed by waste disposal/recycling, vehicles, and stationary fuel combustion sources. Most of the ammonia is emitted by livestock, organic decay, and fertilizer-related sources. Sources of anthropogenic

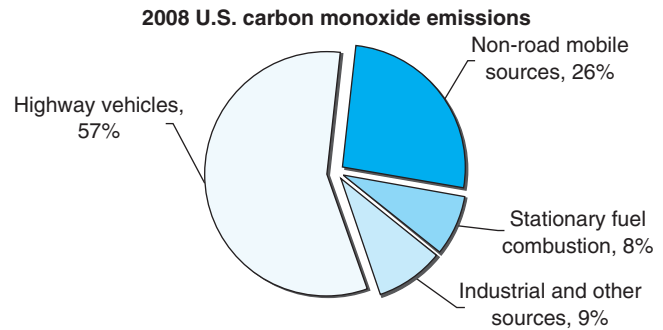


Figure 2–2 U.S. 1998 CO emissions
Source: U.S. EPA (2010).

particulate matter include stationary-source fuel combustion (including managed burning), mobile sources, and industrial processes (which are responsible for about 10 percent of the total). Sources that are highly-localized, such as electric power plants and industrial plants, are often classified as *point sources*, while agricultural operations and urban centers are *distributed sources*. All sources can have a significant impact on local air quality. The distinction, point vs. distributed, is important for modeling local air concentrations of pollutants. In general, point sources are easier to quantify and to control than are distributed sources.

Enclosed Settings and Workplaces

Overview

Air pollution is not just an outdoor problem. In fact, the air in many *enclosed environments* is more contaminated

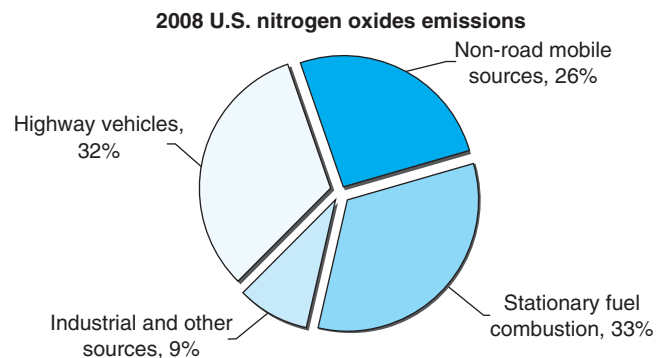


Figure 2–3 U.S. 1998 NO_x emissions
Source: U.S. EPA (2010).

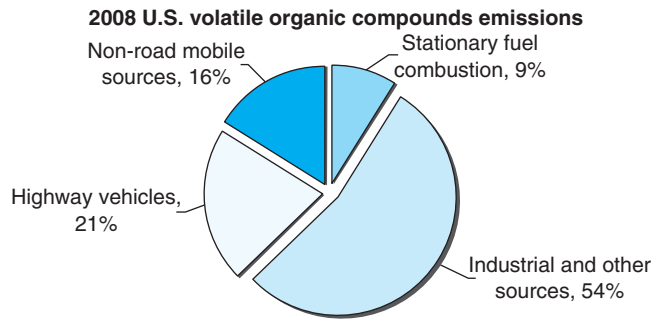


Figure 2-4 U.S. 2008 Volatile organic compound emissions.
Source: U.S. EPA (2010).

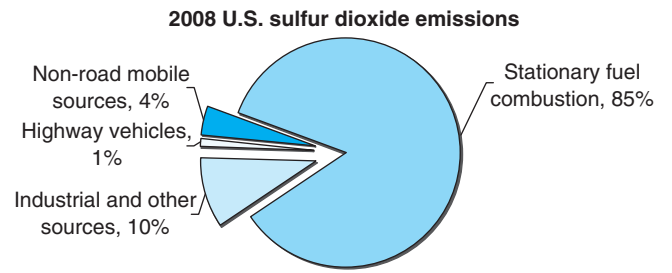


Figure 2-5 U.S. 2008 SO₂ emissions.
Source: U.S. EPA (2010).

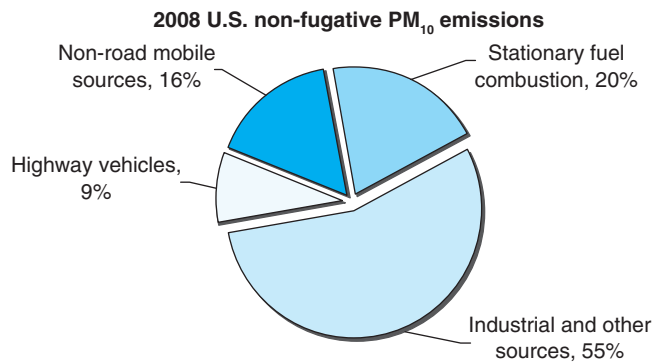


Figure 2-6 U.S. 2008 PM₁₀ (particles under 10 μm diameter) emissions from nonfugitive dust sources.
Source: U.S. EPA (2010).

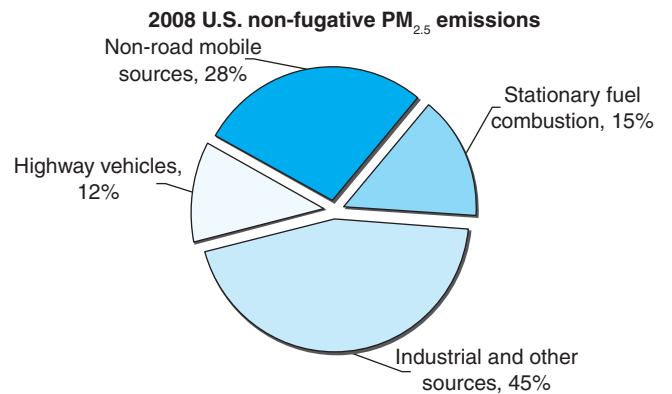


Figure 2-7 U.S. 2008 PM_{2.5} (particles under 2.5 μm diameter) emissions from nonfugitive dust sources.
Source: U.S. EPA (2010).

