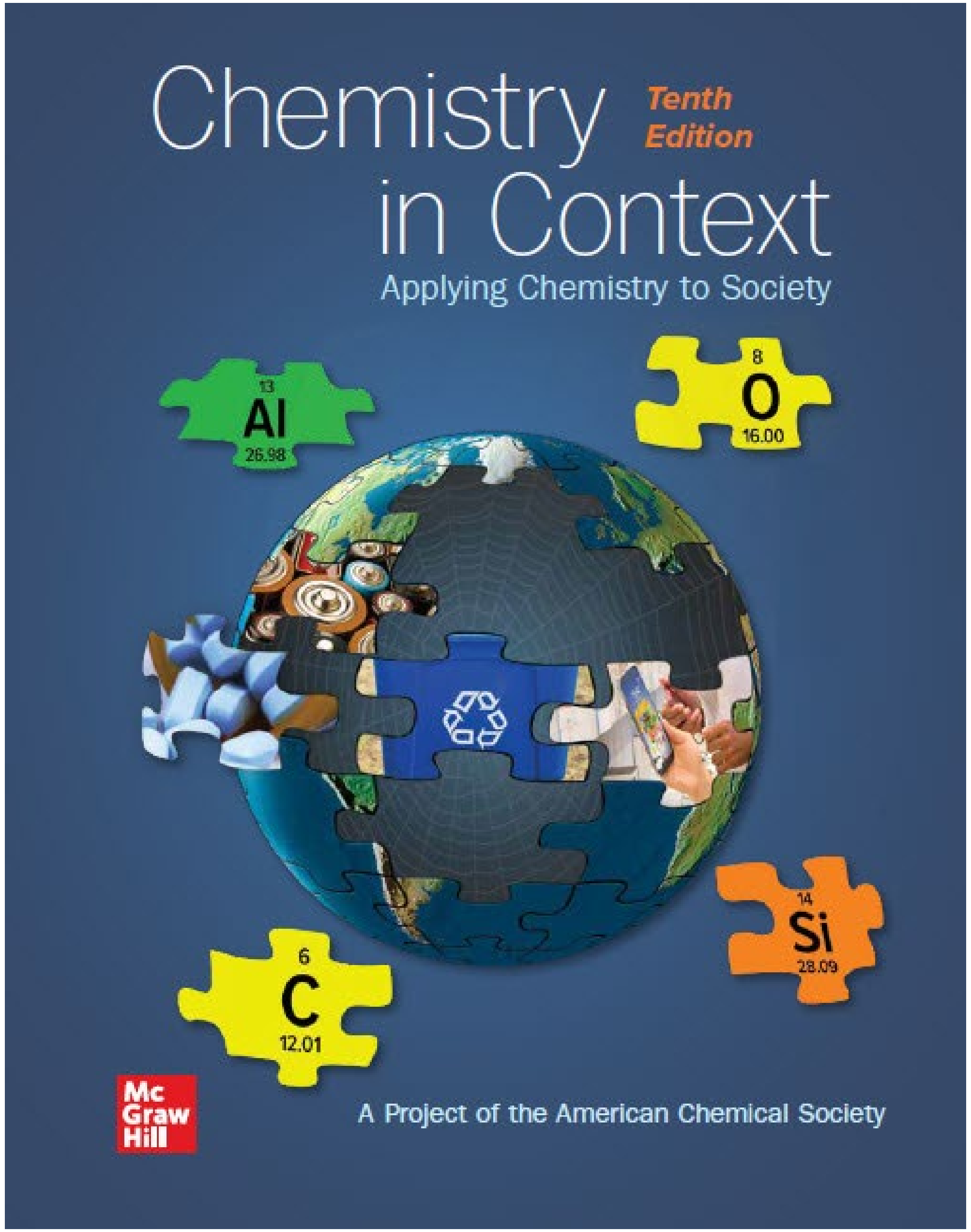
General Chemistry (CH101): Chemistry around Us

Department of Chemistry

KAIST

Chapter 02

The Air We Breathe



What happens during respiration?

A. Sugar and oxygen react to produce carbon dioxide and water
B. Oxygen is used to metabolize food
C. Energy is released to help your body function
D. All of the above

Chapter 2 The Air We Breathe

- What are the components that make up the air we breathe?
- What are the impurities in air and how did they get there?
- What are the health implications of inhaling certain impurities?
- How do we determine if the air is safe to breathe?
- Are there harmful components in the air you breathe indoors?
- Are there ways we can prevent or limit contaminants from polluting our atmosphere?

Reflect

The Components of Air

The air we breathe is composed of a variety of substances. Watch the Chapter 2 opening video and answer the questions below.

a. Identify three indoor and three outdoor sources that emit chemicals into the air around you.

b. Briefly describe how each of these chemicals might affect your health.

[Chapter 2 video]

https://www.acs.org/education/resources/undergraduate/chemistryincontext/interactives/air-we-breathe/chapter-opening.html

The Importance of Breathing

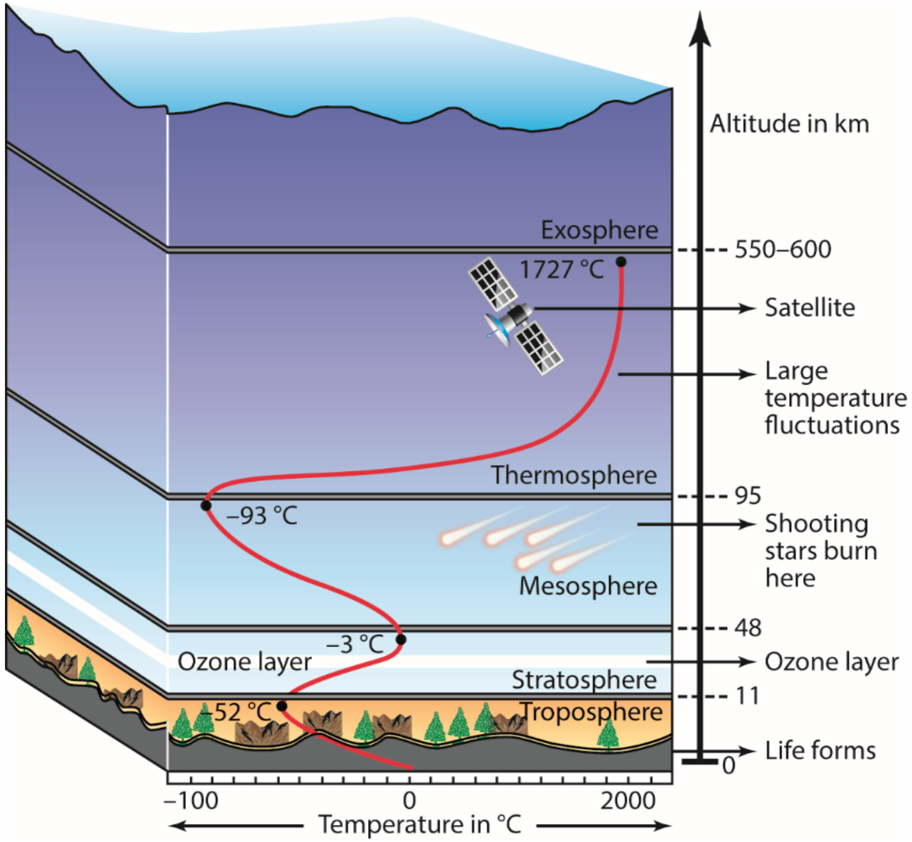
We breathe in air to keep us alive. How much air do you think you breathe in a day?

Your Turn 2.2 Take a Breath

What total volume of air do you inhale (and exhale) in a typical day? Figure this out. First, determine how much air you exhale in a single “normal” breath. Then, determine how many breaths you take per minute. Finally, calculate how much air you exhale per day. Describe how you made your estimate, provide your data, and list any factors you believe may have affected the accuracy of your answer.

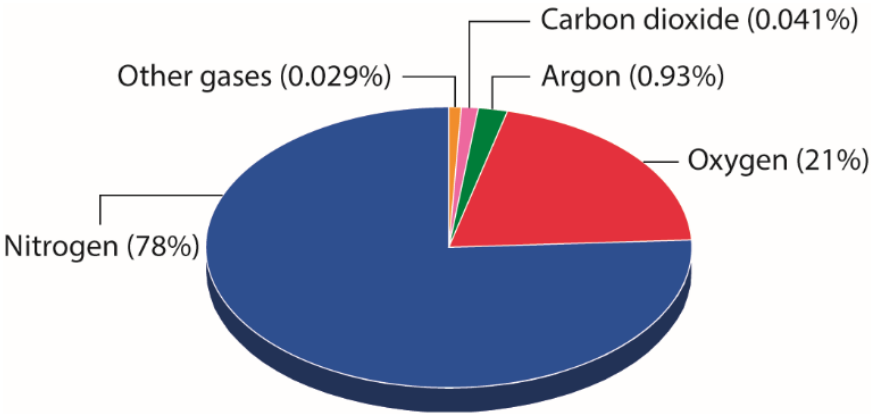
Defining the Invisible: What is Air?

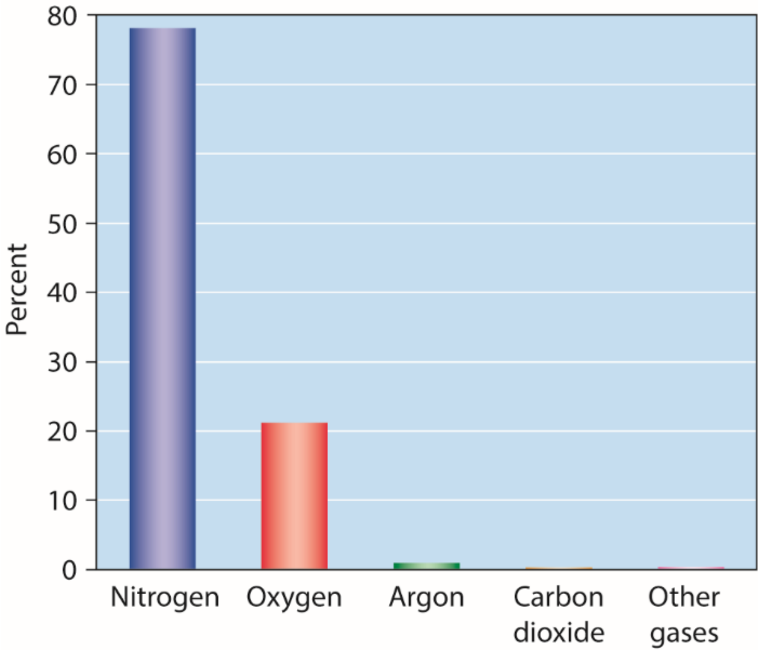
75% of our air, by mass, is in the **troposphere**, the lowest region of the atmosphere in which we live.



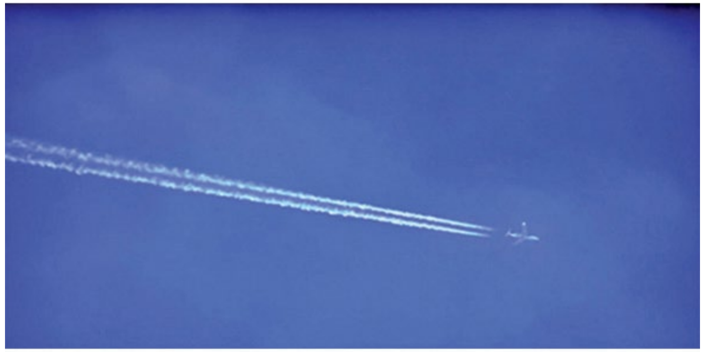
The Composition of Air

Air is a **mixture**: a physical combination of two or more substances present in variable amounts.





Water droplets!



What's in a Breath?

- Nitrogen and argon are unreactive (inert) and makes up most of the air we breathe.
- Oxygen is required by animals for respiration.
- Carbon dioxide is a waste product of respiration.

