

## This lecture will help you understand:

- The Earth's atmosphere
- Outdoor pollution and solutions
- Stratospheric ozone depletion
- Acidic deposition and consequences
- Indoor air pollution and solutions



## Central Case: Charging toward cleaner air in London

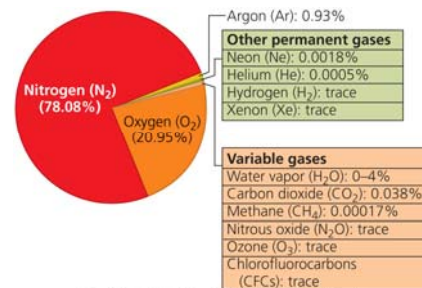
- London has had bad air pollution for centuries that has killed thousands
- Today, smog from traffic is a problem
- The “congestion-charging” program charges drivers to drive into central London during the week
- Congestion decreased, fewer accidents occurred and the air became cleaner



## The atmosphere

- **Atmosphere** = the thin layer of gases that surrounds Earth
  - Absorbs radiation and moderates climate
  - Transports and recycles water and nutrients
  - 78% nitrogen gas, 21% oxygen gas, 1% other gases
  - Its four layers differ in temperature, density and composition
- Minute concentrations of **permanent** (remain at stable concentrations) and **variable gases** (varying concentrations)
- Human activity is changing the amounts of some gases

## The atmosphere's composition



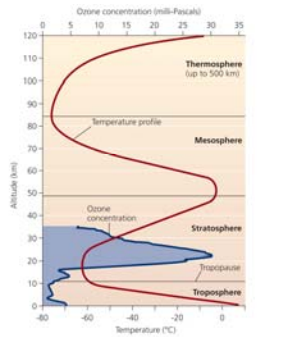
## The first two layers of the atmosphere

- **Troposphere** = bottommost layer
  - Air for breathing, weather
  - Temperature declines with altitude
  - **Tropopause** = limits mixing between troposphere and the layer above it
- **Stratosphere** = 11-50 km (7-31 mi) above sea level
  - Drier and less dense, with little vertical mixing
  - Colder in its lower regions
  - Contains UV radiation-blocking ozone, 17-30 km (10-19 mi) above sea level

## The two highest levels of the atmosphere

- **Mesosphere** = 50-80 km (31-56 mi) above sea level
  - Extremely low air pressure
  - Temperatures decrease with altitude
- **Thermosphere** = atmosphere's top layer
  - Extends upward to 500 m (300 mi)

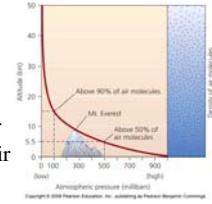
## The atmosphere's four layers



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## Atmospheric properties

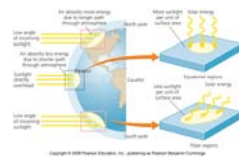
- **Atmospheric pressure** = measures the force per unit area produced by a column of air
  - Decreases with altitude
- **Relative humidity** = the ratio of water vapor a given volume of air contains to the amount it could contain at a given temperature
- **Temperature** = varies with location and time



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## Solar energy heats the atmosphere

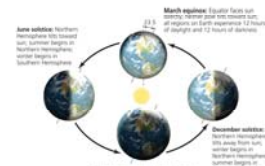
- The spatial relationship between the Earth and sun determines the amount of solar energy striking the Earth
- Energy from the sun
  - Heats air
  - Moves air
  - Creates seasons
  - Influences weather and climate
- Solar radiation is highest near the equator



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## Solar energy creates seasons

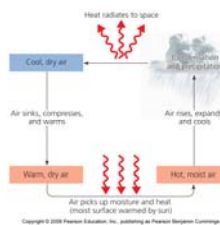
- Because the Earth is tilted
  - Each hemisphere tilts toward the sun for half the year
  - Results in a change of seasons
  - Equatorial regions are unaffected by this tilt, so days average 12 hours through the year



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## Solar energy causes air to circulate

- Air near Earth's surface is warmer and moister than air at higher latitudes
- **Convective circulation** = less dense, warmer air rises and creates vertical currents
  - Rising air expands and cools
  - Cool air descends and becomes denser, replacing warm air
  - Influences both weather and climate