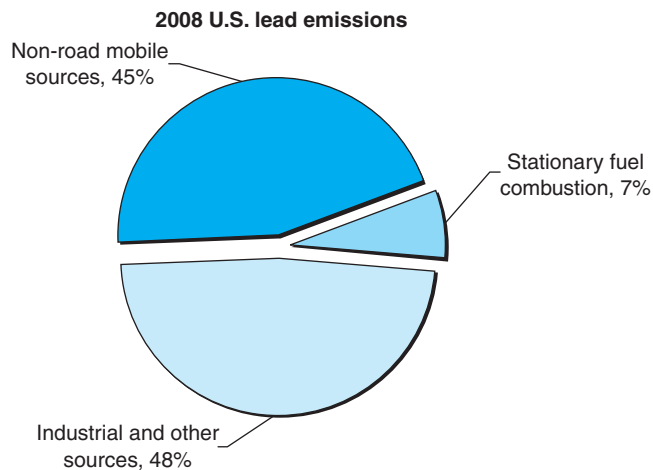


Figure 2-8 U.S. 2008 Lead emissions.
Source: U.S. EPA (2010).

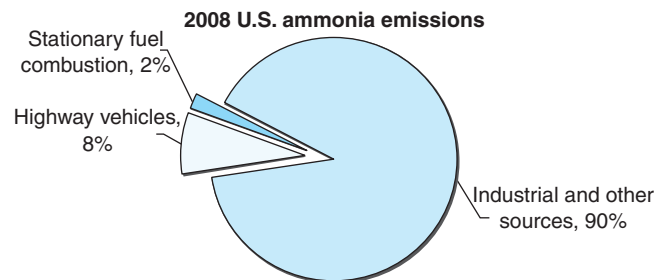


Figure 2-9 U.S. 2008 Ammonia emissions.
Source: U.S. EPA (2010).

than the local outdoor environment. The reasons for this are (1) the limited volumes of dilution air; (2) the low wind speeds indoors; and (3) the sometimes intense indoor sources (e.g., smoking, cooking, and cleaning). Although one might think of residences as the major occupied enclosed settings, workplaces, public buildings, and vehicles are also places in which indoor exposures occur.

Time-activity patterns (how long and where people are exposed) are used to estimate human exposures. People spend about 90 percent of their time in enclosed environments. Each type of indoor setting has its unique characteristics, and important variations in sources and emissions occur within each. Consider two workplaces, an office and a metal foundry; they have very little in common. Similarly, the air quality for an air conditioned, gas-heated residence will differ considerably from one that has no air conditioning and where the source of heat comes from burning coal or wood indoors. A similar contrast could be drawn between air quality in an upscale automobile and an old “clunker.” Because enclosed settings are so variable, this chapter will cover only a few specific examples in order to explore basic principles.

Residences

In contrast to outdoor air pollution, which is both source-dominated and meteorology-dominated, residential air pollution is source-dominated. Pollutants generated in the home are not rapidly dispersed by the wind, and residential air cleaners can seldom overpower uncontrolled pollutant sources. **Table 2–6** lists some of the most common sources of residential air contaminants. **Figure 2–10** illustrates some indoor sources.

Whether or not these sources produce health problems depends on the air contaminant concentrations, whether co-stresses (such as excessive heat, cold, or extreme humidity) are present, and the sensitivity and general health status of the occupants.

Allergens and *irritants* (**Table 2–7**) can pose a significant residential problem, especially for sensitive individuals. Such “sensitives” include people with allergies, asthma, bronchitis, emphysema, respiratory-tract infections, and cardiovascular diseases. These, and other health-related conditions, may both impair normal respiratory tract defenses and lead to exaggerated (even life-threatening) responses to modest levels of air contaminants. Such vulnerable individuals may require a very clean air environment. In some cases, medical advice and treatment by a qualified allergist and/or a pulmonary physician is needed.

It is wise to control indoor sources of air contaminants, both for the sake of the healthy residents and any sensitive or otherwise compromised individuals. **Table 2–8** has a checklist that can be used in the home (also the school, office, etc.) for reducing indoor sources. In addition, commercial air cleaners can be effective if the major pollutant sources have been controlled. Such air cleaners should be selected for their *air throughput rate* and their *cleaning efficiency*. An air cleaner that processes only a few cubic feet of air per minute may be totally ineffective in a room with an air volume of 3,000 cubic feet (8.5 cubic meters). Similarly, an air cleaner that is not capable of removing fine particles (e.g., those from smoking or cooking) or organic vapors, may provide little relief to indoor occupants. An uncontrolled source within a poorly ventilated and/or poorly filtered residence

Table 2–6 Common sources of residential air pollutants.

<i>Pollutant</i>	<i>Sources</i>
Asbestos and other fibers	Old insulation in/on ceilings, walls, stoves, pipes, floor tiles, heaters, etc.
Lead	Old paint, toys, and other commercial products
Biological aerosols	Mold, pets, insects, rodents, people, humidifiers, indoor plants, etc.
Volatile organic compounds (including formaldehyde)	Air fresheners, spray products, solvents, glues, new building-materials, paints, printers, ink, etc.
Combustion products	Smoking, cooking, wood and gas fireplaces, water heaters, candles, incense, etc.
Dust	Vacuuming/cleaning, plants, dirt, outdoor air, etc.
Gases	Off-gassing from water and various products, electrical discharges, combustion, outdoor air, gas appliances, etc.
Radon	Intrusion from soil, masonry, and underground water