Table 2.1 Typical Composition of Inhaled and Exhaled Air

Substance	Inhaled Air (%)*	Exhaled Air (%)*
Nitrogen (N_2)	78.0	78.0
Oxygen (O_2)	21.0	16.0
Argon (Ar)	0.9	0.9
Carbon dioxide (CO_2)	0.04	4.0
Water (H_2O)	Variable	Variable

*In unit of percent by volume, %(v/v)

An example of a gas that you inhale, but your body does not react with it is______________. (Hint: Examine Table 2.1)

A. NO_2 and N_2
B. CO_2 and O_2
C. O_2 and N_2
D. N_2 and Ar

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Concentration Terms

Parts per hundred (percent)

$$\text{The atmosphere is 21\% oxygen} = \frac{\text{21 oxygen molecules}}{\text{100 molecules}}$$

Parts per million (ppm)

$$\text{Midday ozone levels mayreach about 0.4ppm} = \frac{\text{0.4 ozone molecules}}{\text{1,000,000 molecules}}$$

Parts per billion (ppb)

$$\text{Sulfur dioxide in the air should not exceed 30ppb} = \frac{\text{30 sulfur dioxide molecules}}{\text{1,000,000,000molecules}}$$

Your Turn 2.7 Practice with Parts per Million

a. In some countries, the limit for the average concentration of carbon monoxide in an 8-hour period is set at 9 ppm. Express this amount as a percentage.

b. Exhaled air typically contains about 78% nitrogen. Express this concentration in parts per million.

Concentration Conversions

- Carbon dioxide composes 0.0402% of the air we breathe.

0.0402% means

0.0402 parts per hundred

0.402 parts per thousand

4.02 parts per ten thousand

40.2 parts per hundred thousand

402 parts per million

Your Turn [1]

Your Turn 2.6 Really One Part per Million?

Some say that a part per million is the same as one second in nearly 12 days. Is this an accurate analogy? How about one step $(\sim 2.5 \text{ feel})$ in a 568-mile journey? What about 4 drops $(20 \text{ drops} \sim 1 \text{ mL})$ of ink in a 55-gallon barrel of water?

Check the validity of these analogies, explaining your reasoning. Then, come up with an analogy or two of your own.

https://youtu.be/aa-m8a-jZ0k

What Else Is In a Breath?

- These images show Beijing, China from the same vantage point on different days.
- In addition to nitrogen, oxygen, argon, and carbon dioxide… there are harmful nitrogen oxides and particulate matter that contribute to air pollution.

Differences in ppm!

https://youtu.be/a4v5U4J373k

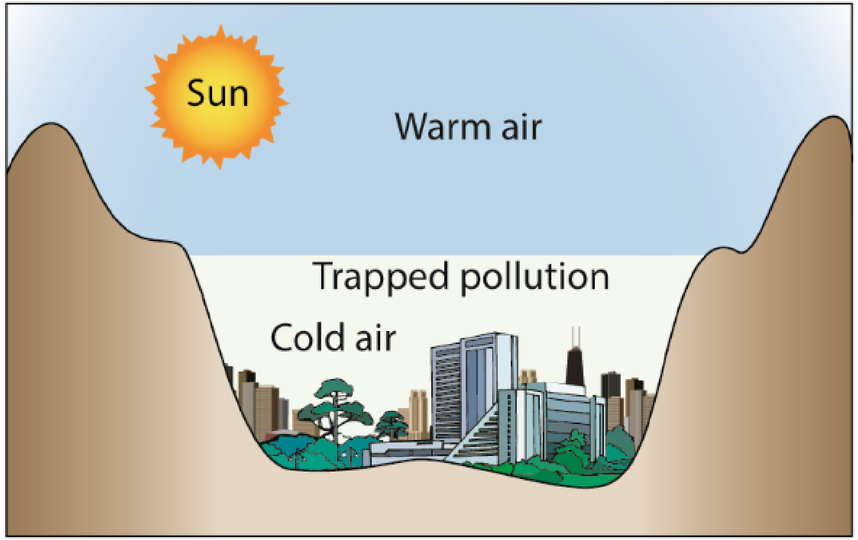
Air Inversions

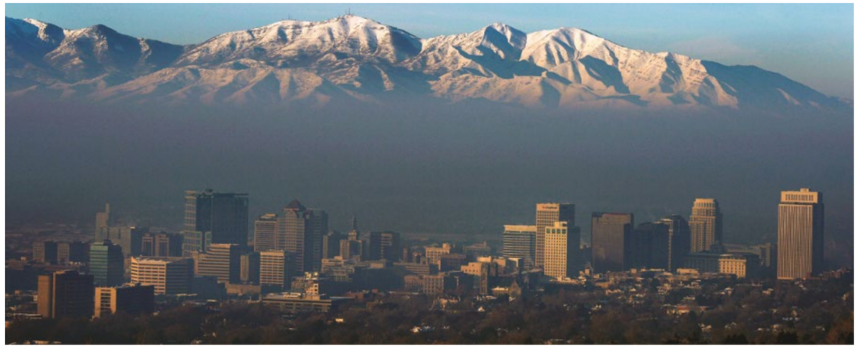
- Cooler air can be trapped beneath warmer air due to weather conditions.
- Pollutants often accumulate in the cooler air of an inversion layer.
- This situation is worsened when air flow is limited, such as in cities surrounded by mountains.

Colorful Convection Currents - Sick Science!

Colorful Convection Currents - DIY Sci

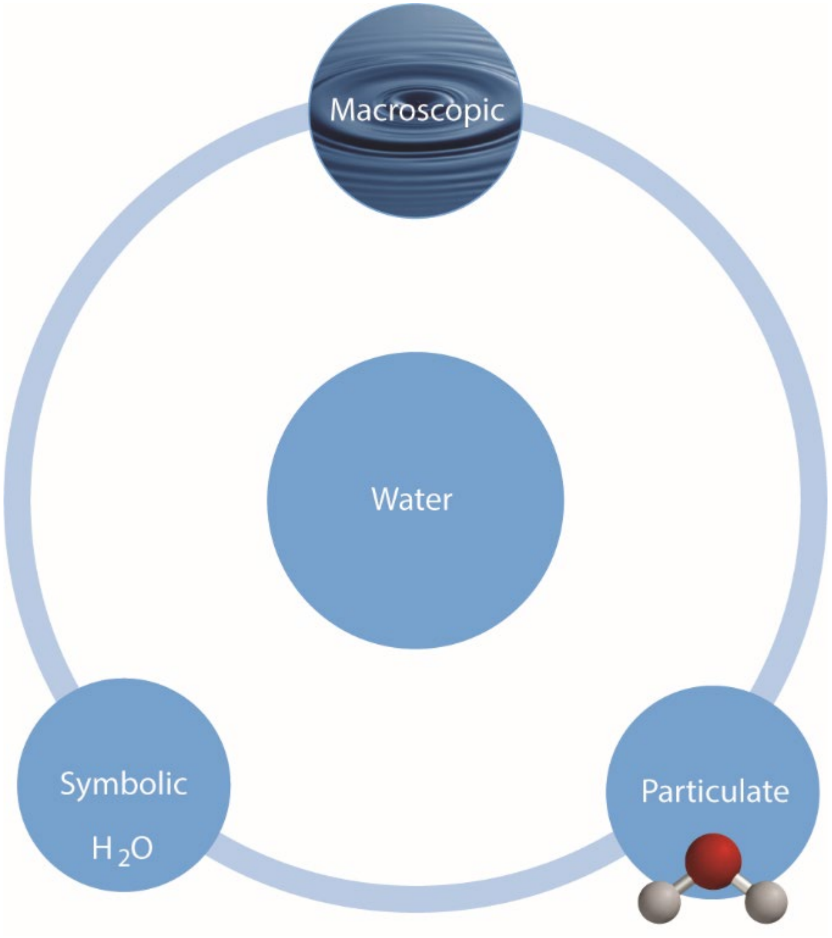
https://youtu.be/RCO90hvEL1I?si=lPryDzp20_htXRfO





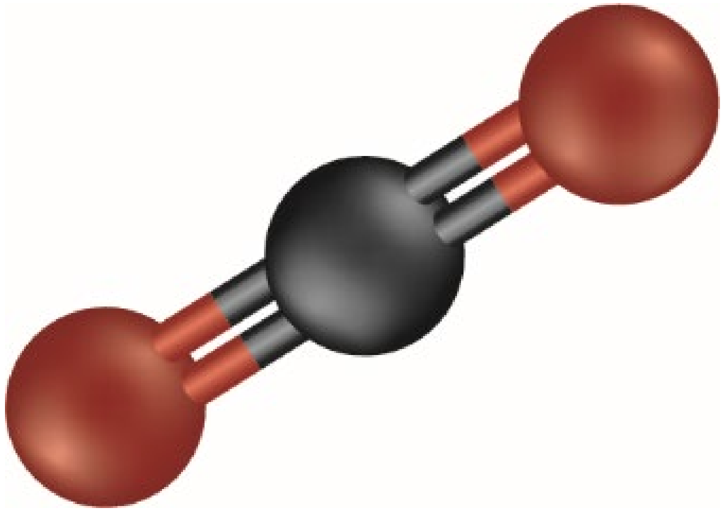
Visualizing the Molecules in Air

- A **molecule** is a fixed number of atoms held together by chemical bonds in a certain spatial arrangement.
- The **chemical formula** symbolically represents the type and number of each element present.
- Chemists use three viewpoints to study and understand matter: *macroscopic*, *symbolic*, and *particulate*.



Molecular Structures

The particulate view of matter shows the 3-dimensional molecular structure, with atoms color-coded.



Naming Molecular Compounds

Prefixes are used to designate the number of each type of element:

Table 2.2 Prefixes Corresponding to the Number of Atoms for Molecular Compounds.

Number of Atoms	Prefix	Number of Atoms	Prefix
1	*mono-*	6	*hexa-*
2	*di-*	7	*hepta-*
3	*tri-*	8	*octa-*
4	*tetra-*	9	*nona-*
5	*penta-*	10	*deca-*

Rules for Naming Molecular Compounds

1. Name each element in the chemical formula, modifying the name of the second element to end in *–ide.*
    - **sulfur** becomes **sulfide.**
    - **oxygen** becomes **oxide.**
2. Use prefixes to indicate the numbers of atoms in the chemical formula.
    - N_2O_5 is **di**nitrogen **pent**oxide.
3. If there is only one atom for the first element in the chemical formula, omit the prefix mono-
    - CO is **carbon monoxide**, not monocarbon monoxide.

Your Turn 2

Your Turn 2.8 Writing Symbols and Naming Oxides

a. Write chemical formulas for nitrogen monoxide, nitrogen dioxide, dinitrogen monoxide, and dinitrogen tetraoxide.

b. Give the names for SO_2 and SO_3.

Common Names

Many compounds have a common name that is more widely used than their systematic name.

What is the common name for these compounds?

- dihydrogen monoxide.
- nitrogen trihydride.
- trioxygen.

Your Turn 2.9 Practice With Common Names

Using the Internet, provide the chemical formula and systematic name for the following molecular compounds: quartz, laughing gas, silane, dry ice, hydrogen sulfide, and phosphine.

The Dangerous Few: A Look at Air Pollutants [1]

Carbon monoxide – *CO*, a.k.a. the silent killer

- Bind to the hemoglobin in your blood more than oxygen.
- Initial symptoms include dizziness and nauseousness, leading to death.

Ozone – O_3

- Reduces lung function.
- Symptoms include chest pain, coughing, sneezing, and lung congestion.

Sulfur dioxide – SO_2

- Dissolves in moist tissues of your lungs to form an acid.
- The young, old, and those with emphysema or asthma are at most risk.

Nitrogen oxides – NO_x

- Dissolves in moist tissues of your lungs to form an acid.
- Has a characteristic brown color that colors urban smog.

Why is Carbon Monoxide So Deadly?

https://youtu.be/lMnaLKlVXxo?si=EtGAHPBWSVAWw2jH

The Dangerous Few 2

Lead – *Pb*

- Affects the central nervous system, immune system, reproductive and developmental systems, and cardiovascular system.
- Infants and young children are especially sensitive; may contribute to behavioral problems and learning deficits.

Particulate matter – *PM*

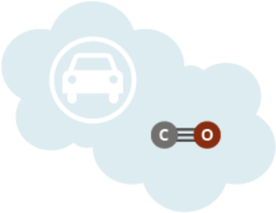
- A complex mixture of tiny solid particles and microscopic liquid droplets.
- Classified by size rather than composition.
- PM_{10} are particles less than $10 \mu m in diameter (10 \times 10^{-6} m)$.
- $PM_{2.5}$ are particles less than $2.5 \mu m in diameter (2.5 \times 10^{-6} m)$.
- Can cause irritation of the lungs and smallest particles can pass into your bloodstream.

