Chapter 16 – Air Pollution

Key Terms

acid deposition
aerosol
aesthetic degradation
ambient air
bronchitis
carbon dioxide
carbon monoxide
chloroflourocarbons
chronic obstructive pulmonary disease
criteria pollutants
fugitive emissions
hazardous air pollutants
nitrogen oxides
ozone
particulate material
primary pollutant
secondary pollutant
stratospheric ozone
sulfur dioxide
temperature inversions
Toxic Release Inventory
volatile organic compounds

Skills

1. Differentiate between the major types of air pollutants. Address sources, environmental impacts, and human health effects of these pollutants.
2. Compare the criteria pollutants to the unconventional air pollutants.
3. Characterize the indoor air pollutants, including their sources, types of buildings affected, and human health effects.
4. Explain what is meant by a sick building, and delineate the criteria required for a building to be considered sick.
5. Differentiate between stratospheric and tropospheric ozone.
6. Propose specific mechanisms to decrease each of the indoor and outdoor air pollutants.
7. Appraise the effectiveness of the Clean Air Act.
8. Recall the chemical reactions involved in contamination of the atmosphere with pollutants.

Take Note: It is important that you understand the impacts of the major air pollutants, including their human health effects and environmental impacts. You should also know the origin of these pollutants and methods to reduce the pollutant. Previous AP essay questions have addressed ozone, lead, mercury, particulates, carbon dioxide, and carbon monoxide. In addition, one essay question was entirely about indoor air pollutants. Multiple-choice questions will also reference the pollutants.

Natural Sources of Air Pollution

Volcanoes are a natural source of particulates, sulfur dioxide, carbon oxides, hydrogen sulfide, and other noxious air pollutants. Forests release large amounts of volatile organic compounds that form ozone upon exposure to sunlight. Sea spray releases sulfur compounds into the atmosphere, as does decaying vegetation. Dust creates particulate pollution. Natural decomposition releases tremendous amounts of the greenhouse gas methane.

Anthropogenic Air Pollutants

Primary air pollutants are chemicals that are considered pollutants when they are released. A secondary air pollutant forms when exposure to another factor causes the chemical to be toxic. Many times secondary pollutants are a result of a photochemical reaction or a reaction with water. For example, photochemical oxidants like ozone and atmospheric acids like nitric or sulfuric acids are secondary air pollutants. Fugitive emissions are emissions that do not arise from a smokestack. They may be from leaking pipes and valves or may be dust from erosion, mining, or construction.

According to the Environmental Protection Agency, the United States has deemed six pollutants as criteria air pollutants. These pollutants have legal limits, or national ambient air quality standards (NAAQS), which control their release into the environment. The pollutants are ozone, nitrogen dioxide, particulate matter, sulfur dioxide, carbon monoxide, and lead. Other air pollutants that must be considered include volatile organic compounds (VOCs), carbon dioxide, and mercury.

Air Pollution and Human Health

Often, preexisting lung diseases are exacerbated upon exposure to air pollutants. Bronchitis, or inflammation of the bronchi and bronchioles, results in constricted airways. Chronic obstructive pulmonary disease (COPD), or emphysema, is the breakdown of the alveoli in the lungs. As a result, the surface area for gas exchange is greatly lowered, resulting in decreased absorption of oxygen. Smoking cigarettes, or exposure to environmental tobacco smoke, is the leading cause of COPD and preventable death in the world. Each of the pollutants addressed in this chapter has specific health impacts that will be addressed as the pollutant is discussed.

Sulfur dioxide

Sulfur compounds enter the atmosphere from a variety of natural and anthropogenic sources. Natural sources include sea spray, volcanic gases, and biogenic sulfur compounds from bacterial decomposition. Anthropogenic sources include smelting, coal combustion, and petroleum distillation. Sulfur dioxide can directly damage the tissue of living organisms. Once it is in the atmosphere it readily oxidizes to form sulfur trioxide (SO_3). The SO_3 reacts with water vapor (H_2O) in the atmosphere to form sulfuric acid (H_2SO_4), a secondary air pollutant. The sulfuric acid, in wet or dry form, is one of the primary acids involved in acid deposition. Sulfate particles create the sulfur haze that reflects sunlight, causing a global cooling. The particles reduce visibility, as well.