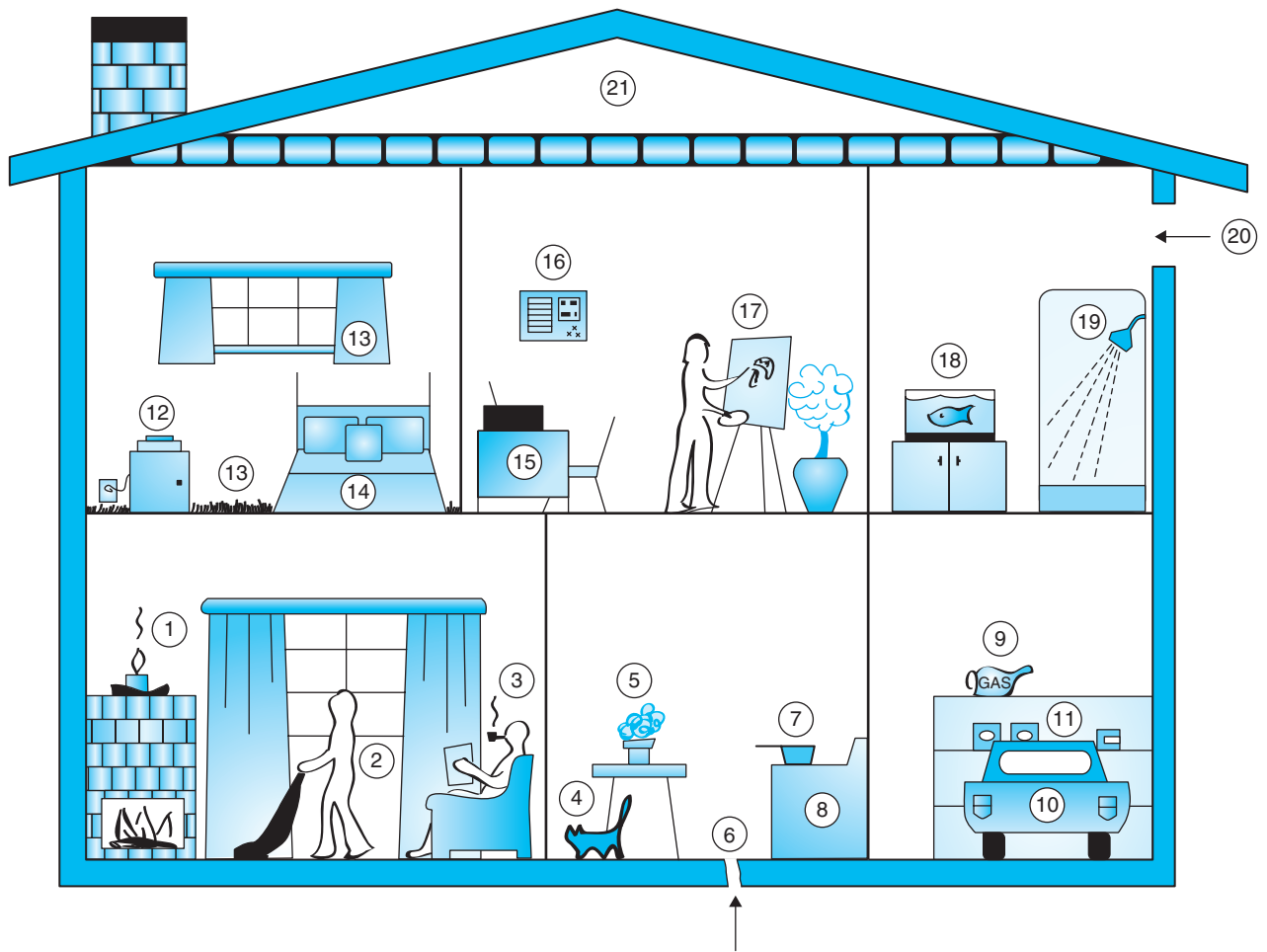


Figure 2-10 Some common sources of residential air contaminants include: (1) fireplace, candles, and incense; (2) vacuuming and cleaning; (3) smoking; (4) indoor pets; (5) potted plants; (6) insects, radon, and methane; (7) food preparation; (8) gas appliances; (9) stored fuel; (10) vehicles; (11) paint, thinner, etc.; (12) humidifier; (13) carpet and drapes; (14) bedding and furniture; (15) computer/printer; (16) air conditioner; (17) hobbies; (18) fish tank; (19) shower; (20) outdoor air; and (21) insulation.

Source: The University of California Air Pollution Health Effects Laboratory, with kind permission.

Table 2-7 Irritants and allergens in residences.

A. Irritants (examples only)	Sources
Solvents, alcohols, etc.	Cleaning and polishing agents, plastics, liquid fuels, hobbies that involve glue, paint and/or solvents, etc.
Formaldehyde	Air fresheners, other spray products, solvents, glues, new building-materials, paints, printers, ink, etc.
Dust	Vacuuming/cleaning, plants, dirt, outdoor air, etc.
B. Allergens (examples only)	
Insect products (droppings, body parts)	Dust mites, cockroaches, other insect infestations
Pet-related	Cat, dog, and rodent allergens from saliva, fur, droppings, bedding, food, water dishes
Plant-related	Pollens, molds (from dead plant material and soil), volatile fragrances, etc.

Table 2–8 Indoor air pollutant control checklist.

- _____ 1. House dust
- _____ 2. Deteriorating cloth, rubber, wood, plastic, paper
- _____ 3. Indoor animals (birds, dogs, cats, rodents, fish tank bubblers, etc.)
- _____ 4. Pet bedding, food, water, and litter boxes
- _____ 5. Sprays (air fresheners, paints, insecticides, cleaners, cosmetics)
- _____ 6. Smoking (cigarettes, cigars, pipes) and burning incense and candles
- _____ 7. Fireplaces, wood, coal, and kerosene stoves
- _____ 8. Smoke from cooking food
- _____ 9. Poorly-vented or broken ovens, stoves, heaters, clothes dryers, and water heaters
- _____ 10. Dusty or soiled carpets, drapes, blankets, pillows, sheets, or mattresses
- _____ 11. Dirty air filters, soiled or dusty air ducts
- _____ 12. Dirty humidifier and dehumidifier water tanks
- _____ 13. Standing water or evidence of mold
- _____ 14. Damp cloth, paper, wood, carpets, walls, etc.
- _____ 15. Indoor plants with pollen or mold growth on container or soil
- _____ 16. Dust-catching decorations, stuffed toys, and drapery
- _____ 17. Hobby-associated activities and materials
- _____ 18. Paints and solvents that are not tightly sealed
- _____ 19. Insects, including mites, ants, fleas, roaches, spiders, and flies
- _____ 20. Poorly-ventilated rooms
- _____ 21. Garbage and spills
- _____ 22. Odorous building materials, insulation, carpets, drapes or furniture

Note: If completing this checklist does not resolve a residential air problem, air cleaners with sufficient throughput and efficiency should be used. Use of an air cleaner in the bedroom may be particularly effective, if the contaminant sources have been removed. When sensitive or ill residents are present, or when symptoms persist, professional medical help is needed.