A Brief Guide to Atmospheric Pollutants

Periodic Graphics: Air pollution masks

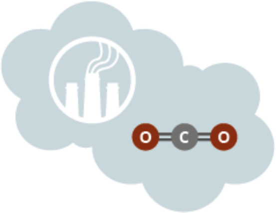
A BRIEF GUIDE TO ATMOSPHERIC POLLUTANTS

A number of different chemical entities, from a range of sources, can contribute towards atmospheric pollution, the consequences of which can include global warming and smog. This graphic looks at a selection of major groups of atmospheric pollutants, their major sources, and their effects.



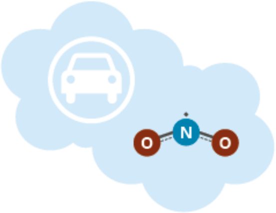
CARBON MONOXIDE

A gas generated by the incomplete combustion of fuels – primarily from road transport. Affects human health, as it reduces oxygen-carrying capacity of the blood. It also reacts with other atmospheric gases to produce ozone.



CARBON DIOXIDE

A gas generated by the burning of fossil fuels in the production of electricity. Also emitted by natural processes. Human emissions are linked with rising atmospheric CO_2 levels and anthropogenic global warming.

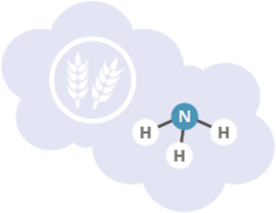


NITROGEN OXIDES

Primarily created by combustion in road transport. Nitrous oxide is an important global warming contributor, whilst nitrogen dioxide is involved in ground-level ozone forming reactions, and is also a component of smog.

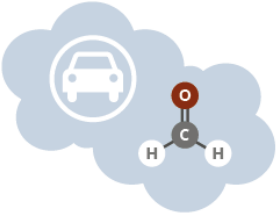
SULFUR DIOXIDE

The primary source of sulfur dioxide is the burning of fossil fuels to generate electricity. It can contribute to smog, reacts with water to produce acid rain, and can also cause wheezing and breathing problems for asthmatics.



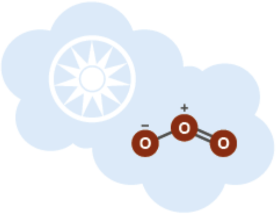
AMMONIA

Ammonia's primary atmospheric source is from its use in agriculture, such as manure & fertilisers. It can react with other pollutants to produce particulate matter. It also has the ability to over-enrich ecosystems with nitrogen.



VOCs

VOCs (volatile organic compounds) are emitted naturally by vegetation. Amongst significant human sources is road transport, as well as solvents. They can contribute to formation of ground-level ozone and smog.



OZONE

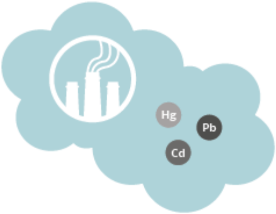
The ozone layer shields us from UV radiation, but ground-level ozone is a major pollutant. It's formed from other pollutants in the presence of sunlight. Ozone is a major component of smog, and can also cause health effects.

POPs

POPs (persistent organic pollutants) are volatile chemicals released into the atmosphere, often from agricultural or industrial uses. They persist in the environment and can have health effects on both wildlife & humans.

PARTICULATE MATTER

Particulate matter is composed of a huge number of different components. Some are directly emitted, while others are generated by reactions in the atmosphere. They cause haze and can also cause lung problems if inhaled.



HEAVY METALS

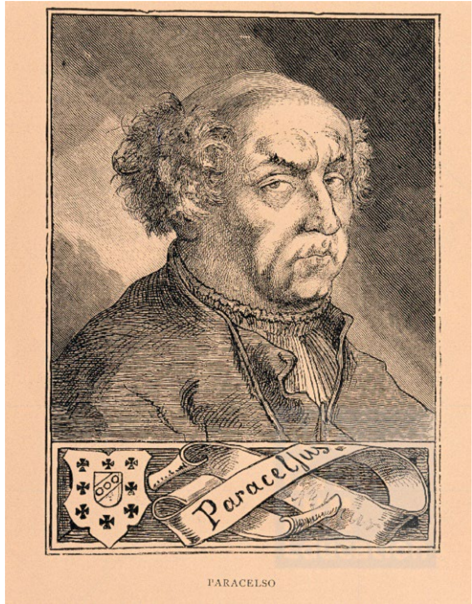
Heavy metals are released into the atmosphere from a range of sources, including burning of fossil fuels and road transport emissions. Some, such as mercury and lead, have toxic health effects in humans.

Assessing the Risk of Air Pollutants

Risk Assessment – evaluating scientific data and making predictions in an organized manner about the probabilities of an occurrence. Risk is based on *toxicity* and *exposure:*

Toxicity – the intrinsic health hazard of a substance.

Exposure – the amount of substance encountered.



"All things are poison, and nothing is without poison, the dosage alone makes it so a thing is not a poison."

– Paracelsus, 15th century Swiss physician

Table 2.3 U.S. Ambient Air Quality Standards.

Pollutant	Standard (ppm)	Approximate Equivalent Concentration (μg/m^3)
carbon monoxide		
1-h average	35	40,000
8-h average	9	10,000
nitrogen dioxide		
1-h average	0.100	200
Annual average	0.053	100
ozone		
8-h average	0.070	140
particulates		
PM_{10}, 24-h average	–	150
$PM_{2.5}$, 24-h average	–	35
$PM_{2.5}$, annual average	–	12
sulfur dioxide		
1-h average	0.075	210
lead		
3-mo average	–	0.15

If pollutant levels are below these standards, presumably the air is healthy to breathe.

Your Turn

Your Turn 2.11 Estimating Toxicities.

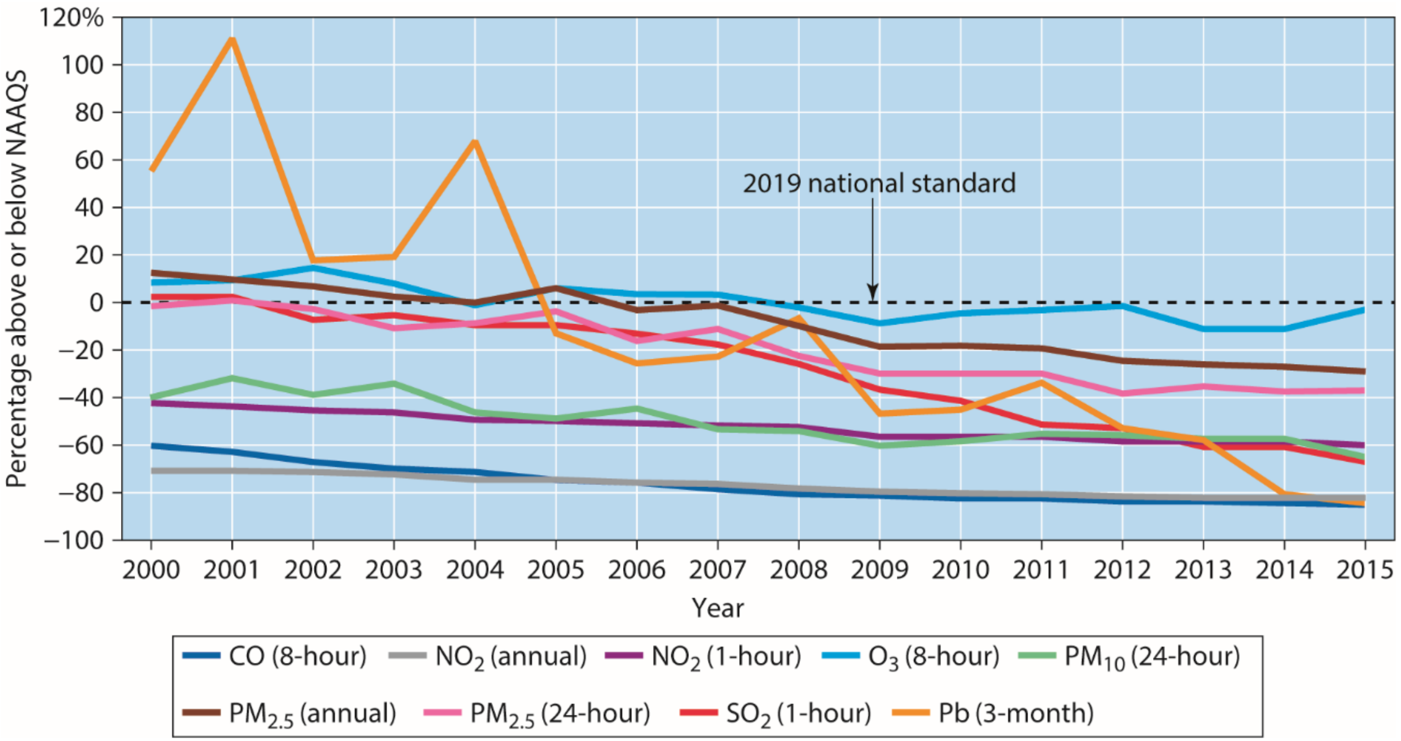
a. Which pollutant in Table 2.3 is likely to be the most toxic? Exclude particulate matter. Share a reason for your decision.

b. Examine the particulate matter standards. Earlier, we stated that “fine particles,” $PM_{2.5}$, are more deadly than the coarser ones, PM_{10}. Do the values in Table 2.3 support this claim? Why or why not?

c. Is Pb more toxic than particulate matter? Explain your reasoning.

U.S. Average Levels of Air Pollutants

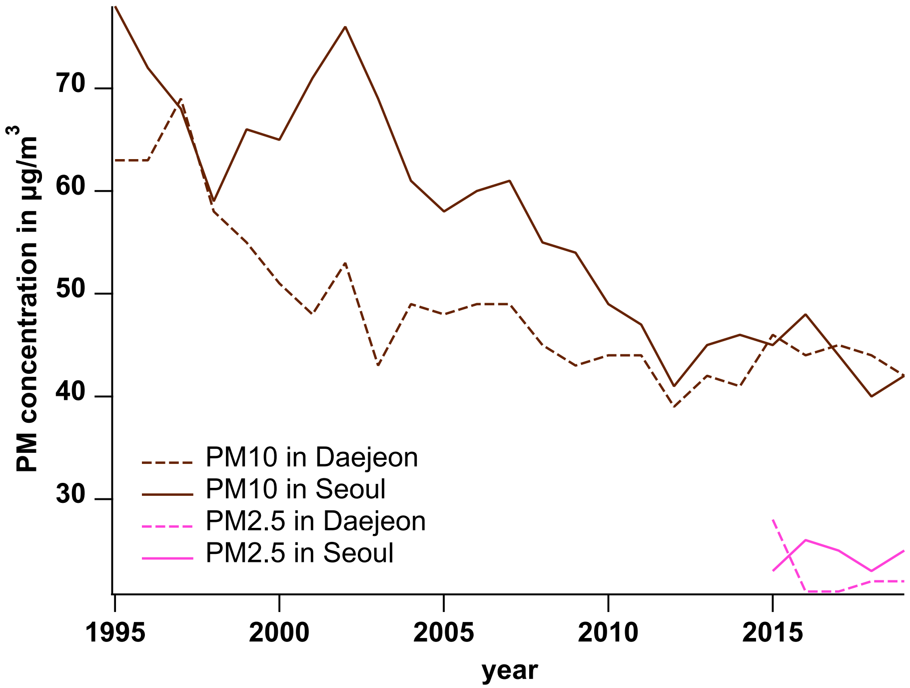
The average concentration of air pollutants in the United States have decreased dramatically since 2000.