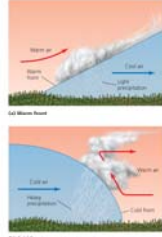
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## The atmosphere drives weather and climate

- **Weather** = specifies atmospheric conditions over short time periods and within a small geographic areas
- **Climate** = describes patterns of atmospheric conditions across large geographic regions over long periods of time
- Mark Twain said "Climate is what we expect; weather is what we get"

## Air masses produce weather

- **Front** = the boundary between air masses that differ in temperature, moisture, and density
- **Warm Front** = the boundary where warm moist air replaces colder, drier air
- **Cold Front** = the boundary where colder, drier air displaces warmer, moister air

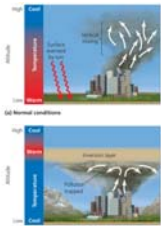


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## Air masses have different atmospheric pressures

- **High-pressure system** = air that moves away from a center of high pressure as it descends
  - Brings fair weather
- **Low-pressure system** = air moves toward the low atmospheric pressure at the center of the system and spirals upward
  - Clouds and precipitation

## Thermal inversion



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Usually, tropospheric air temperature decreases as altitude increases

- Warm air rises, causing vertical mixing

**Thermal inversion** = a layer of cool air occurs beneath a layer of warmer air

- **Inversion layer** = the band of air in which temperature rises with altitude
- Denser, cooler air at the bottom of the layer resists mixing

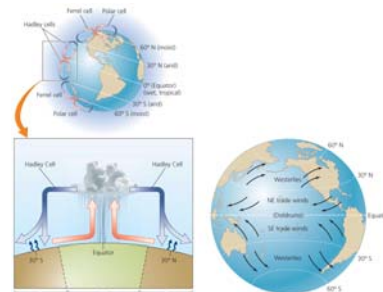
## The atmosphere

- Convective currents contribute to climatic patterns and affect moisture distribution
- **Hadley cells** = near the equator, surface air warms, rises, and expands
  - Releases moisture and heavy rainfall near the equator
- **Ferrel cells and polar cells** = lift air
  - Creates precipitation at 60 degrees latitude north and south
  - Causes air to descend at 30 degrees latitude

## Global wind patterns

- The atmospheric cells interact with Earth's rotation to produce global wind patterns
  - As Earth rotates, equatorial regions spin faster
- **Coriolis effect** = the north-south air currents of the convective cells appear to be deflected from a straight path
  - Results in curving global wind patterns

## Climate patterns and moisture distribution



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## Wind patterns

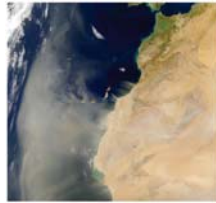
- **Doldrums** = near the equator
  - Few winds
- **Trade winds** = between the equator and 30 degrees latitude
  - Blow from east to west
- **Westerlies** = from 30 to 60 degrees latitude
  - Originate from the west and blow east
- People used these winds to sail their ships across the ocean

## Outdoor air pollution

- **Air pollutants** = gases and particulate material added to the atmosphere
  - Can affect climate or harm people
- **Air pollution** = the release of pollutants
- **Outdoor (ambient) air pollution** = pollution outside
  - Has recently decreased due to government policy and improved technologies in developed countries
  - Developing countries and urban areas still have significant problems

## Natural sources pollute: dust storms

- **Dust storms** = Hundreds of millions of tons of dust are blown westward across the Atlantic Ocean by trade winds every year
  - From Africa to the Americas
  - Unsustainable farming and grazing, erosion and desertification



(A) Dust storm off west coast of Africa  
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## Natural sources pollute: volcanoes

- Release large quantities of particulate matter, sulfur dioxide & other gases
  - Can remain for months or years
  - **Aerosols** = reflect sunlight back into space and cool the atmosphere and surface



(B) Mount Saint Helens eruption, 1980  
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## Natural sources pollute: fires

- Pollutes atmosphere with soot and gases
- Over 60 million ha of forests and grasslands burn per year
- Severe fires are caused by human interaction
  - Cleared forests, harsh droughts, and climate change (El Niño)



(C) Natural fire in California  
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## Types of outdoor air pollution