Source: The University of California Air Pollution Health Effects Laboratory, with kind permission.

could result in a rapid buildup of contaminants within the living space. Thus, elimination or effective control of a contaminant source is often more critical to air quality than its dilution or mechanical removal from the air.

Workplaces

The variety of air pollutants and their sources in workplaces is great enough to defy any succinct summary. Offices may have solvents, ozone (from printers and copiers), allergens from insect infestations, dust, microorganisms from ducts and air conditioners, carbon monoxide from air intakes near truck loading zones, and a variety of air contaminants from nearby industrial

operations. In addition, crowded offices will have human-generated air contaminants from clothing fibers, dander, coughing, and sometimes body-generated odors. Manufacturing operations may produce airborne solvents, organic and inorganic dusts, exotic chemicals, metal fumes, and many other substances. In addition, heat, noise, vibration, and extremes in humidity can exacerbate the direct effects of air pollutants on workers.

Manufacturing and other heavy industrial operations usually require the participation of trained Industrial Hygienists to control the potential risks. It is essential that workplaces conform to modern air quality criteria as well as standards for heat, noise, vibration, and other

hazards. In the United States, private professional organizations, such as the *American Conference of Governmental Industrial Hygienists* (ACGIH®) and the *American Industrial Hygiene Association* (AIHA) publish voluntary guidelines that are applicable to workplaces. Also, governmental organizations, such as the *National Institute for Occupational Safety and Health* (NIOSH), the *Occupational Safety and Health Administration* (OSHA), the *Centers for Disease Control and Prevention* (CDC), the *Mine Safety and Health Administration* (MSHA), and numerous state agencies publish important reports, guidelines, and regulations. Although the cost of maintaining a healthful workplace may be substantial, it is usually negligible to the alternative (i.e., significant worker illnesses). A good example of air quality and other workplace recommendations can be found in the ACGIH® publication *TLVs® and BEIs®* (2010). TLVs® are 8-hour averaged threshold limit values (air concentrations) not to be exceeded for air contaminants, and BEIs® are *biological exposure indices*, which are concentrations in blood, urine, etc., that can be measured in workers to determine their actual exposures. The ACGIH® publication also covers other “agents” such as (1) noise; (2) electromagnetic radiation and fields (including lasers, ultraviolet light, and ionizing radiation); (3) thermal (heat and cold) stress; and (4) ergonomics (lifting, vibration, etc.). These other agents, if not controlled, can produce direct harm and increase the risks associated with exposure to air pollutants.

Even if all of the recommendations for workplace air are followed, some workers may not be adequately protected. The TLVs® and BEIs® acknowledge and caution that the recommendations are designed to protect “healthy” working adults, and that they may not protect all workers. Sensitive individuals may require reassignment of duties, stringent local engineering controls, and if all else fails, additional personal protective equipment (e.g., respiratory protection) to reduce exposures.

Criteria Air Pollutants vs. Hazardous Air Pollutants

Criteria air pollutants (CAPs) and *hazardous air pollutants* (HAPs) are specific agents that have been defined by legislation such as the U.S. *Clean Air Act*, or similar international standards. In the United States, there are seven criteria air pollutants (see Exhibit 6–1, Chapter 6). Each one has associated *National Ambient Air Quality Standards* (NAAQS) that are to be revisited

and possibly revised by the U.S. EPA at least every five years. The NAAQS include *primary pollutant criteria* for protecting human health and *secondary pollutant criteria* for other effects such as reduced visibility, and/or damage to monuments, crops, or livestock. Primary NAAQS must protect sensitive subpopulations and include a *margin of safety*. Considerations of the cost and feasibility of attainment for primary and secondary NAAQS are currently prohibited by law.

Hazardous air pollutants (HAPs), also designated by the U.S. EPA, currently comprise about 200 substances, including both specific agents (such as asbestos, benzene, and formaldehyde) and chemical classes (such as arsenic compounds, coke oven emissions, nickel compounds, and radionuclides). The distinction between CAPs and HAPs is twofold: (1) CAPs have been determined to present a general risk to the health of the public, and HAPs are believed to cause adverse health and/or environmental effects; and (2) unlike CAPs, HAPs may be added to or deleted from their listings, and they do not have the mandated five-year review cycle.

Similar approaches to listing air pollutants have been established by Canada, the United Kingdom, and the World Health Organization, to name a few. However, nations differ in their standards, often significantly. Two main points are (1) that air standards are constantly evolving; and (2) that different approaches are used throughout the world.

Accidents and Disasters

An accidental release of air pollutants can produce a major health catastrophe for a local community. Explosions, fires, industrial containment failures, railroad car derailments, and trucking accidents can release substantial quantities of fuels, solvents, combustion products, radionuclides, and/or toxic air contaminants. Similarly, natural accidents, such as volcanic eruptions, earthquakes, forest fires, and hurricanes can generate high levels of air pollutants. Such accidents can take hundreds to thousands of lives. Warfare and terrorist attacks must also be included in the list of causes of air pollution disasters. Poison gases (e.g., sulfur and nitrogen mustards, phosgene, chlorine, hydrogen cyanide and nerve agents), biological aerosols (e.g., botulin, ricin, anthrax bacteria, and viruses), and radionuclides (from atomic, hydrogen and so-called “dirty” bombs) are among the potential air pollutants. Warfare agents are sought by terrorists in order to achieve their ends.

Air pollution is not simply a problem caused by industry, transportation, agriculture, and other activities that are often essential to maintaining public health.

An especially-tragic industrial disaster occurred in 1984 in *Bhopal*, India. An explosion at a pesticide facility during an atmospheric inversion released tons of methyl isocyanate into the air of a nearby community, and about 200,000 people were exposed. The highly-irritant chemical most likely produced over 3,000 deaths, including those at the time of the explosion and those over the following four years. Thousands more delayed Bhopal fatalities are projected into the future. Such disasters lead to public fear, and they result in pressure on governments to provide better protection.