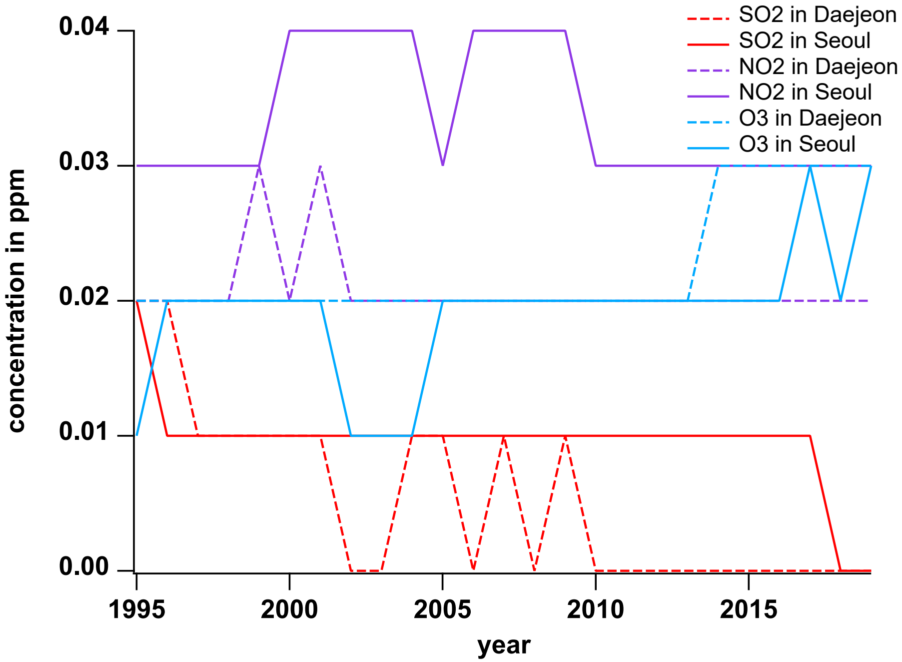


NAAQS = National Ambient Air Quality Standards

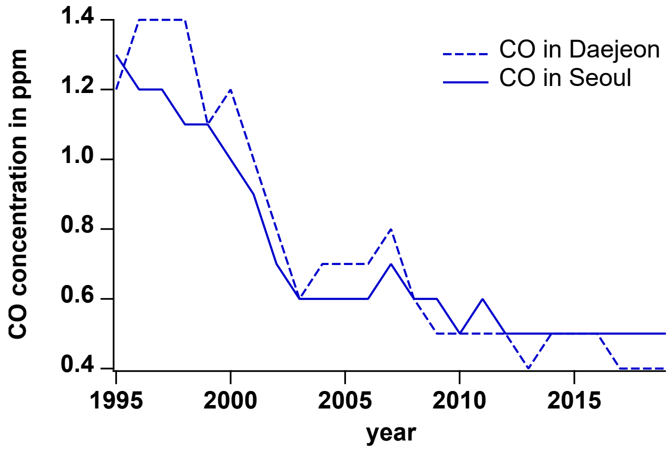
Source: EPA

Air Pollutants in Korea



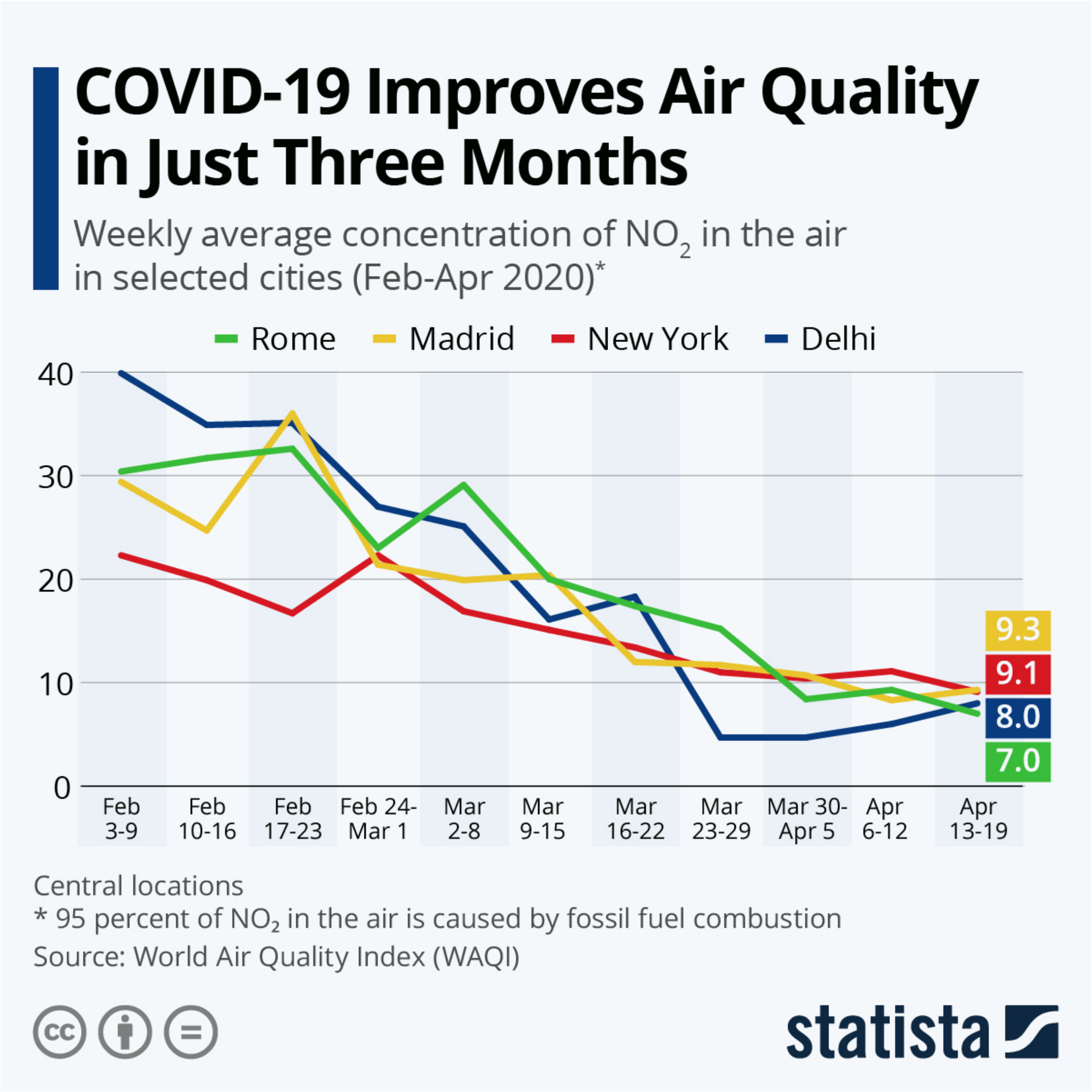


Pollutant	ppm	(μg/m³)
carbon monoxide	9	10,000
nitrogen dioxide	0.053	100
ozone	0.070	140
PM_{10} $PM_{2.5}$	– –	150 35
sulfur dioxide	0.075	210