Nitrogen Dioxide

Nitrogen oxides are released when fossil fuels are burned. The first pollutant released is nitric oxide (NO), which readily oxidizes to form nitrogen dioxide (NO_2). When nitrogen dioxide reacts with water vapor it forms nitric acid (HNO_3), a secondary air pollutant that is the other major acid involved in acid deposition. NO_x refers to all of the nitrogen and oxygen compounds that are air pollutants. Another NO_x is N_2O, a greenhouse gas, which arises from feedlots and use of fertilizers.

An important effect of nitrate release in the atmosphere is contamination of aquatic systems that results in eutrophication. It is also suspected that these excess atmospheric nitrates may be enriching soil and promoting the growth of weed species.

Ozone

Photochemical oxidants are created when primary pollutants are acted upon by photons of light. When nitrogen dioxide loses an oxygen atom when exposed to a photon, that free radical oxygen combines with a molecule of O_2 to create ozone (O_3). Ozone is a powerful oxidant that damages vegetation, building materials, and mucus membranes. In humans, ozone irritates the respiratory system resulting in discomfort, coughing, and throat irritation, and it exacerbates lung disease. Ozone is a major component of photochemical smog.

Particulate Matter

An aerosol is any solid or liquid suspended in gas. All atmospheric aerosols, regardless of state, are considered particulate matter (PM). Examples of PM include acid droplets, ash, soot, dust, microscopic biological particles, and smoke. Erosion and desertification dramatically increase the PM in the atmosphere. PM also arises from combustion of fossil fuels or incineration. Power plants frequently use controls for particulate emissions, so most of the particulate pollution in the United States is from diesel engines. Some municipalities in the United States are banning wood-burning stoves and fireplaces due to the particulate pollution. The primary environmental impacts of PM are to decrease visibility and coat plants and structures with deposits. Any small particle, less than 2.5μm in diameter, is particularly dangerous to human health because smaller particles are more likely to be deeply inhaled and affect lung tissue. Larger particles tend to settle out of the air or be trapped in the hair and mucus lining human respiratory systems. Particulates irritate the respiratory tract, leading to coughing and difficulty breathing. Exposure to PM also exacerbates lung and heart disease and are linked to heart attacks, asthma, bronchitis, lung cancer, and even abnormal fetal development.

Carbon Monoxide

Carbon monoxide, CO, is a colorless, odorless gas produced during the incomplete combustion of fossil fuels or biomass. Most of the CO in the United States is released by internal combustion engines. In other countries, fires to clear vegetation and cooking fires also release large amounts of CO. Its primary deleterious effect is on human health. CO binds irreversibly to hemoglobin with more affinity than does oxygen, resulting in suffocation. Acute symptoms of CO exposure are fatigue, impaired vision, headache, dizziness, nausea, and confusion. High concentrations of CO are lethal.

Lead

The primary atmospheric source of lead in the United States was leaded gasoline, which was banned, resulting in a 90 percent decline in the blood levels of lead in American children. Lead is a neurotoxin that binds enzymes and inactivates them. Lead bioaccumulates in bone, and this chronic exposure to an endogenous toxin induces developmental retardation, impaired IQ, attention

deficits, hyperactivity and learning disorders, and aggression. Lead also binds hemoglobin and reduces the ability of red blood cells to carry oxygen.

Volatile Organic Compounds

Volatile organic compounds enter the atmosphere as a gas. Most VOCs are produced naturally by forests. Biogenic methane also contributes to the VOCs in the atmosphere. Usually these VOCs are degraded into CO and CO_2 in the atmosphere. Synthetic VOCs released into the atmosphere include formaldehyde, benzene, toluene, vinyl chloride, phenols, and chloroform. The origin of these pollutants ranges from combustion of fossil fuels, refineries, and chemical plants. VOCs, like NO_x, contribute to the formation of photochemical smog.

Photochemical Smog

Photochemical smog, or brown air smog, occurs in warm sunny areas with large numbers of automobiles. The chemical reactions involved in the formation of photochemical smog are shown in figure 16.1. Ozone and the other photochemical oxidants irritate mucous membranes in animals and directly damage plant tissues. Smog also reduces visibility due to the haze that it creates.