- Air pollution can come from mobile or stationary sources
- **Point Sources** = specific spots where large quantities of pollutants are discharged (power plants and factories)
- **Nonpoint Sources** = more diffuse, consisting of many small sources (automobiles)
- **Primary Pollutants** = directly harmful and can react to form harmful substances (soot and carbon dioxide)
- **Secondary Pollutants** = form when primary pollutants interact or react with constituents or components of the atmosphere (tropospheric ozone and sulfuric acid)

### Legislation addresses pollution

- Congress passed a series of laws starting in 1955
- The Clean Air Act of 1970
  - Sets standards for air quality, limits on emissions
  - Provides funds for pollution-control research
  - Allows citizens to sue parties violating the standards
- The Clean Air Act of 1990
  - Strengthens standards for auto emissions, toxic air pollutants, acidic deposition, stratospheric ozone depletion
  - Introduced emissions trading

### The EPA sets standards

- Environmental Protection Agency (EPA) sets nationwide standards for emissions of toxic pollutants
- States monitor air quality and develop, implement, and enforce regulations within their borders
  - If a state's plans for implementation are not adequate, the EPA can take over enforcement

### Criteria pollutants: carbon monoxide

- **Criteria pollutants** = pollutants judged to pose especially great threats to human health
- **Carbon monoxide (CO)**
  - A colorless, odorless gas
  - Produced primarily by incomplete combustion of fuel
  - Poses risk to humans and animals, even in small concentrations

### Criteria pollutants: sulfur and nitrogen dioxide

- **Sulfur dioxide (SO<sub>2</sub>)** = colorless gas with a strong odor
  - Coal emissions from electricity generation and industry
  - Can form acid precipitation
- **Nitrogen dioxide (NO<sub>2</sub>)** = highly reactive, foul smelling reddish brown gas
  - **Nitrogen oxides (NO<sub>x</sub>)** = nitrogen and oxygen react at high temperatures
  - Vehicle engine and industrial combustion, electrical utilities
  - Contributes to smog and acid precipitation

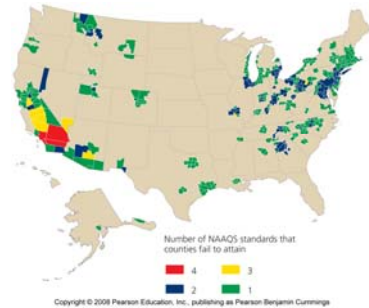
### Criteria pollutants: tropospheric ozone

- **Tropospheric ozone (O<sub>3</sub>)** = a colorless gas with a strong odor
  - A secondary pollutant
  - Results from interactions of sunlight, heat, nitrogen oxides, and volatile carbons
  - A major component of smog
  - Poses a health risk as a result of its instability

### Criteria pollutants: particulate matter and lead

- **Particulate matter** = solid or liquid particles suspended in the atmosphere
  - Primary pollutants: dust and soot
  - Secondary pollutants: sulfates and nitrates
  - Damages respiratory tissue when inhaled
  - Most is wind-blown dust
- **Lead** = particulate pollutant added to gas and used in industrial metal smelting
  - Bioaccumulates and causes nervous system malfunction
  - Banned in gasoline in developed, but not in developing countries

## Areas in the U.S. fail air NAQS standards

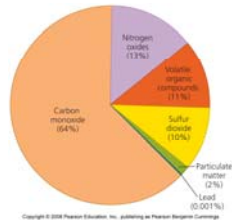


## Agencies monitor pollutants

- State and local agencies also monitor, calculate, and report to the EPA the emissions of pollutants
  - Four criteria pollutants: carbon monoxide, sulfur dioxide, particulate matter, and lead
  - All nitrogen oxides
  - Not tropospheric ozone (no emissions to monitor)
  - Volatile organic compounds (VOCs)** = carbon-containing chemicals used emitted by vehicle engines and industrial processes

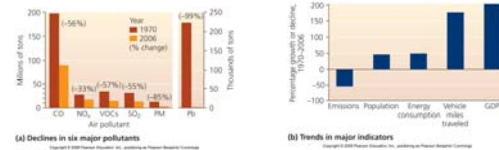
## U.S. air pollution

In 2006, the U.S. emitted 137 million tons of the six major pollutants



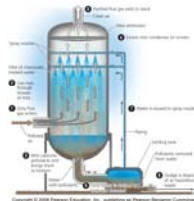
## Air pollution has decreased since 1970

- Total emissions of the six monitored pollutants have declined
  - Despite increased population, energy consumption, miles traveled, and gross domestic product