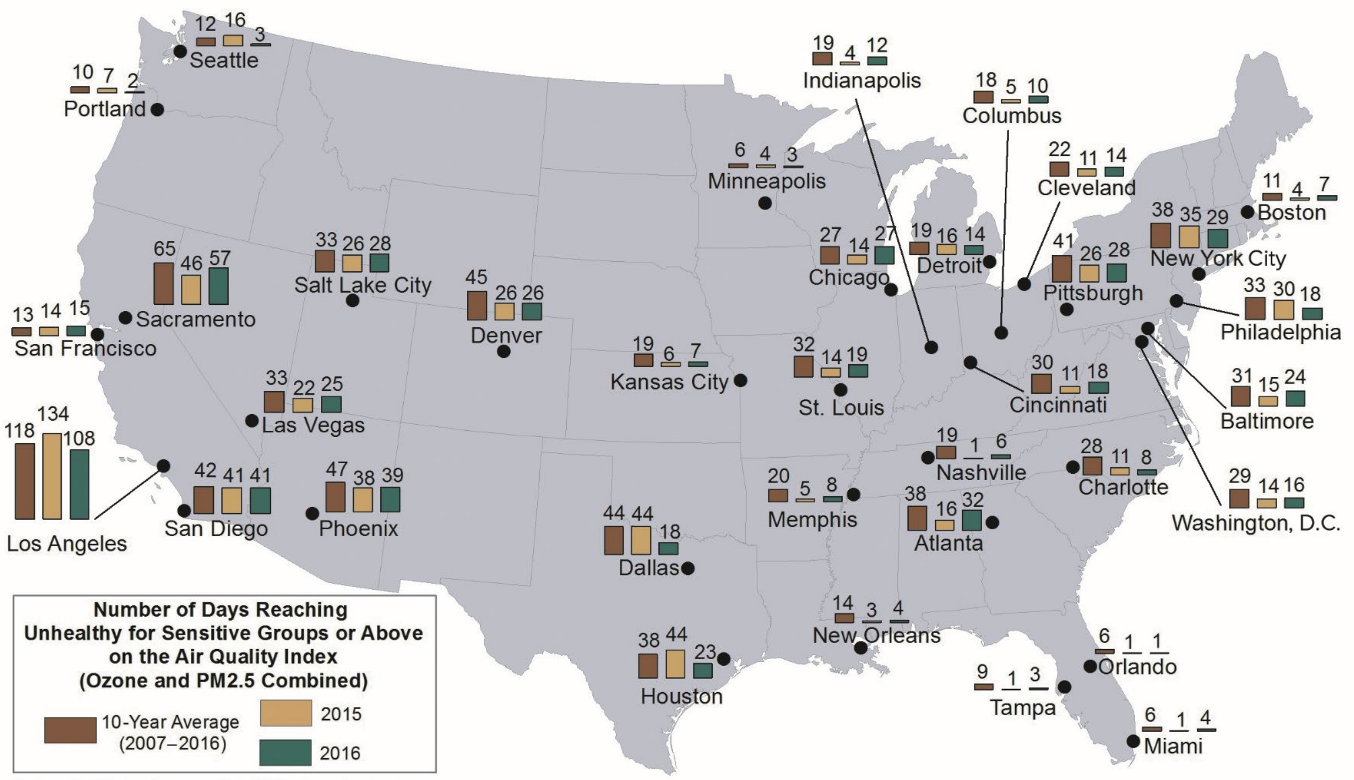


https://www.airkorea.or.kr/eng/annualAirQualityTrends?pMENU_NO=161

Worldwide Air Pollution Since COVID



Air Quality Data for U.S. Metro Areas



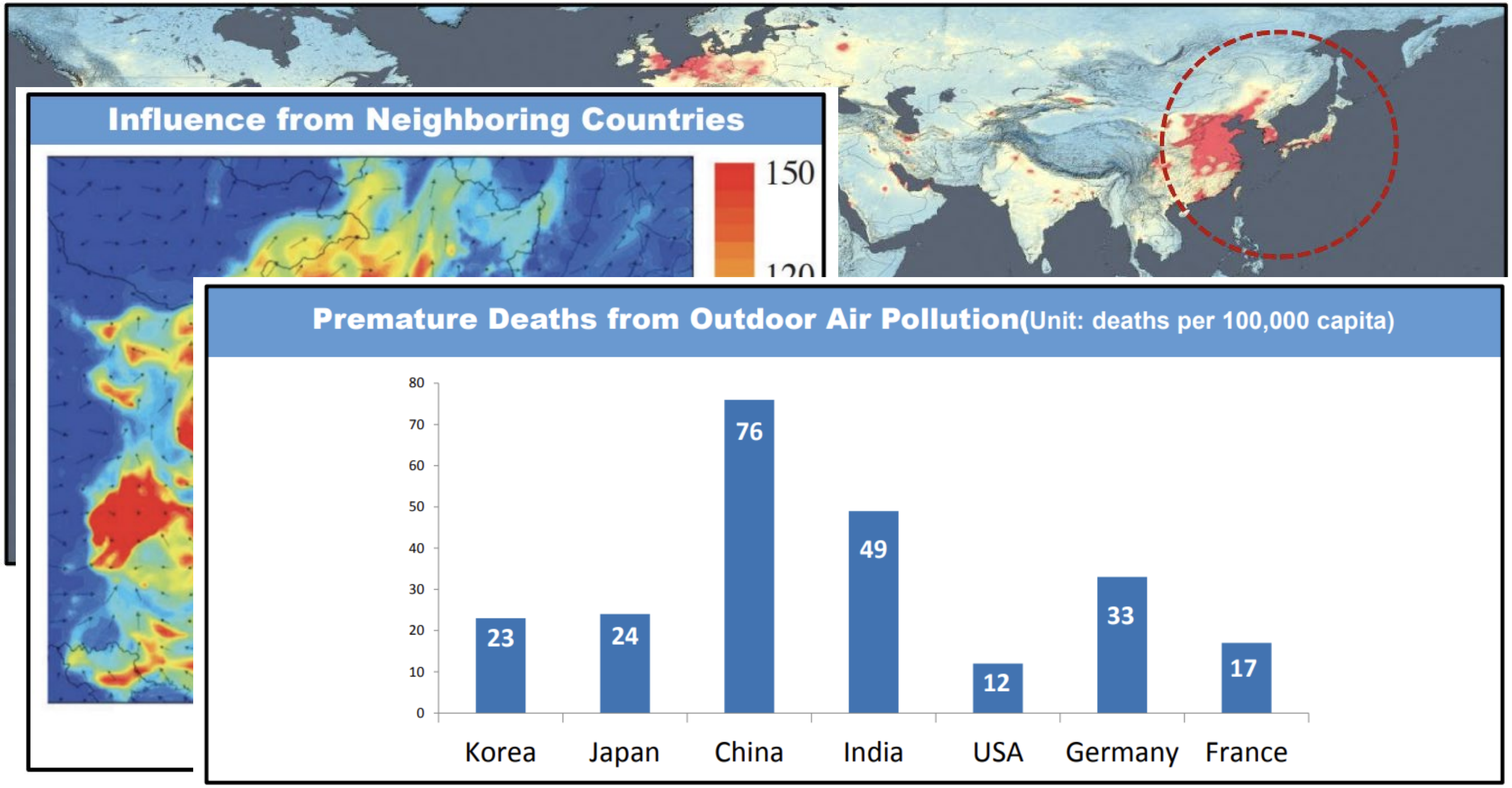
It is estimated that more than 41% of the U.S. population lives in counties that have unhealthy levels of either ozone or particulate pollution.

[Our Nation's Air]

Source: EPA

❖ According to NASA Satellite Air Quality Map*, South Korea is one of the most concerned countries regarding air pollution (averaged over 2014).

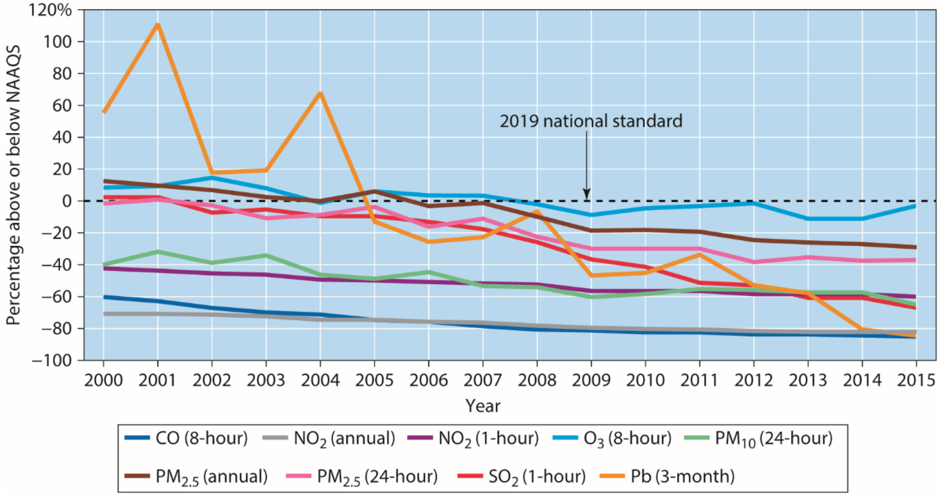
* Its major index is NOx mostly caused by power plants and automobiles.



Source: WHO(2016), Ambient Air Pollution: A Global Assessment of exposure and burden of disease

https://www.unescap.org/sites/default/files/Session%201.1.%20Youngsook%20Yoo_ROK.pdf

Your Turn 4



Your Turn 2.15 Our Nation's Air

Each year, the EPA publishes an interactive report entitled "Our Nation's Air," which highlights trends in the U.S. air quality.

Consult the data in the 2017 annual report, and answer these questions:

1. Which emissions dropped the most substantially from 1990 to 2016? What factors have likely contributed to these improvements in air quality?
2. The lead emissions spiked in 1993 and then sharply declined. What are some reasons for this trend (both the spike and sharp decrease in Pb levels)?
3. The listed PM emissions do not include "miscellaneous emissions" such as agricultural dust and wildfire emissions. Plot the trend in $PM_{2.5}$ and PM_{10} emissions from 1990 to the present if these sources were included. (***Hint:*** You will need to click on "Emission Trends" to find out more details.) Why do you think the EPA has chosen to omit these PM emission sources from the annual trends?
4. Evaluate the annual concentration trends for criteria pollutants of ozone, lead, SO_x, NO_x, and PM. Although concentrations have decreased nationwide since 1990, are there any regions of the country in which some of these pollutants have remained consistently higher than the national average? If so, what are some factors responsible for these relatively high emission trends?

Our Nation's Air

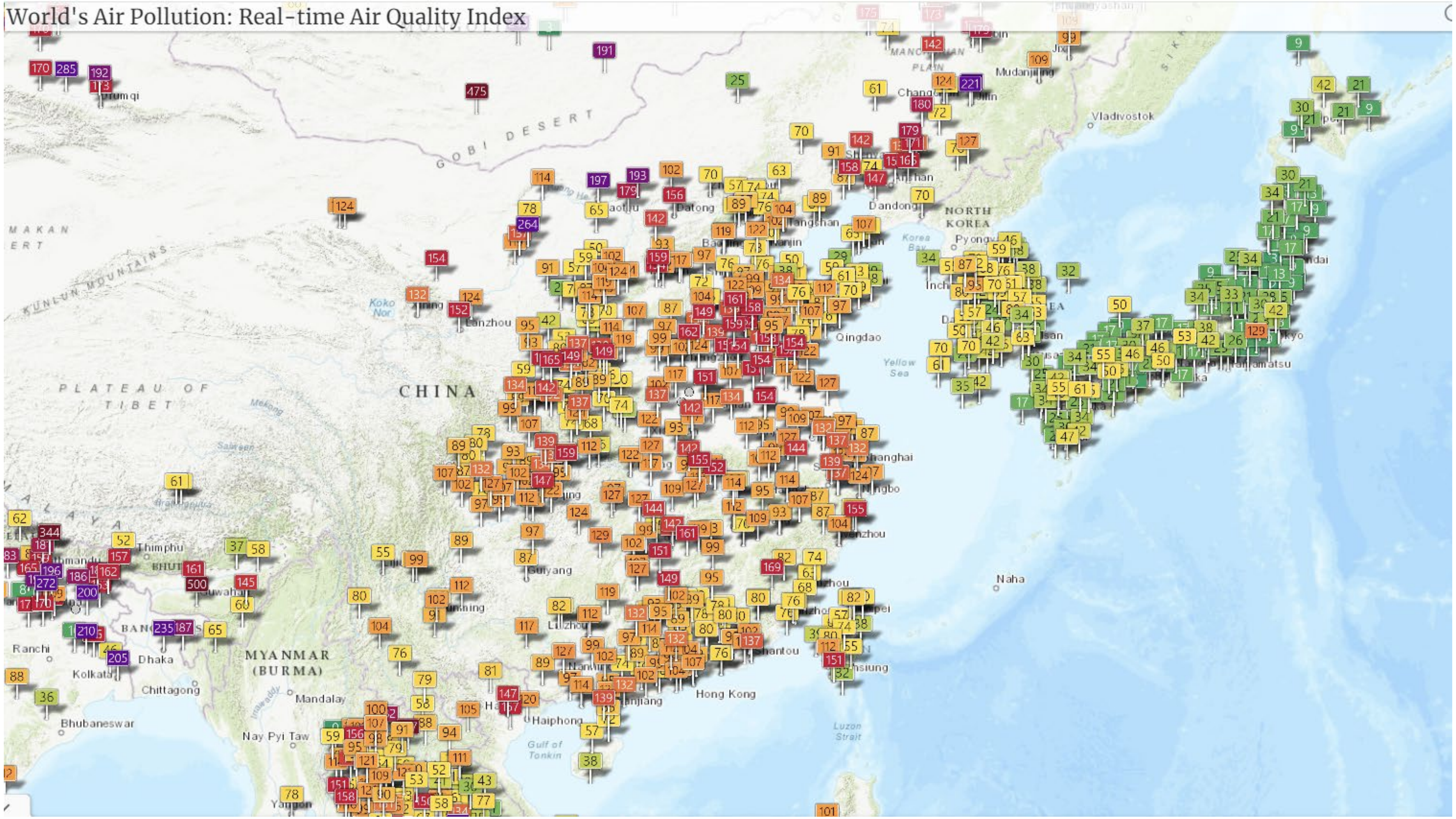
US EPA’s Air Quality Index

The EPA AQI is based on the national ambient air quality standards.

- AQI of 100 equals the standard concentration for that pollutant.

Table 2.4 Levels for the Air Quality Index (AQI).

When the AQI is in this range:	… air quality conditions are:	… as symbolized by this color:
0 to 50	Good	Green
51 to 100	Moderate	Yellow
101 to 150	Unhealthy for sensitive groups	Orange
151 to 200	Unhealthy	Red
201 to 300	Very unhealthy	Purple
301 to 500	Hazardous	Maroon