Figure 16.1 Chemical reactions involved in the generation of photochemical smog

1. $NO + VOC \longrightarrow NO_2$ (nitrogen dioxide)
2. $NO_2 + UV \longrightarrow NO + O$ (nitric oxide + atomic oxygen)
3. $O + O_2 \longrightarrow O_3$ (ozone)
4. $NO_2 + VOC \longrightarrow$ PAN, etc. (peroxyacetyl nitrate)

Net results:

$NO + VOC + O_2 + UV \longrightarrow O_3$, PAN, and other oxidants

Carbon Dioxide

The major natural source of carbon dioxide, CO_2, in the atmosphere is cellular respiration. The level of CO_2 in the atmosphere is increasing due to deforestation, burning of biomass, and combustion of fossil fuels. Carbon dioxide is a greenhouse gas, and it will form carbonic acid (H_2CO_3) when it reacts with water vapor in the atmosphere and thus contributes to acid deposition.

Mercury

Mercury is released naturally by volcanoes, weathering of rock, and evaporation of sea water. Mercury contamination arises anthropogenically from coal combustion, incineration, and smelting. Mercury in the atmosphere enters surface water via precipitation, and the inorganic mercury is methylated by bacteria to create the most toxic form, called methyl mercury. Inorganic mercury salts may be in fungicides and disinfectants. Human exposure is from eating contaminated fish and shellfish. Sharks, swordfish, kingfish, and tilefish contain high levels of methyl mercury because the metal is readily bioaccumulated and biomagnified. The acute

effects of mercury toxicity are difficulty walking, loss of coordination, difficulty swallowing, and tremors. Chronic effects are due to the mutagenic, teratogenic, and carcinogenic effects of the metal. Additional effects include hallucinations, psychosis, and irreversible brain damage. Fetal exposure results in mental retardation, attention disorders, seizures, and blindness. The blood level considered to be safe is less than 5.8 μg/l. Mercury emission from power plants is regulated with pollution credits rather than strict emission controls.

Other Metals

Other atmospheric pollutants include arsenic, nickel, beryllium, cadmium, thallium, uranium, cesium, and plutonium. Arsenic is released from smelters and coal combustion. Acute exposure induces anemia and nausea in humans. Chronic exposure induces chronic fatigue, gastrointestinal disease, anemia, and eventually death. Arsenic is linked to numerous types of cancers and birth defects.

Hazardous Air Pollutants

Hazardous air pollutants (HAPs) are those pollutants that cause cancer, birth defects, mutation, or that are neurotoxic, immunotoxic, or endocrine disrupters. The EPA requires that companies relay to the public their Toxic Release Inventory, a record of any toxic materials released over the minimum amount in a year.

Noise Pollution

Noise pollution is any unwanted or undesirable anthropogenically created sound. Noise pollution increases aggression and blood pressure. Examples of noise pollution would be congested traffic, loud music, or airport traffic. Chronic exposure to loud sound may induce deafness. Noise pollution not only reduces the quality of life for human beings, but it may interfere with animal behavior such as migration, courtships, or circadian rhythms.

Geography Can Exacerbate Air Pollution

Geography plays an important role in the impact of air pollution. Temperature inversions typically occur in a valley. The air closest to the ground, filled with pollutants, is prevented from rising by a layer of colder air. The pollutants thus remain concentrated, and the human health impacts of the pollutants are far greater. Examples of cities that suffer from temperature inversions are Mexico City and Los Angeles, both surrounded by mountains. Photochemical smog becomes worse throughout the day as more NO_x and VOCs are added through vehicle traffic and industrial processes. The pollutants cannot escape due to the night cap of cool air and become worse over time.

Cities also create urban heat islands, due to the lack of cooling green vegetation and the microclimate that the vegetation creates. The heat is also generated because of increased precipitation runoff due to lack of permeable surfaces. The heat holds in pollutants, particularly dust and particulates, creating dust domes.

Air pollutants from one area can enter atmospheric circulation and fall in the convection cells in anther area. Therefore many air pollutants tend to be regional pollutants, not simply local pollutants.

Indoor Air Pollutants

Indoor air pollution is created partially because of inadequate ventilation. Pollution indoors may be exacerbated by high temperatures and humidity. The leading indoor air pollutant is environmental tobacco smoke (ETS). In developing countries that use wood smoke to heat homes and cook food, indoor air pollution is high. The pollutants include carbon monoxide, particulates, and other toxins. The World Health Organization estimates that 2.5 billion people are negatively affected by this smoke in a year.