## Reasons for the decline in U.S. pollution

- Cleaner-burning vehicles and catalytic converters decrease carbon monoxide
- Permit-trading programs and clean coal technologies reduce SO<sub>2</sub> emissions
- Scrubbers** = technologies that chemically convert or physically remove pollutants before they leave the smokestacks
- Phaseout of leaded gasoline
- Improved technologies and federal policies



## Toxic substances also pollute

- Toxic air pollutants** = substances known to cause cancer; reproductive defects; or neurological, development, immune system, or respiratory problems
  - Some are produced naturally: hydrogen sulfide
  - Most are produced by humans: smelting, sewage treatment, industry
- Not monitored as closely as the six criteria pollutants
  - Monitoring is improving

### Recent policies have been contentious

- President G.W. Bush has pushed proposals that would overturn key aspects of legislation
- **New source reviews** = old utility plants have to install the best available technology when upgrading
  - The Bush administration proposed abolishing this requirement and dropped lawsuits against violators
- **Clear Skies Initiative** = establishes a market-based cap-and-trade program for some pollutants
  - Stopped in the Senate, because it would increase pollution
  - The EPA had skewed its analysis to promote the legislation

### Burning fossil fuels produces industrial smog

- **Smog** = unhealthy mixtures of air pollutants over urban areas
- **Industrial (gray air) smog** = industries burn coal or oil
  - Occurs in cooler, hilly areas
  - Government regulations in developed countries reduced smog
  - Coal-burning industrializing countries face significant health risks



(a) Donora, Pennsylvania, at midday in the 1948 smog event  
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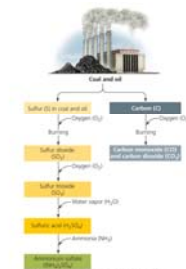
### Photochemical (brown air) smog

- Produced by a series of reactions
  - Hot, sunny cities surrounded by mountains
  - Light-driven reactions of primary pollutants and normal atmospheric compounds
  - Morning traffic exhaust releases pollutants
  - Irritates eyes, noses, and throats
  - Vehicle inspection programs in the U.S. have decreased smog



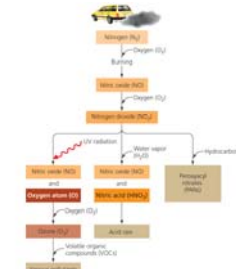
(b) Photochemical smog over Mexico City  
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### Industrial smog



(a) Burning sulfur-rich oil or coal without adequate pollution control technologies  
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### Photochemical smog



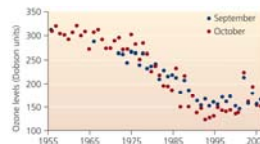
(b) Formation of photochemical smog  
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### Synthetic chemicals deplete stratospheric ozone

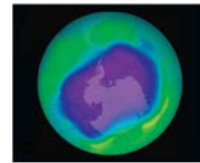
- **Ozone layer** = ozone in the lower stratosphere
  - 12 ppm concentrations effectively block incoming damaging ultraviolet radiation
- **Chlorofluorocarbons (CFCs)** = chemicals that attack ozone
  - 1 million metric tons/year were produced
  - Releases chlorine atoms that split ozone

### The hole in the ozone

- **Ozone hole** = ozone levels over Antarctica had declined by 40-60%
  - Depletion also in the Arctic and globally
  - Causes skin cancer, harms crops and decreases ocean productivity



(a) Monthly mean ozone levels at Halley, Antarctica  
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(b) The "ozone hole" over Antarctica, September 24, 2004  
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## The Montreal Protocol addressed ozone depletion

- **Montreal Protocol** = 180 nations agreed to cut CFC production in half
  - Follow-up agreements deepened cuts, advanced timetables and addresses other ozone-depleting chemicals
  - Today, production and use of ozone-depleting chemicals has decreased 95%
  - The ozone layer is beginning to recover
- Challenges still face us
  - CFCs will remain in the stratosphere for a long time
  - Nations can ask for exemptions to the ban