https://waqi.info/#/c/29.877/122.831/5z

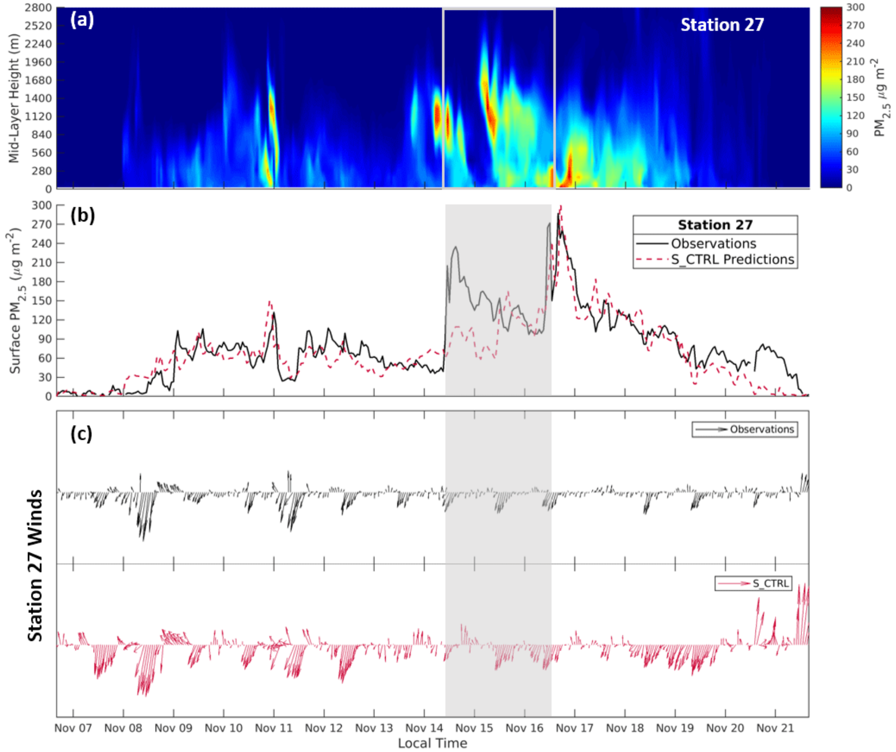
Example Air Quality Index

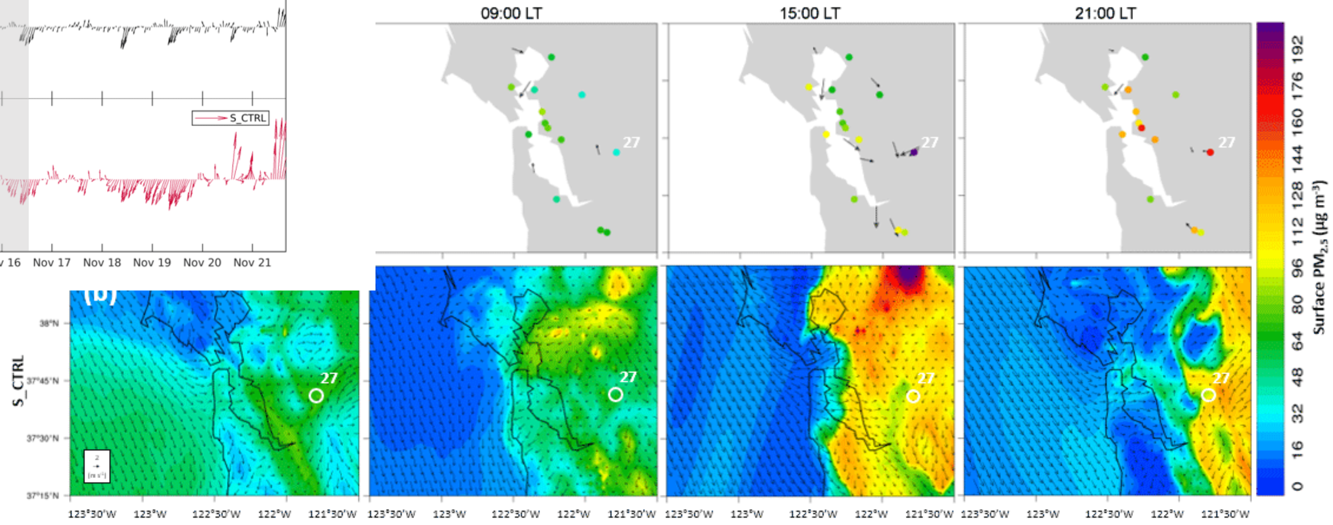
- Variations in the AQI reflect variations in the local weather patterns.
- Regional events such as forest fires and volcanic eruptions can influence air quality.
- Air quality forecast for Spokane, WA for August 21 to 24, 2018 during a period of extensive wildfires in Washington and northwest Montana:

FORECAST DATE / AIR POLLUTANT	TUES 8/21/2018	WED 8/22/2018	THURS 8/23/2018	FRI 8/24/2018
O_3	61	90	112	42
PM_{10}	61	64	77	62
$PM_{2.5}$	139	134	154	114

Air Quality Index and Regional Events

From November 8 – November 25, 2018, the Camp Fire in northern California was the deadliest wildfire in the US in a century: AirNow





https://acp.copernicus.org/articles/20/14597/2020/

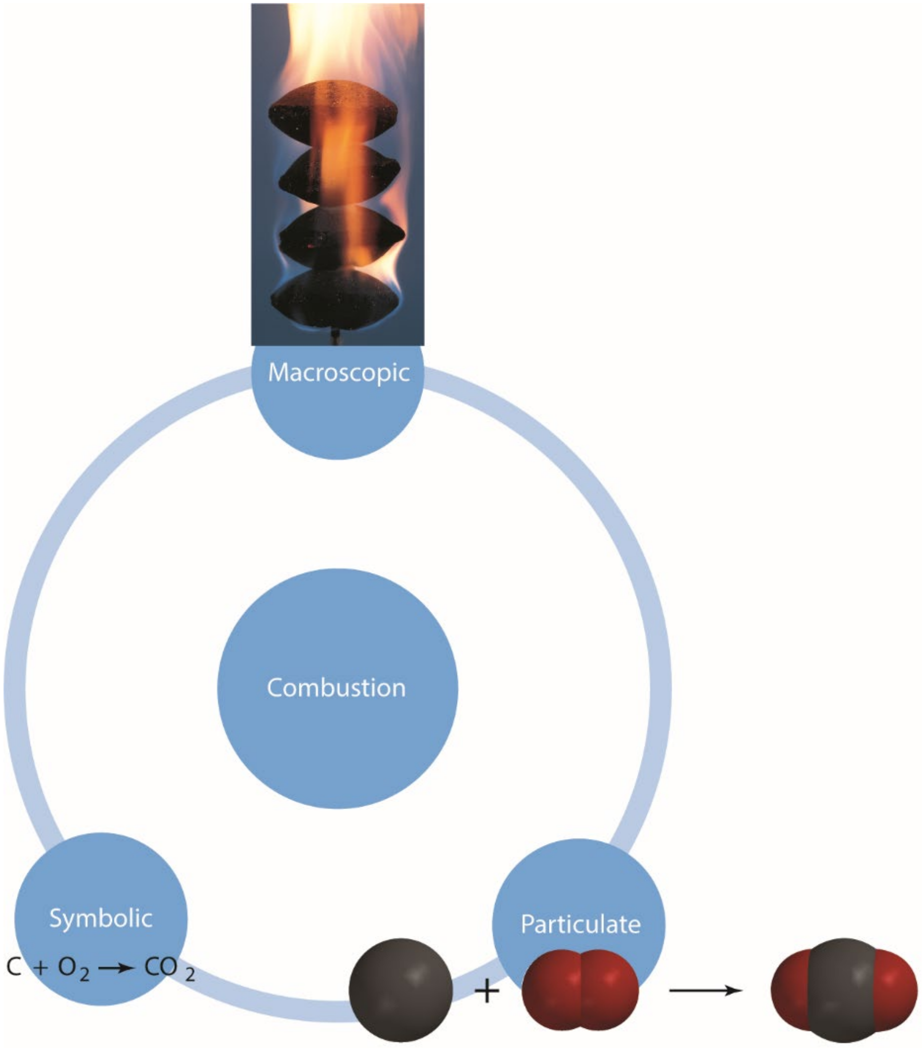
Source: EPA AirNow

Chemical Reactions

Chemical reactions are characterized by the rearrangement of atoms when **reactants** are transformed into **products.**

- Combustion is one type of reaction where oxygen is reacted with another material releasing a large amount of energy.

The number of atoms on each side of the arrow must be equal (Law of Conservation of Mass).



Balancing Equations – Tips

Tips for balancing equations:

- If an element is present in just one compound on each side, balance it *first.*
- Balance anything that exists as a free element *last.*
- Balance polyatomic ions as a unit.
- Check when done – same number of atoms, and same total charge (if any) on both sides.

Check out this simulation for more practice:

Balancing Chemical Equations

Chemical Equations

Table 2.5 Characteristics of Chemical Equations

Always Conserved
Identity of atoms in reactants = identity of atoms in products
Number of atoms of each element in reactants = number of atoms of each element in products
Mass of all reactants = mass of all products
May Change
Number of molecules in reactants may differ from the number in products
Physical states (*s*, *l*, or *g*) of reactants may differ from those of products

Balancing Chemical Equations: An Example

As an example, consider the combustion of methane (CH_4) to generate carbon dioxide (CO_2) and water (H_2O):

$$\mathrm{CH_4 + O_2 \rightarrow CO_2 + H_2O (unbalanced)}$$

$$\mathrm{CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O (balanced)}$$

When balanced, there is 1 carbon atom, 4 oxygen atoms, and 4 hydrogen atoms on either side of the equation.

Another Balancing Example

$C_3H_8 + O_2 \rightarrow CO_2 + H_2O$

3 C atoms	1 C atom
8 H atoms	2 H atoms
2 O atoms	3 O atoms

$C_3H_8 + 5O_2 \rightarrow 3CO_2 + 4H_2O$

3 C atoms	3 C atoms
8 H atoms	8 H atoms
10 O atoms	10 O atoms

Limiting reagent: The reactant that is fully consumed during the reaction, which limits the number of product molecules that may be formed.

Your Turn

Your Turn 2.19 Chemical Equations

Balance these chemical equations and draw representations of all reactants and products. Also describe the final balanced equations in words.

a. $H_2 + O_2 \rightarrow H_2O$

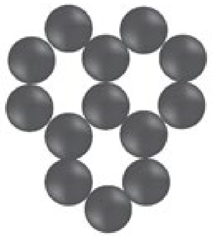
b. $N_2 + O_2 \rightarrow NO_2$

Visualizing Reactions

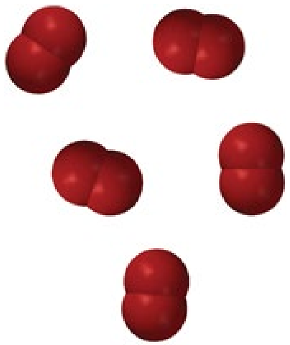
Your Turn 2.17 How Does Carbon React with Oxygen?

Examine the two particulate representations of the reactants: solid carbon and oxygen gas. Note that carbon is illustrated as a region of the graphite allotrope, featuring hexagonal rings of carbon atoms ***Hint:*** Revisit Figure 1.9.

a. Draw two or more pictures showing the reaction between oxygen molecules and solid carbon as it progresses to form (i) carbon dioxide and (ii) carbon monoxide products.



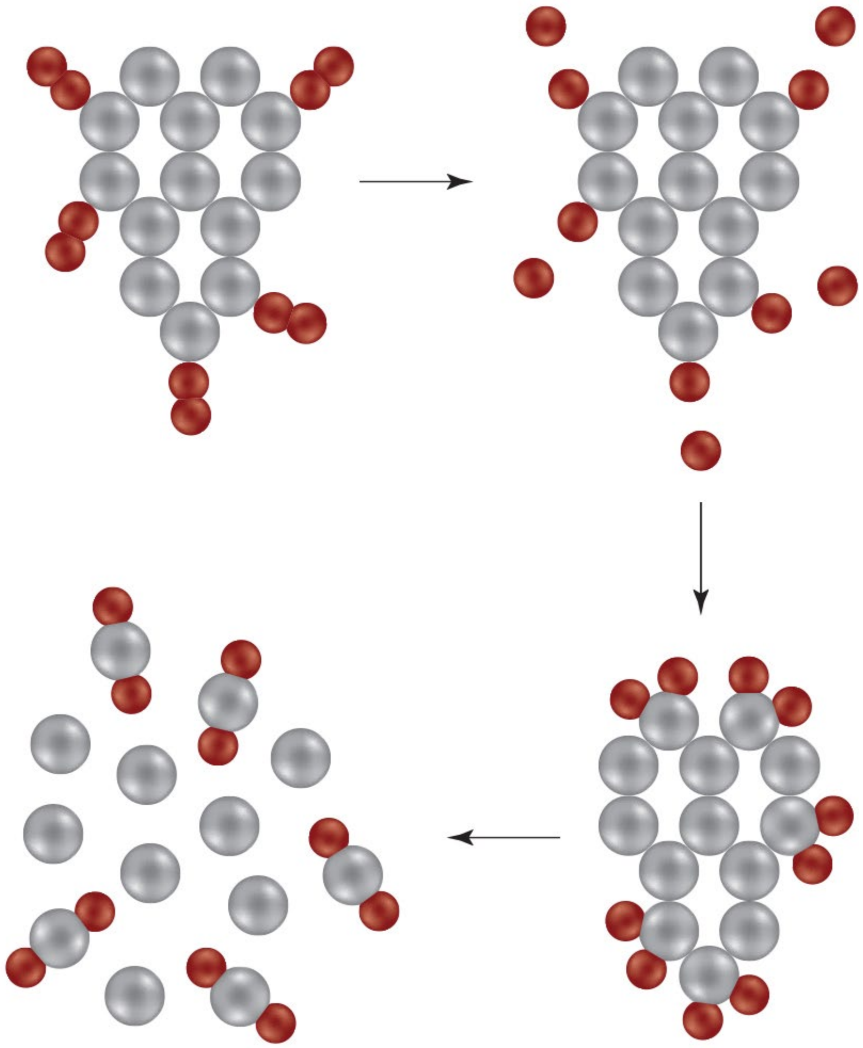
Solid carbon (graphite)