Radon

Radon is a colorless, tasteless, radioactive gas naturally produced by the radioactive decay of uranium in bedrock. Radon accumulates in buildings with basements and buildings with slab foundations. Energy-efficient homes, which lack leaks, tend to have a greater risk of radon exposure. Increasing ventilation will decrease radon dangers, as will sealing cracks around plumbing, sewage, and gas connections in foundations. Radon is the second leading cause of lung cancer and the leading cause of lung cancer in nonsmokers.

Formaldehyde

Formaldehyde is released from building materials such as plywood, pressboard, textiles, furniture stuffing, and carpets. The human health effects of formaldehyde include dizziness, rashes, breathing problems, headaches, and nausea. To prevent formaldehyde exposure, other materials can be used in a building. For example, tile may be used instead of carpeting. Building materials and furniture can also be purchased that do not contain formaldehyde. Improved ventilation will also decrease exposure to formaldehyde.

Environmental Tobacco Smoke

Cigarette smoking is the leading cause of lung cancer, and exposure to secondhand smoke is the third leading cause of lung cancer, behind radon exposure. Cigarette smoking is also blamed for deaths from heart attacks, strokes, and other diseases induced by inhalation of the chemicals in environmental tobacco smoke (ETS). Banning smoking inside has resulted in a decrease in deaths due to secondhand smoke.

Asbestos

Asbestos is a naturally occurring fiber used because of its fire-retardant nature. It was used in insulation, ceiling tiles, roofing, and brake lining in automobiles. Once it was realized that asbestos induced the chronic lung disease asbestosis, lung cancer, and mesothelioma (a rare, fatal cancer), the EPA began to regulate its use, and it was phased out of use by 1997. The first response to asbestos in buildings was to remove it, which is more dangerous than leaving it in place. Only damaged, torn

asbestos materials are dangerous because the small fibers separate and can be easily inhaled. Current asbestos policies are to leave the asbestos in place if it is intact or to seal it behind another material. If it has to be removed, only qualified individuals should be allowed to remove the asbestos.

Sick Building Syndrome

A sick building is a building in which deleterious health effects are linked to being in the building. These health effects include headache, eye and throat irritation, cough, dizziness, nausea, and fatigue. These symptoms improve once an individual leaves the building. A building is defined as sick if 20 percent of the occupants experience symptoms in the building but recover once they leave the building. Sick buildings are linked to inadequate ventilation, new buildings that contain chemicals such as formaldehyde from building products, or biological contaminants like mold or pollen.

Ozone Depletion

The ozone layer is present in the stratosphere. It is created when lightning causes oxygen gas to break into oxygen radicals ($O^{\cdot}$). These radicals are unstable and bind with oxygen gas (O_2) to form ozone (O_3). The thinning of the ozone layer was first observed over Antarctica in September and October of 1985. In 1974 Mario Molina and Sherwood Rowland had demonstrated that chlorofluorocarbons (CFCs) had the ability to rise into the stratosphere where sunlight causes them to break down, releasing the $Cl^{\cdot}$, which reacts with ozone, converting it into oxygen. They, along with Paul Crutzen, were awarded the Nobel Prize for Chemistry in 1995 for their research.

CFCs were widely used as refrigerants (Freon), coolants, and propellants. Halons is used in fire extinguishers, and carbon tetrachloride and methyl chloroform are used in a variety of industrial processes. Methyl bromide is used as a crop fumigant. The halons and methyl bromide release $Br^{\cdot}$, even more damaging to ozone than $Cl^{\cdot}$. Once it was realized the impact that ozone depletion was having, an international meeting occurred in Montreal in 1987. The meeting is now called the Montreal Protocol. It was agreed that nations cease the use of CFCs by the year 2000, although they later moved the date up to 1996 because viable alternative chemicals were available. The primary substitutes used are hydrochloroflourocarbons, which release less chlorine per molecule.

Human health effects of ozone depletion include increased cataracts, weakened immune systems, and greater incidence of skin cancers. Sensitive aquatic species also suffer from the increased UV radiation that now strikes earth. Intense UV radiation also damages plant tissues, resulting in reduced crop productivity and biomass in natural systems.