## The Montreal Protocol is a success

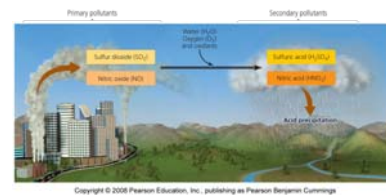
- Considered the biggest environmental success story
  - Policymakers included industry in helping solve the problem
  - Implementation of the plan allowed an adaptive management strategy that changed strategies in response to new scientific data, technological advances, and economic figures
- The Montreal Protocol can serve as a model for international environmental cooperation

## Acid deposition is another transboundary issue

- **Acidic deposition** = the deposition of acid, or acid-forming pollutants, from the atmosphere onto Earth's surface
  - **Acid rain** = precipitation of acid
  - **Atmospheric deposition** = the wet or dry deposition on land of pollutants

## Sources of acid deposition

- Originates from burning fossil fuels that release sulfur dioxide and nitrogen oxides
  - These compounds react with water to form sulfuric and nitric acids

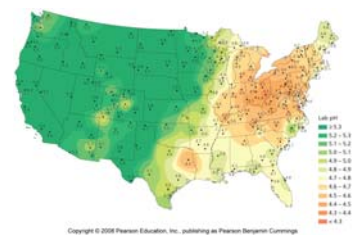


## Effects of acid deposition

- Nutrients are leached from topsoil
- Soil chemistry is changed
- Metal ions (aluminum, zinc, etc.) are converted into soluble forms that pollute water
- Widespread tree mortality
- Affects surface water and kills fish
- Damages agricultural crops
- Erodes stone buildings, corrodes cars, erases writing on tombstones



## pH of precipitation in the U.S.



*Many regions of acidification are downwind of major sources of pollution*



### Acid deposition has not been greatly reduced

- New technologies such as scrubbers have helped
- SO<sub>2</sub> emissions are lower
- But, NO<sub>x</sub> emissions are higher
- Acid deposition's effects are worse than predicted
  - The Clean Air Act cannot restore ecosystems
  - More must be done to control acid deposition

### Indoor air pollution

- Indoor air contains higher concentrations of pollutants than outdoor air
  - 6,000 people die per day from indoor air pollution
- The average U.S. citizen spends 90% of the time indoors
  - Exposed to synthetic materials that have not been comprehensively tested
  - To reduce heat loss and improve energy efficiency, building ventilation systems were sealed off and windows put in that did not open, trapping pollutants inside

### Indoor air pollution in the developing world

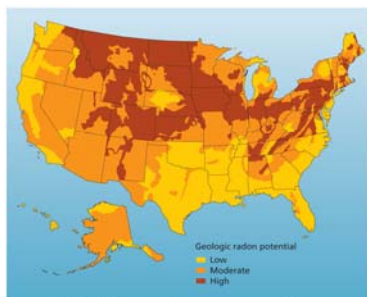
- Stems from burning
  - Wood, charcoal, dung, crop wastes
  - Little to no ventilation
- Fuel burning pollution causes an estimated 1.6 million deaths per year
  - Soot and carbon monoxide
  - Causes pneumonia, bronchitis, allergies, cataracts, asthma, heart disease, cancer and death



### Tobacco smoke and radon

- The most dangerous indoor pollutants in the developed world
- Secondhand smoke from cigarettes is especially dangerous
  - Containing over 4000 dangerous chemicals
  - Causes eye, nose, and throat irritation
  - Smoking has declined in developed nations
- Radon causes 20,000 deaths a year in the U.S.
  - A radioactive gas resulting from natural decay of rock;

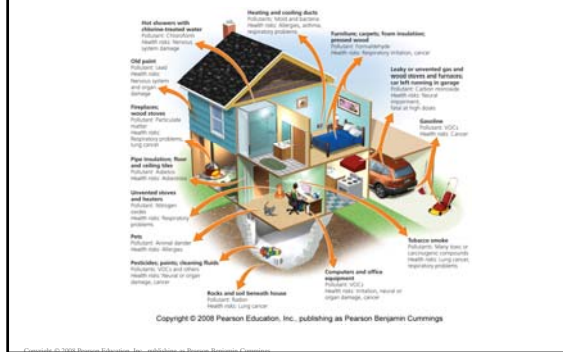
### Radon risk across the U.S.