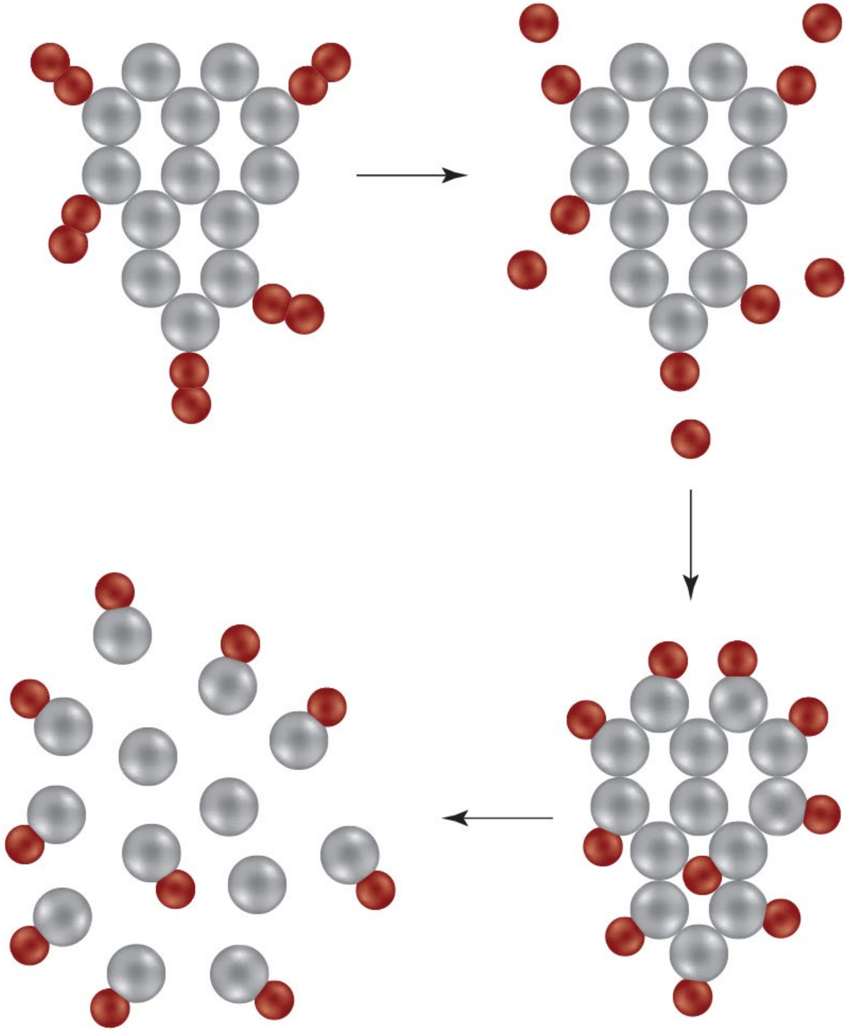
Gaseous oxygen

b. For each of the reactions you have drawn in part **a.**, how many product molecules may be formed from these reactants? Are there any reactant atoms or molecules left over after the reaction has gone to completion? Why or why not?

i)



ii)

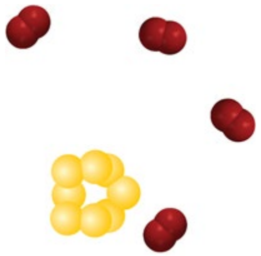


Limiting Reagents

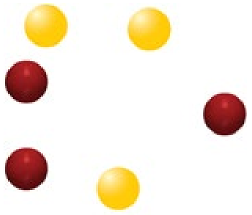
Your Turn 2.18 Modeling Sulfur Dioxide Formation

Consider the two representations of the reactants solid sulfur and oxygen gas. Picture A is correct while picture B is incorrect. Note that sulfur is illustrated as the S_8 allotrope, a common elemental form of sulfur.

a. Describe the features represented in picture **A** that make it correct and the features in picture **B** that make it incorrect.



A



B

b. Predict the products (either SO_2 or SO_3) that are formed from the reactants in picture **A**. Draw a picture of the products, including the correct quantities.

c. Would all of the oxygen atoms react completely with all of the sulfur atoms? How did you arrive at your answer?

d. True or False: After the reaction goes to completion, unreacted sulfur atoms are left over. What evidence supports your answer?

Incomplete Combustion

If the amount of oxygen is limited, the hydrocarbon can burn incompletely:

$$2C_8H_{18} + 25O_2 \rightarrow 16CO_2 + 18H_2O \quad \text{(complete combustion)}$$

$$2C_8H_{18} + 17O_2 \rightarrow 16CO + 18H_2O \quad \text{(incomplete combustion)}$$

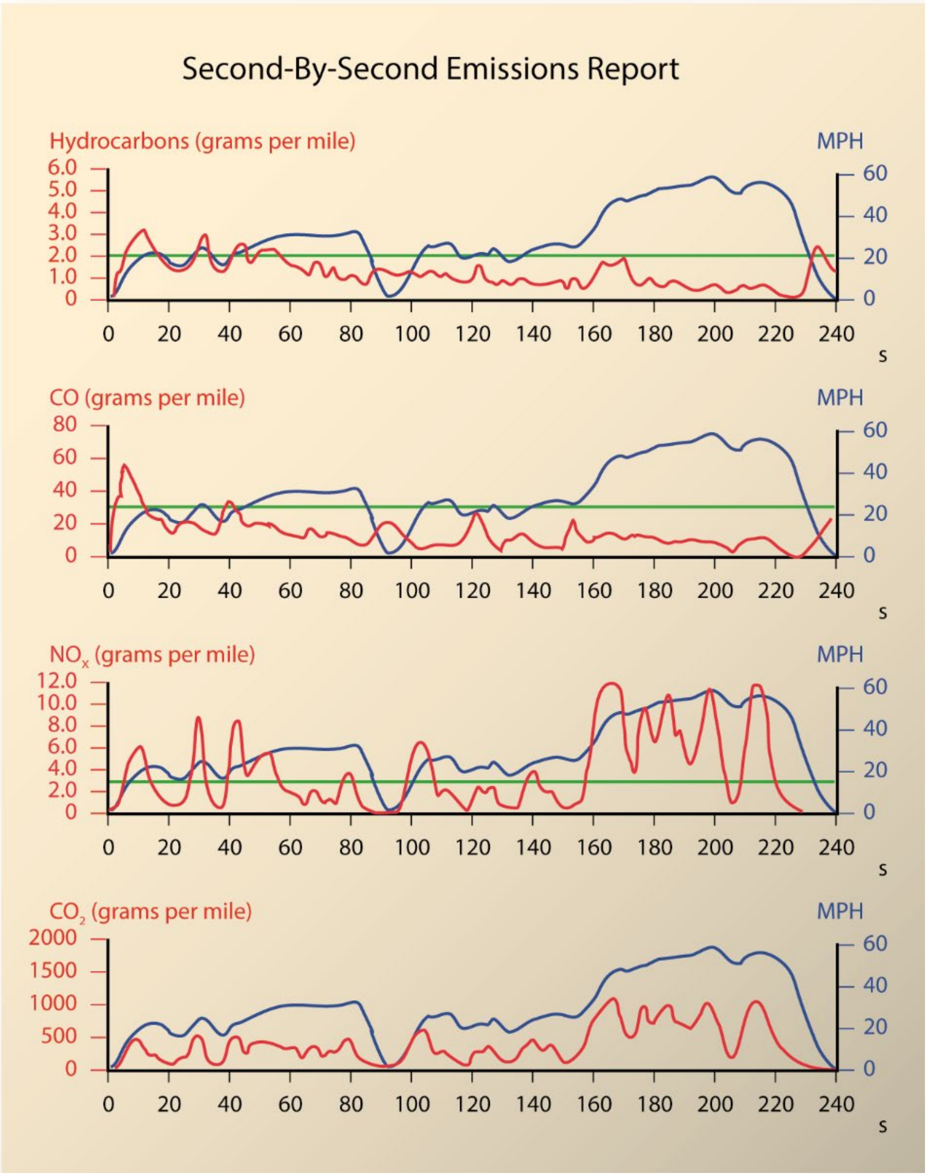
Verify that both of these equations are properly balanced.

Vehicle Emissions

This auto emissions report shows the amount of CO generated from the exhaust, which can tell if the vehicle is operating properly or exhibits incomplete combustion products.

- Green line represents the emissions standards for this state or region.

Question: Why is the green line missing on the bottom graph?

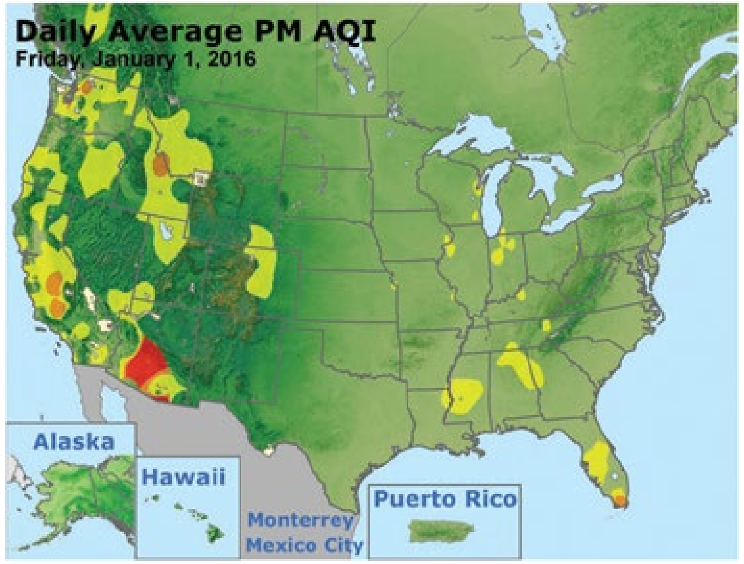


Source: Data from Cathy Middlecamp

Particulate Emissions

Your Turn 2.26 Particles Where You Live

Shown is a map of the continental U.S. that shows $PM_{2.5}$ data for January 1, 2016.



a. In terms of air quality, what do the green, yellow, orange, and red colors indicate?

b. Which groups of people are most sensitive to particulate matter?

c. Visit "State of the Air," a website posted by the American Lung Association. How many days a year does your state have "orange days" and "red days" for particulate pollution? What is the difference?

d. Using the interactive map at www.acs.org/cic, select three regions of the U.S., and summarize their composition trends for $PM_{2.5}$ pollution. What are some possible sources for these particulates, and why do their relative concentration profiles vary by quarter?

Source: EPA AirNow

Direct Source of Sulfur Trioxide

Sulfur in coal reacts with oxygen in two steps to form sulfur trioxide.

$$S + O_2 \rightarrow SO_2$$

$$2SO_2 + O_2 \rightarrow 2SO_3$$

Sulfur trioxide then reacts with water to produce sulfuric acid, a contributor to acid rain.

$$H_2O + SO_3 \rightarrow H_2SO_4$$

Good news: Since 1985, we have seen a 55% reduction of SO_2 emissions in the US.

Direct Source of Nitrogen Oxides

Nitrogen reacts with oxygen to form nitrogen oxides.

$$N_2 + O_2 \rightarrow NO$$

$$2NO + O_2 \rightarrow 2NO_2$$

Requires high temperatures such as found in combustion engines or combustion power plants

Nitrogen dioxide then reacts with water to produce nitric acid, another contributor to acid rain.

$$H_2O + NO_2 \rightarrow HNO_3$$

Other more complex reactions to produce nitrogen oxides involve incompletely burned carbon-containing compounds called Volatile Organic Compounds (VOCs)

Vehicle Catalytic Converters

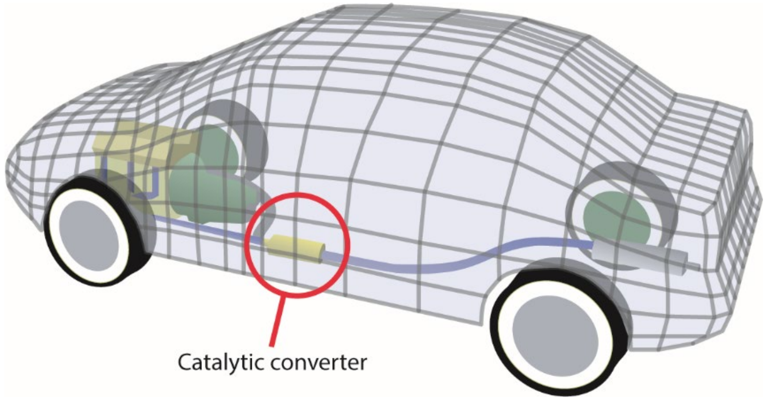
Catalytic converters reduce the amount of CO in exhaust due to catalyzing the combustion of CO to $CO_{2.}$

- Newer designs also limit the release of NO_x by reducing them to N_2 and $O_{2.}$

A **catalyst** is a substance that participates in a chemical reaction and influences its rate, but is not used up in the reaction.