Acid Deposition

Acid deposition results from the deposition of the secondary air pollutants sulfuric, nitric, and carbonic acids. Sulfuric acid is responsible for about two-thirds of the acid deposition damage in the world and nitric acid the remaining one-third. In urban areas where NO_x are released by the numerous vehicles, the damage from each type of acid is nearly equal. The deposition may be rain, snow, fog, or dry deposition. Normal unpolluted rain has a pH of about 5.6 due to the natural levels of CO_2 in the air that create carbonic acid. Most acid deposition in the United States has a pH of

about 4.3. Ecosystems based upon carbonate rocks have the ability to buffer the impact of the acids. The pH does not dramatically change in these ecosystems. Ecosystems present on igneous rock lack buffering ability and are far more susceptible to ecosystem acidification.

Vegetation is impacted by acid deposition. Acid directly damages cuticles (the waxy coat on leaves) on plant leaves, which makes the plants more susceptible to infections from bacteria, nematodes, and fungi. As a result, not only are forests damaged, but crop yields are reduced in acidified ecosystems. Forest damage is exemplified by the devastation in the Great Smokey Mountains in the United States and the Black Forest in Europe. Acid increases aluminum solubility and thus its toxicity, while leaching the important plant nutrients magnesium and calcium.

Acid deposition lowers the pH in aquatic systems and results in stress in sensitive organisms. The eggs and juveniles of sensitive species are susceptible to a pH of 5, thus interfering with reproduction. The acids therefore decrease biodiversity by reducing food available at lower trophic levels, which may have a resultant reduction of biomass. Sensitive fish species include game fish such as trout and salmon. Trash fish species, such as gar and carp, are more pollution tolerant.

Acid deposition also has an aesthetic impact on human structures. Buildings and statues made of carbonate rock sensitive to chemical weathering, such as limestone and marble, are etched and deeply damaged by years of acid deposition. Steel is corroded by exposure to these acids, as are paints and rubber.

Prevention of Air Pollution

The easiest way to prevent air pollution is to reduce the need for fossil fuels to be burned. Improving the efficiency of automobiles uses less gasoline. Efficiency can also be increased in home appliances, such as air conditioners, washing machines, dryers, and electrical heaters. Homes may also have more insulation and employ solar heating or cooling methods to decrease fossil fuel combustion. If a combustion energy source is required, natural gas is preferred over coal or oil because it releases less air pollution per unit of energy. Alternative energies, such as hydroelectric, geothermal, solar, and wind power may be used to alleviate air pollution. These mechanisms reduce all air pollutants.

Many pollution control strategies are dependent upon the pollutant. For example, sulfur dioxide may be reduced precombustion, during combustion, and postcombustion. Precombustion methods include using a higher grade of coal (anthracite) and washing the coal to remove excess sulfur. Coal may also be converted into a gas or oil, which removes the sulfur. A combustion method of removing sulfur from coal emissions is using fluidized bed combustion. Fluidized bed combustion is carried out by burning the crushed coal with crushed limestone. The sulfur in the coal combines with the calcium in the limestone to form calcium sulfate, or gypsum. This bottom ash can then be disposed of in a proper fashion. Postcombustion methods include using catalytic converters to oxidize the sulfur to yield sulfur compounds. A lime scrubber in a smokestack may also be used. In a wet scrubber, a slurry of lime mixed with water is sprayed across the exiting gases. The sulfur mixes with the calcium, forming the calcium sulfate, which falls to the bottom of the smokestack as bottom ash.

Particulates can be removed from coal combustion by burning coal that has been washed to decrease the ash content. Most particulate removal is postcombustion. The resultant particle mixture must often be discarded in a hazardous waste landfill. Bag filters are a series of bags, somewhat like a bag in vacuum cleaner, which catch the particulates as they rise in the smoke. The bags are periodically emptied of their ash. Electrostatic precipitators remove 99 percent of the particulates in coal emissions. They function by passing the coal emissions past a series of charged plates, thus charging the particulates, which then bind to an oppositely charged plate. Cyclone collectors create a vortex in a smokestack, causing the particles to collide and fall to the bottom of the stack as bottom ash.

Smog forming pollutants can be controlled in a variety of ways. NO_x can be decreased in any combustion system by controlling the combustion temperature. In automobiles, catalytic converters are used to promote complete combustion, which decreases NO_x, VOCs, and carbon monoxide. Many newer cars have systems that retrieve VOCs from the automobile engine and return them to the engine combustion chamber. This system is called a positive crankcase ventilation (PCV) system. One problem with reducing NO_x is that when you minimize their emissions, you tend to have an increase in VOCs. Therefore a balance is usually struck to minimize both as much as possible.