V. POLLUTANT TRANSPORT

Overview

The transport of air pollutants is largely driven by weather phenomena. Vertical air motions along with prevailing winds both dilute and disperse particles and gases emitted from any given source. On a global scale, unequal solar heating causes warm air near the equator to rise and then descend as it cools and travels toward the north and south poles. This effect alone would produce wind circulation toward the poles at high altitudes and toward the equator at low altitudes. But several other phenomena complicate the global weather picture. The Earth's rotation has two effects, surface friction that drags surface air in the direction of rotation and a *Coriolis force* that, in general, turns air movement to the right in the Northern hemisphere and towards the left in the Southern hemisphere. The Coriolis force occurs as a consequence of the Earth's rotation. Surface characteristics (e.g., oceans and other large bodies of water vs. land areas) that modify the air temperature and moisture content also influence large air flow patterns. Mountains, forests, and even cities affect wind patterns more locally; **Figure 2–11** depicts the major convective cells and the general climate systems. Although the principles of weather phenomena are understood, long-range weather predictions are highly uncertain due to the effects of small-scale phenomena. Weather is a *chaotic system*, in that small changes in initial conditions can produce large long-term consequences.

If emitted particles and gases strictly followed the winds, concentrations downwind could be accurately predicted over the time scale of a few days. However,

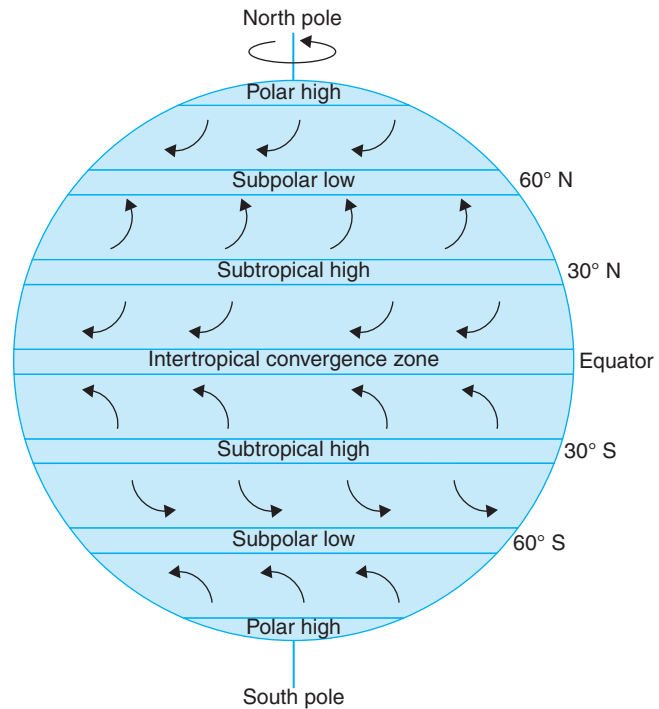


Figure 2–11 The large-scale motion of the Earth's atmosphere. This motion is influenced by thermal gradients, friction between the air and rotating Earth, and the Coriolis force.

Source: The University of California Air Pollution Health Effects Laboratory, with kind permission.

such predictions are risky because airborne particles and gases can separate from their air parcels (the volume of air into which they were emitted), due to diffusion and sedimentation. Also, local meteorology can influence the rise and transport of air on a local scale. Such local meteorology includes air inversions and convective phenomena (as produced by local heating effects, eddies, terrain effects, and other phenomena).

Gases and vapors more closely follow wind patterns, but they have diffusion velocities that can cause them to spread beyond the air parcel into which they are emitted.

Particles with large aerodynamic diameters (20 μm and above; see Chapter 3 on aerodynamic diameters) have behaviors strongly influenced by gravity and by the particle's inertia. Therefore, they readily settle out of the air parcels in which they are entrained. Particles in this size regime settle out of the air at velocities that exceed 3 m per hour. Thus, if such particles are emitted

1 m above the surface they will settle to the ground in about 20 minutes, unless they encounter substantial updrafts or descending terrain. Small particles, e.g., those 1 μm or smaller in diameter have settling velocities (see Chapter 3) of less than a few cm per hour. Such particles can travel in the wind for more than several km before settling to the ground. Very small particles can travel thousands of km before settling out of the air.

Other phenomena that produce the loss of contaminant particles, gases, and vapors from the air include:

- evaporation of volatile particles;
- chemical transformations;
- capture by vegetation and other objects (both anthropogenic and natural);
- capture by precipitation (rain, snow, etc.); and
- attachment to particles that settle out.

Gaussian Plume Model

The Gaussian plume model is used for estimating downwind pollutant concentrations emitted from point sources. The model is three-dimensional in that downwind, crosswind, and vertical dispersing components are considered. At the emission point, pollutant dilution occurs in direct proportion with the wind speed. The plume shape near the source is Gaussian (i.e., bell-shaped normal-distributions) in its cross-sections. The standard deviations of the normal distributions increase with distance from the emission point source. The model is useful for predicting air pollutant concentrations down-

wind from smokestacks. However, the basic model does not include pollutant losses (or formations) in the plume caused by chemical reactions and particle sedimentation. Chemical reactions in plumes can lead to significant acidification and hence downwind acid deposition (see **Exhibit 2-1**).

Plumes and Smokestacks

Plumes from smokestacks present a good case study in which to examine air pollutant transport. Increasing the height of a smokestack will usually decrease the near-stack ground level concentrations of emitted particles and gases and cause emissions to dilute and deposit further downwind, which is why smokestacks tend to be tall. Ambient air velocity has effects on stack emissions. Low winds tend to increase nearby ground level concentrations, but at high wind speeds the additional dilution of the emissions decreases downwind concentrations. As an example, if the pollutant concentration downwind from a point emission source is 10 mg/m^3 of air, then doubling the wind speed should result in a concentration of about 5 mg/m^3 , or half the original concentration.

The buoyancy of a plume is a factor in initial plume rise. A warmer or otherwise lower-density plume will rise to a height where it matches the density of the air. Interestingly, humid air has a lower density than dry air. This is because the molecular weight of H_2O vapor (18 atomic mass units) is less than that of both

Exhibit 2-1 Acid deposition (acid rain, snow, and aerosols).