- Catalytic converters use rare metals such as platinum and rhodium.

The Chemistry of Vehicle Emissions Reduction & The Volkswagen Scandal



REDUCING VEHICLE EMISSIONS WITH CHEMISTRY

Millions of Volkswagen cars have been found to emit up to 40 times more nitrogen oxides in normal operation than they did during emissions testing, miring the company in controversy. This graphic looks at the devices present in a vehicle to help reduce pollution, and how they work.

POLLUTING COMPOUNDS

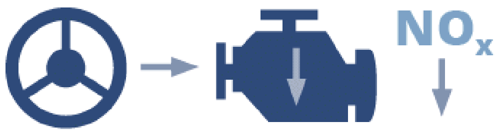
NO_x – NITROGEN OXIDES (E.G. NITRIC OXIDE, NITROGEN DIOXIDE)

CO – CARBON MONOXIDE

HC – UNBURNT HYDROCARBONS (FROM FUEL)

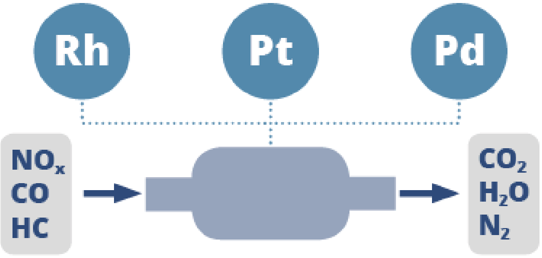
THE 'DEFEAT DEVICE'

The 'defeat device' found in Volkswagen cars is not a physical device, but a piece of software that detects when the car is being tested. When it detected this, it tuned the engine's performance reducing the NO_x emissions. In normal driving conditions they were much higher.



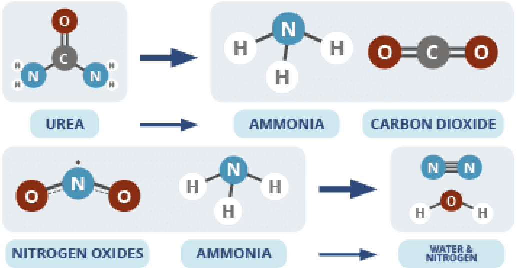
The car detected when it was in test conditions (potentially by monitoring steering wheel movement or traction control deactivation).

CATALYTIC CONVERTERS



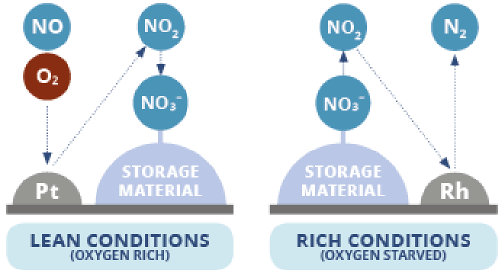
Three-way catalytic converters are present in all petrol-powered cars, and help remove carbon monoxide, unburnt hydrocarbons, and nitrogen oxides. They contain precious metals such as rhodium, platinum, and palladium to accomplish this. Three-way catalytic converters can't be used in diesel engines, as diesel's oxygen-rich exhaust gases make their removal of NO_x inefficient.

SELECTIVE CATALYTIC REDUCTION



Selective catalytic reduction (SCR) is a method for NO_x removal that is utilised in some diesel engines. It involves the injection of urea into the exhaust stream of the vehicle, where it produces ammonia, which is adsorbed onto a catalyst. The ammonia can then react with the nitrogen oxides in the exhaust stream to produce nitrogen and water. SCR is capable of achieving NO_x reductions of up to 90%.

NO_x ADSORBERS



NO_x adsorbers can also be used in diesel engines. The majority of NO_x emissions from the diesel engines are NO, and this is converted to NO_2 by reaction with oxygen using a platinum catalyst. The NO_2 is then absorbed in the form of nitrates by the storage material (often barium oxide). Once the trap is full, the nitrate can be desorbed, converted to nitrogen over a rhodium catalyst, and released.

Ozone: A Secondary Pollutant [1]

Unlike nitrogen and sulfur oxides that are direct pollutants, ozone is a **secondary pollutant**.

- It is produced from one or more other pollutants (VOCs and NO_2).

$$\mathrm{NO_2} \xrightarrow{\text{sunlight}} \mathrm{NO} + \mathrm{O}$$

$$\mathrm{O} + \mathrm{O_2} \rightarrow \mathrm{O_3}$$

Ozone: A Secondary Pollutant 2

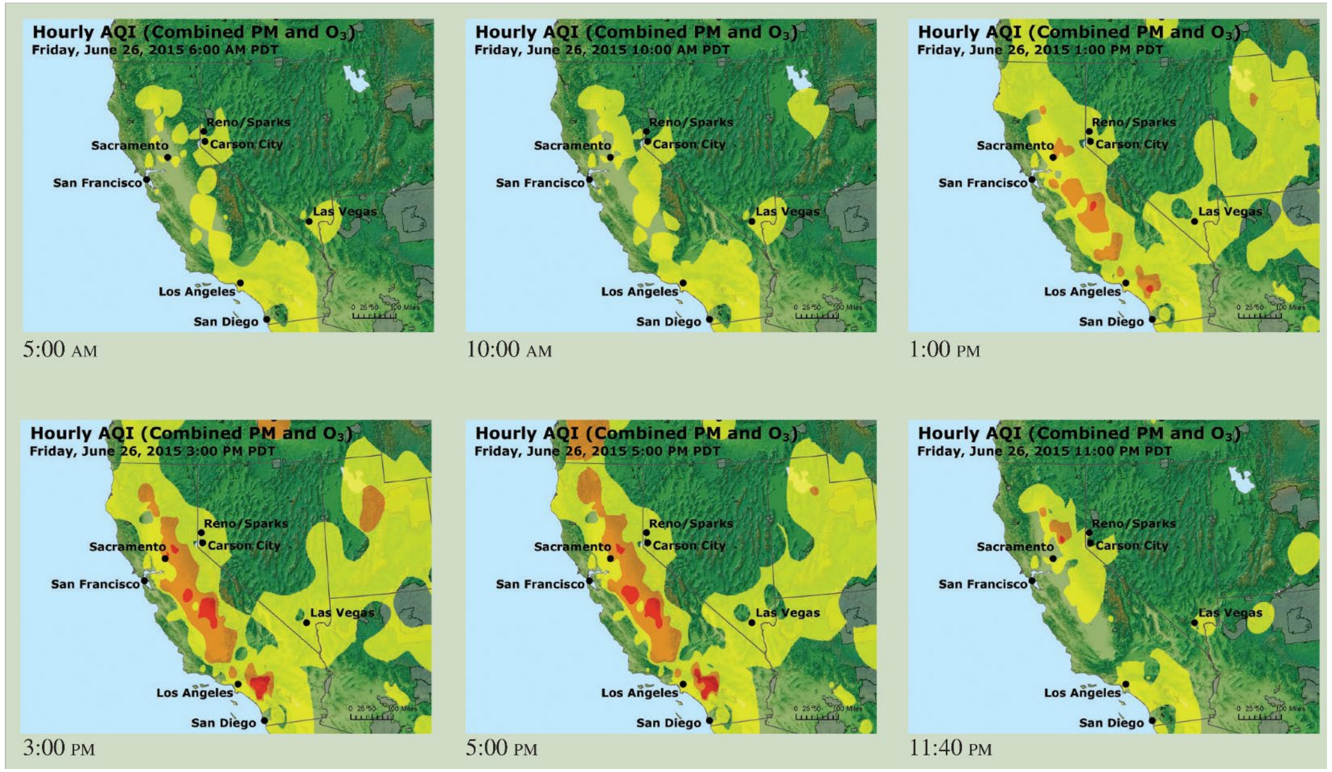
Your Turn 2.27 Ozone Around the Clock

Ozone concentrations vary during the day, as shown in Figure 2.20.

a. Near which cities is the air hazardous to one or more groups?

b. At about what time does the ozone level peak?

c. Can moderate levels (shown in yellow) of ozone exist in the absence of sunlight? Assume sunrise occurs around 6 am and sunset about 8 pm.



Source: EPA AirNow

Indoor Pollution and “Sick” Buildings

There are many sources of indoor pollution.

- Increased insulation for energy efficiency reduces air exchange with outside, trapping pollution indoors.

Your Turn 2.32 Indoor Activities

Name 10 activities that add pollutants or VOCs to indoor air. To get you started, two are pictured in Figure 2.22. Remember that some pollutants have no detectable odors.

Figure 2.22

Examples of activities that can cause indoor air pollution.

Is There A Sustainable Way Forward?

Making decisions with a concern not only for today's outcomes, but also for the needs of future generations.

It is easier to prevent pollution than to clean it up.

Begun under the EPA Design for the Environment Program, **green chemistry** reduces pollution through the design or redesign of chemical processes:

- Use less energy.
- Create less waste.
- Use fewer resources.
- Use renewable resources.

The Twelve Principles of Green Chemistry: What it is, & Why it Matters

Green Chemistry Challenge Winners

The 12 Principles of

GREEN CHEMISTRY

Green chemistry is an approach to chemistry that aims to maximize efficiency and minimize hazardous effects on human health and the environment. While no reaction can be perfectly 'green', the overall negative impact of chemistry research and the chemical industry can be reduced by implementing the 12 Principles of Green Chemistry wherever possible.

1. WASTE PREVENTION

Prioritize the prevention of waste, rather than cleaning up and treating waste after it has been created. Plan ahead to minimize waste at every step.

2. ATOM ECONOMY

Reduce waste at the molecular level by maximizing the number of atoms from all reagents that are incorporated into the final product. Use atom economy to evaluate reaction efficiency.

3. LESS HAZARDOUS CHEMICAL SYNTHESIS

Design chemical reactions and synthetic routes to be as safe as possible. Consider the hazards of all substances handled during the reaction, including waste.

4. DESIGNING SAFER CHEMICALS

Minimize toxicity directly by molecular design. Predict and evaluate aspects such as physical properties, toxicity, and environmental fate throughout the design process.

5. SAFER SOLVENTS & AUXILIARIES

Choose the safest solvent available for any given step. Minimize the total amount of solvents and auxiliary substances used, as these make up a large percentage of the total waste created.

6. DESIGN FOR ENERGY EFFICIENCY

Choose the least energy-intensive chemical route. Avoid heating and cooling, as well as pressurized and vacuum conditions (i.e. ambient temperature & pressure are optimal).

7. USE OF RENEWABLE FEEDSTOCKS

Use chemicals which are made from renewable (i.e. plant-based) sources, rather than other, equivalent chemicals originating from petrochemical sources.

8. REDUCE DERIVATIVES

Minimize the use of temporary derivatives such as protecting groups. Avoid derivatives to reduce reaction steps, resources required, and waste created.

9. CATALYSIS

Use catalytic instead of stoichiometric reagents in reactions. Choose catalysts to help increase selectivity, minimize waste, and reduce reaction times and energy demands.

10. DESIGN FOR DEGRADATION

Design chemicals that degrade and can be discarded easily. Ensure that both chemicals and their degradation products are not toxic, bioaccumulative, or environmentally persistent.

11. REAL-TIME POLLUTION PREVENTION

Monitor chemical reactions in real-time as they occur to prevent the formation and release of any potentially hazardous and polluting substances.

12. SAFER CHEMISTRY FOR ACCIDENT PREVENTION

Choose and develop chemical procedures that are safer and inherently minimize the risk of accidents. Know the possible risks and assess them beforehand.

Example topics that you can delve into further...

You can check Korean air quality data at
https://www.airkorea.or.kr/eng/

1) Check correlations between air quality and wildfire such as Samcheok fire in 2022.

2) Check the level of secondary pollutants as a function of seasons and rationalize

3) Check the website below and demonstrate your own experiment (test the ozone level of your daily environment).
https://www.acs.org/education/resources/undergraduate/chemistryincontext/interactives/air-we-breathe/investigating-air-pollution.html

4) Check the website below
Green Chemistry Challenge Winners | US EPA
Learn what type efforts have been made and discuss ideas