Legislation

The main legislation that controls air pollution is the Clean Air Act of 1963. It was dramatically amended in 1970 and 1990. The original act was designed to assist states in decreasing air pollution. The amendments created the list of criteria air pollutants and set the NAAQS. As needed, the NAAQS are modified by the EPA. For example, regional haze, caused by particulates, is being examined by the EPA. The cap and trade program devised by President Bush is designed to allow utilities not in compliance with EPA NAAQS to buy, sell, or trade pollution credits for sulfur dioxide, nitrogen dioxide, and particulates. The expense of these credits is a strong incentive to utilities to decrease their emissions to reduce their overall costs.

Developing Countries

As developing countries undergo demographic transition, they use more fossil fuels. These emissions are usually not subject to control because the goal is industrialization. Mexico City is one of the most polluted cities in the world. China has no air pollution controls on its coal burning plants, and thus the particulate, sulfur dioxide, and carbon dioxide emissions are high.

Chapter 16 Questions

Use the following for questions 1–4.

a. mercury
b. ozone
c. formaldehyde
d. carbon dioxide
e. radon

1. may contribute to sick building syndrome
2. biomagnifies in trophic levels
3. is a secondary air pollutant
4. contributes to global warming

Use the following for questions 5–8.

a. CFCs
b. VOCs
c. lead
d. methane
e. nitrogen dioxide

5. contribute(s) to the breakdown of ozone in the stratosphere
6. exposure in young children causes attention deficit, learning, and hyperactivity disorders
7. the majority of this air pollutant arises from natural sources
8. contributes to acid deposition

9. All of the following are criteria air pollutants except
a. lead. b. mercury. c. ozone. d. carbon monoxide. e. nitrogen dioxide.

10. The primary source of carbon dioxide in the atmosphere is
a. deforestation. b. photosynthesis. c. cellular respiration.
d. fossil fuel combustion. e. biomass combustion.

11. Radon exposure causes
a. nausea. b. breathing disorders. c. lung cancer.
d. endocrine disruption. e. attention deficit disorders.

12. Which of the following is correct regarding asbestos?
a. was used as a refrigerant and propellant
b. causes endocrine disorders when humans are exposed to it
c. removal is relatively safe and easy to accomplish
d. causes lung cancers and mesothelioma
e. causes kidney diseases in susceptible people

13. All of the following statements regarding stratospheric ozone are true except
a. ozone rises easily from the troposphere to the stratosphere.
b. ozone is formed when an oxygen radical created by the splitting of oxygen by lightning binds to oxygen gas.
c. chlorine radicals from chlorofluorocarbons cause ozone to break down into oxygen gas.
d. stratospheric ozone absorbs UV radiation.
e. the hole in the stratospheric ozone is easily observed in Antarctica.

14. Which of the following is not a greenhouse gas?
a. N_2O b. CO_2 c. CH_4 d. SO_2 e. H_2O vapor

15. Which of the following rocks are susceptible to damage due to acid deposition?
a. sandstone b. granite c. basalt d. limestone e. slate

16. Sulfur dioxide emissions can be prevented by all of the following except
a. lime scrubbers in a smokestack.
b. switching to bituminous coal or lignite.
c. converting coal into a gas or liquid.
d. fluidized bed combustion.
e. washing the coal prior to use.

17. The automobile component used to lower NO_x emissions is the
a. afterburner. b. bag filter. c. catalytic converter.
d. electrostatic precipitator. e. scrubber.

18. Carbon monoxide
a. is one of the major greenhouse gases.
b. is released from incomplete combustion of biomass or fossil fuels.
c. causes lung cancer.
d. directly damages plant tissues.
e. causes increased crop yields.

19. All of the following lower particulate emissions except
a. lime scrubber. b. bag filters. c. electrostatic precipitators.
d. cyclone collectors. e. fluidized bed combustion.

20. Mercury
a. bioaccumulates in bone.
b. is released into the atmosphere by gasoline combustion.
c. is converted into its most toxic form by bacteria.
d. causes lung cancer in individuals exposed to the metal.
e. is directly harmful to plants