The deposition of acidic air pollution can have adverse effects on soil and fresh water lakes that are downwind from large sources of sulfur dioxide, sulfuric acid, NO , NO_2 , and nitric acid. Acid deposition, which refers to the deposition of rain, snow, fog, or acid aerosols, can cause immediate and/or delayed decreases in the pH of water and soil. The delayed effects are mainly due to the melting of acidified snow and the subsequent runoff. The effects, which depend on the buffering capacity of lakes and soil, include decreases (or elimination) of sensitive species of fish and decreased growth of forests. The Eastern United States and Eastern Europe have been most heavily impacted by acid deposition, primarily due to the presence of emissions of acids and acid precursors. Emission controls, e.g., sulfur reductions in coal, are partially directed toward reducing the adverse effects of acid deposition in impacted areas.

The chemistry of acid rain, snow, fog, and aerosols has been extensively studied. The neutral pH of pure water, i.e., neither acidic nor basic, is 7.0. Even pristine rain has a slightly-acidic pH of 5.0 to 5.65, due to the natural CO_2 and other substances in the air. Downwind of some types of industries and electric power plants, the pH of rain can be as low as 4.2. This acidity forms over time in plumes. Interestingly, taller smokestacks can produce more acidic conditions downwind because of the longer times available for acids to form.

N_2 (28 atomic mass units) and O_2 (32 atomic mass units), which make up most of the air; therefore, water vapor displaces these heavier gases.

When the smokestack emits a plume at a low upward velocity and at a temperature and density near ambient conditions one can observe the interaction of the plume with the wind and the vertical air temperature profile. **Figure 2–12** shows two likely vertical temperature profiles in the atmosphere. The solid line shows the standard lapse rate, which is the normal decrease in air temperature with altitude in the troposphere. The standard lapse rate is 9.8°C per km, but it can vary. The dashed line represents the temperature profile in a low-level (400 m) inversion condition. Such inversions, which can be lower or higher than 400 m, are not uncommon. **Figure 2–13** shows a top view of a typical smokestack plume carried by a wind moving from left to right. Note that the plume spreads outward and is diluted as it travels with the wind. The concentration of pollutants in the plume is usually greatest along its centerline, tapering to low concentrations at its periphery, as predicted by the Gaussian plume model. Similarly, if viewed from the side, the centerline of the plume will have the highest concentration of stack emissions.

Figure 2–14 shows the effect of wind on a plume in the normal lapse-rate case. With no wind, the typical

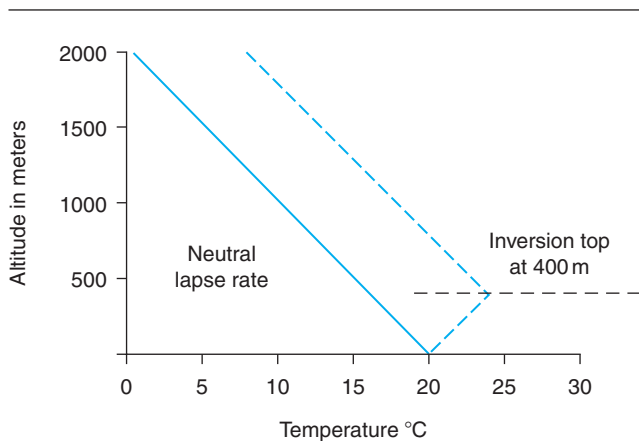


Figure 2–12 Variation of air temperature vs. height above the Earth's surface. The slope of the solid line is the neutral lapse rate of 9.8°C per km. The dashed line depicts a hypothetical inversion layer at 400 m above ground level.

Source: The University of California Air Pollution Health Effects Laboratory, with kind permission.

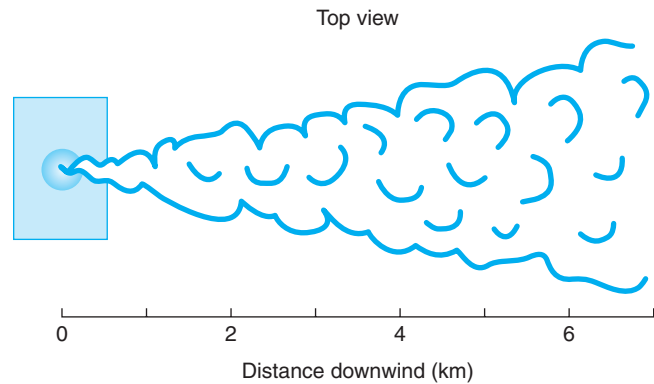


Figure 2–13 Top view of a point-source plume in a light wind. *Source:* The University of California Air Pollution Health Effects Laboratory, with kind permission.

plume will rise and spread laterally. In a wind, the plume will also spread as it is blown. The spreading plume may touch the nearby ground if the smokestack is short, which can produce high levels of emissions at ground level near the stack.

Figure 2–15 demonstrates plume behavior in an inversion condition when the smokestack is above or below the inversion height. As for the short smokestack, an emission below the inversion layer can produce substantial local ground-level concentrations. The condition of a low inversion height and an even shorter smokestack is called *trapping*.

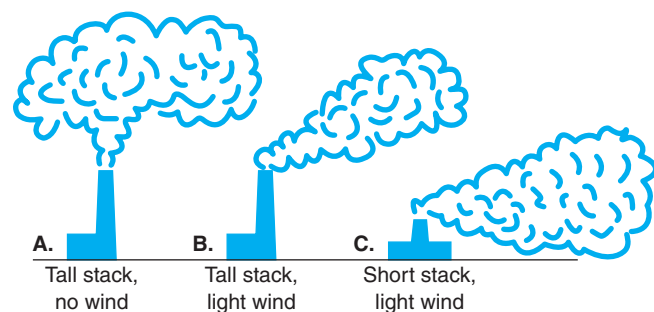


Figure 2–14 Plumes from: A: tall stack with no wind; B: tall stack with a light wind; and C: short stack, with a light wind.

Source: The University of California Air Pollution Health Effects Laboratory, with kind permission.