### Volatile Organic Compounds (VOCs)

- The most diverse group of indoor air pollutants
  - Released by everything from plastics and oils to perfumes and paints
  - Most VOCs are released in very small amounts
  - Unclear health implications due to low concentrations
  - Also include pesticides, which are found indoors more often than outdoors due to seepage
  - Formaldehyde, which leaks from pressed wood and insulation, irritates mucous membranes and induces skin allergies

## Sources of indoor air pollution



## Living organisms can pollute indoors

- Tiny living organisms can also pollute
- Includes dust mites and animal dander worsen asthma
- Fungi, mold, mildew, airborne bacteria cause severe allergies, asthma, and other respiratory ailments
- **Sick building syndrome** = a sickness produced by indoor pollution with general and nonspecific symptoms
  - Solved by using low-toxicity building materials and good ventilation

## We can reduce indoor air pollution

- In developed countries:
  - Use low-toxicity material
  - Monitor air quality
  - Keep rooms clean
  - Limit exposure to chemicals
- In developing countries:
  - Dry wood before burning
  - Cook outside
  - Use less-polluting fuels (natural gas)

## Conclusion

- Indoor air pollution is a potentially serious health threat
  - We can significantly minimize risks
- Outdoor air pollution has been addressed by government legislation and regulation in developed countries
- Reduction in outdoor air pollution represents some of the greatest strides in environmental protection
  - There is still room for improvement, especially in developing countries

## QUESTION: Review

The major component of Earth's atmosphere is ...

- Nitrogen gas
- Oxygen gas
- Argon gas
- Water vapor

## QUESTION: Review

Ozone in the \_\_\_\_\_ is a pollutant, but in the \_\_\_\_\_ is vital for life

- Stratosphere, troposphere
- Troposphere, stratosphere
- Troposphere, tropopause
- Stratosphere, thermosphere

**QUESTION: Review**

\_\_\_\_\_ is defined as the ratio of water vapor in the atmosphere compared to the amount the atmosphere could contain

- a) Atmospheric pressure
- b) Ozonification
- c) Temperature
- d) Relative humidity

**QUESTION: Review**

If you were on a sailing ship going from Europe to the United States, you would want to be in the \_\_\_\_\_

- a) Doldrums
- b) Trade winds
- c) Westerlies
- d) Polar cell

**QUESTION: Review**

The Clean Air Act does all of the following, except:

- a) Allows higher levels of emissions of some criteria pollutants
- b) Provides funds for pollution control research
- c) Allows citizens to sue violators
- d) Sets standards for air quality

**QUESTION: Review**

Which criteria pollutant is colorless, odorless, and poses a risk to humans, even in small amounts?

- a) Sulfur dioxide
- b) Nitrogen dioxide
- c) Tropospheric ozone
- d) Carbon monoxide

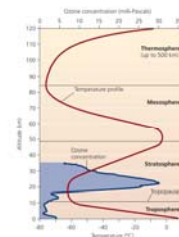
**QUESTION: Review**

The Montreal Protocol addressed \_\_\_\_\_

- a) Global warming, and was not successful
- b) Criteria pollutants, and was successful
- c) Ozone depletion, and was successful
- d) Acid deposition, and was successful

**QUESTION: Interpreting Graphs and Data**

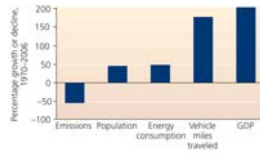
What does this graph show about the mesosphere?



- a) It contains the most ozone
- b) It is a very thin layer
- c) Temperature decreases with increasing altitude
- d) Temperature increases with increasing altitude

**QUESTION: Interpreting Graphs and Data**

Which conclusion can you draw from this graph?



(b) Trends in major indicators  
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- a) Even though population and consumption increased, emissions have decreased
- b) Along with population decreases, emissions have decreased
- c) People have increased emissions, but only slightly
- d) All factors show major decreases

**QUESTION: Viewpoints**

Think of a major city near you. Do you think it should adopt congestion charging (drivers have to pay to drive downtown)?

- a) Yes, if mass transit is available
- b) Yes, but only charge people who do not live in the downtown area
- c) No; it's my right to drive where ever I want to
- d) I don't care, because I don't own a car

**QUESTION: Viewpoints**

Should the government be able to prevent restaurants from allowing smoking, to protect people from secondhand smoke?

- a) Yes; I don't want to be exposed to this form of pollution
- b) Yes, only if the restaurant agrees
- c) No, let the restaurant owner decide
- d) No; I want to be able to smoke in a restaurant