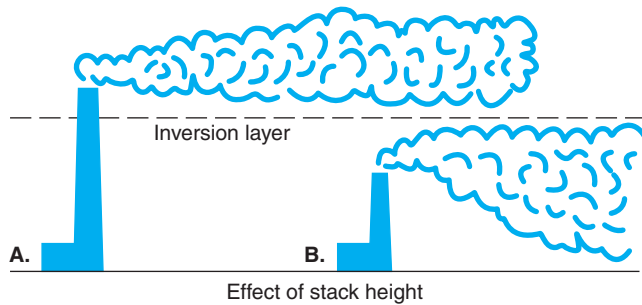


Figure 2–15 Effect of stack height: A: above inversion layer; and B: below inversion layer.

Source: The University of California Air Pollution Health Effects Laboratory, with kind permission.

Figure 2–16 shows the effect of the strength (steepness of the air temperature profile) of the environmental lapse rate. If the lapse rate is strong, *looping* of the plume can occur, which can cause the plume to descend to the surface, rise, and descend again. If the lapse rate is weak, the plume tends to remain aloft.

The most serious conditions, such as a short smokestack, an emission below a low inversion, and a strong lapse rate, have the potential for producing high ground-level concentrations of emissions. In the ideal case the smokestack will be tall enough to allow substantial dilution of the plume before it reaches the surface. The examples given demonstrate just some of the fates of smokestack plumes. The principles of smoke stack plume

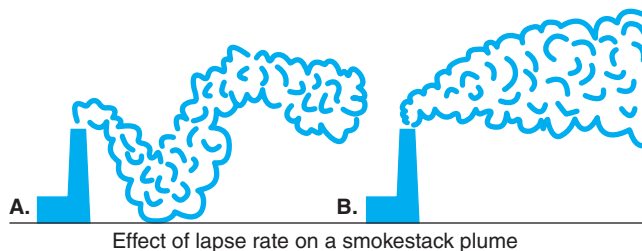


Figure 2–16 Effect of lapse rate on a smokestack plume: A: for a strong lapse rate in which the decrease in temperature vs. altitude is much greater than normal, producing looping of the plume; B: for a normal lapse-rate condition.

Source: The University of California Air Pollution Health Effects Laboratory, with kind permission.

dispersion also apply to other emission point sources, such as factories, vehicles, and fires.

VI. SUMMARY OF MAJOR POINTS

The surface of the Earth has a limited air volume, the *troposphere*, which supports life. Above the troposphere, the *stratosphere* is also essential to life because it shields the surface from harmful radiations and helps to stabilize the temperature of the planet. Several scientific disciplines, each with their own nomenclature, study air pollutants in the atmosphere. Air pollution studies require quantitation and precise units of measurement in order to develop reliable knowledge and to devise acceptable air quality standards. There are several ways to define the term “air pollution” depending on one’s perspective. Regulated (e.g., criteria and toxic) air pollutants are a main focus of modern research. Air pollutants are emitted by a variety of sources, which may be “natural” or “anthropogenic,” “outdoor” or “indoor,” “stationary” or “mobile,” and “point” or “distributed.” Enclosed spaces and workplaces are highly varied with respect to sources and emissions of air pollutants. However, due to the lack of effective dilution and wind dispersal, strict source control is usually needed in order to protect occupants in these environments. Although governmental regulation has been effective in controlling “normal” emissions, periodic accidents and natural disasters add to the continuing health-related toll of air pollution.

The *transport* of air contaminants must be considered in order to understand their downwind concentrations, and thus exposures of people, animals, and plants. One aspect of transport that has been well studied is the dispersion of plumes. Smokestack plumes are dispersed under the influence of meteorological conditions (e.g., wind speed and vertical air temperature profiles) and smokestack design (specifically smokestack height above the surface).

VII. QUIZ AND PROBLEMS

Quiz Questions

(select the best answer)

1. The “troposphere”:
 - a. is a term that describes the uppermost region of the Earth’s air.

38 CHAPTER 2 SOURCES AND EMISSIONS OF AIR POLLUTANTS

- b. is over 1,000 km thick.
 - c. provides the air in which the Earth's living things exist.
 - d. consists of 80 percent oxygen and 20 percent ozone.
2. An air inversion is caused by:
 - a. stagnant winds.
 - b. low atmospheric pressure.
 - c. cooler air on top of warmer air.
 - d. warmer air on top of cooler air.
 3. The three air contaminants, ozone, sulfur dioxide, and carbonaceous fine particles, are:
 - a. only natural air contaminants.
 - b. only anthropogenic air contaminants.
 - c. both natural and anthropogenic air contaminants.
 - d. neither natural nor anthropogenic air contaminants.
 4. How do air pollutant concentrations of 10^{-3} and 10^{-6} mg/m³ compare to each other?
 - a. 10^{-3} is a thousand times greater than 10^{-6} .
 - b. 10^{-6} is two times greater than 10^{-3} .
 - c. 10^{-3} is two times greater than 10^{-6} .
 - d. 10^{-6} is three times greater than 10^{-3} .
 5. What factors can classify a substance as an air pollutant?
 - a. presence in the air.
 - b. interference with human health or welfare, damage to materials or objects of value, or interference with important scientific processes.
 - c. both a and b.
 - d. None of the above are true.
 6. How would one classify the population of cross-country motorcycles as sources of air pollution?
 - a. stationary, distributed, and natural.
 - b. mobile, distributed, and anthropogenic.
 - c. mobile, point, and natural.
 - d. stationary, point, and anthropogenic.
 7. The major anthropogenic sources of particulate air pollutants are:
 - a. stationary-source fuel combustion.
 - b. mobile-source fuel combustion.
 - c. volcanic eruptions and natural fires.
 - d. both a and b.
 8. Indoor air pollution is:
 - a. source-dominated.
 - b. meteorology dominated.
 - c. negligible in comparison to outdoor air pollution.
 - d. independent of the activities of occupants.
 9. The use of air cleaners indoors:
 - a. is the best way to deal with building-related illnesses.
 - b. is the primary means of controlling indoor air quality in the home.
 - c. is a good method for controlling indoor carbon monoxide, but not indoor allergens.
 - d. are effective if the major sources of air pollutants have been removed and the filtering rate and efficiency are sufficient.
 10. The U.S. EPA's designated hazardous air pollutants (HAPs):
 - a. are also called "secondary NAAQS."
 - b. is a list of substances that can change through both additions and deletions by the U.S. EPA.
 - c. include classes of air pollutants, but not individual substances.
 - d. have been determined to cause adverse environmental effects but not adverse human health effects.
 11. How does the height of a smokestack influence the ground-level concentrations of its emitted particles and gases?
 - a. It is not an important factor.
 - b. It is only important if there is an inversion condition.
 - c. It is only important when wind speeds are low.
 - d. None of the above are true.
 12. Which meteorological factors are important in influencing ground-level air pollutant concentrations?
 - a. precipitation.
 - b. wind speed.
 - c. inversions.
 - d. All of the above are true.

Problems

1. Convert the following to ppm.
 - 10 percent
 - 100 percent
 - 1 ppb

2. If the Earth and its atmosphere shrunk to the size of an apple, how thick would the troposphere be?
3. How much time is required for an air cleaner with a throughput air rate of 15 cubic feet per minute (1 cubic foot = 0.0283 m³) to filter the volume of air in a room 20 feet by 20 feet by 10 feet (1 foot = 0.305 m)?
4. Using Table 2–4, estimate the percent of total PM₁₀ emissions that come from vehicles.
5. If an asthmatic child lived in your home, name six sources of air pollutants that should be eliminated or greatly reduced.
6. Recommendations for children at school include allowing them to go outside during recess even in smoggy cities. How can this recommendation be justified?
7. If gasoline-powered cars were all replaced by electric vehicles, what air pollutants would be reduced? What air pollutants, if any, would not be reduced?

VIII. DISCUSSION TOPICS

1. What are the major sources and emissions of air pollutants in your community? Do the sources benefit the community? How would one decide on whether or not a specific pollutant source should be shut down or required to reduce its emissions?
2. What jobs/occupations expose workers to the poorest air quality? Contrast the air quality-related hazards for an elementary school teacher, a farmer, a paramedic, and a construction worker. Which occupation is most likely to develop lung disease?
3. Should indoor potted plants be recommended for treating people with asthma? Discuss the pros and cons associated with your selection.
4. Can the air in a city be too clean?
5. You are charged with the task of designing a smokestack for a new chemical plant that will be built somewhere near a large city. The adverse public health effects are a concern. What factors would you take into account that would influence your design?

References and Recommended Reading

- ACGIH® (American Conference of Governmental Industrial Hygienists), *ACGIH®, TLVs®, and BEIs®*, American Conference of Governmental Industrial Hygienists, Cincinnati, OH, 2010.
- Costa, D. L., “Air pollution,” in *Casarett and Doull’s Essentials of Toxicology*, Klaassen, C. D., and Watkins, J. B., III, eds., McGraw–Hill, New York, 2003, Chapter 28, pp. 407–418.
- Finlayson–Pitts, B. J. and Pitts, J. N. Jr., *Atmospheric Chemistry: Fundamentals and Experimental Techniques*, John Wiley & Sons, New York, 1986.
- Gammage, R. B. and Berven, B. A., eds., *Indoor Air and Human Health, 2nd Edition*, Lewis Publishers, Boca Raton, FL, 1996.
- Grant, L. D., Shoaf, C. R., and Davis, J. M., “United States and international approaches to establishing air standards and guidelines,” in *Air Pollution and Health*, Holgate, S. T., Samet, J. M., Koren, H. S., and Maynard, R. L., eds., Academic Press, San Diego, CA, 1999, Chapter 42, pp. 947–982.
- Hinds W. C., *Aerosol Technology: Properties, Behavior and Measurement of Airborne Particles, 2nd Edition*, Wiley–Interscience, New York, 1999.
- Lippmann, M. and Maynard, R. L., “Air quality guidelines and standards,” in *Air Pollution and Health*, Holgate, S. T., Samet, J. M., Koren, H. S., and Maynard, R. L., eds., Academic Press, San Diego, CA, 1999, Chapter 43, pp. 983–1017.
- (NOAA) National Oceanic and Atmospheric Administration, National Aeronautics and Space Administration and U.S. Air Force, *U.S. Standard Atmosphere*, 1976, NOAA–S/T 76–1562, Washington DC, 1976.
- Perkins, J. L., *Modern Industrial Hygiene, Vol. I: Recognition and Evaluation of Chemical Agents, 2nd Edition*, American Conference of Governmental Industrial Hygienists, Cincinnati, OH, 2008.
- Rom, W. N. and Markowitz, S., eds., *Environmental and Occupational Medicine, 4th Edition*, Lippincott Williams & Wilkins, Hagerstown, MD, 2006.
- Samet, J. M. and Spengler, J. D., eds., *Indoor Air Pollution: A Health Perspective*, Johns Hopkins University Press, Baltimore, MD, 1991.
- Scaillet, B., Are volcanic gases serial killers? *Science*, 319:1628–1629, 2008.
- Seinfeld, J. H. and Pandis, S. N., *Atmospheric Chemistry and Physics, 2nd Edition*, Wiley–Interscience, New York, 2006.

- Sidel, V. W., Onel, E., Geiger, H. J., Leaning, J., and Foege, W. H., "Public health responses to natural and human-made disasters," in *Public Health and Preventive Medicine, 13th Edition*, Last, J. M., and Wallace, R. B., eds., Appleton & Lange, Norwalk, CT, 1992, Chapter 74, pp. 1173–1186.
- Stern, A. C., ed., *Air Pollution, Vol. 1, 3rd Edition*, Academic Press, New York, 1976.
- U.S. EPA (United States Environmental Protection Agency) *Building Air Quality: A Guide for Building Owners and Facility Managers*, EPA/400/1–91/033, U.S. Environmental Protection Agency, Washington DC, 1991.
- U.S. EPA (United States Environmental Protection Agency) *National Air Pollutant Emission Trends*, EPA–454/R–00–02, U.S. Environmental Protection Agency, office of Air Quality Planning and Standards, Research Triangle Park, NC, 2000.
- U.S. EPA (United States Environmental Protection Agency), *Our Nation's Air: Status and Trends Through 2008*, EPA–454/R–09–002, U.S. Environmental Protection Agency, Research Triangle Park, NC, 2010.