

## 16.15: Exercises

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*Access to and use of the internet is assumed in answering some of the questions. Some questions are designed to promote inquiry and thought rather than just finding material in the text. So in some cases there may be several “right” answers. Therefore, if your answer reflects intellectual effort and a search for information from available sources, your answer can be considered to be “right.”*

### 16.1: Chemistry is Good...and Unavoidable

1. What is the definition of green chemistry?

**Answer**

The practice of chemistry in a manner that maximizes its benefits while eliminating, or at least greatly reducing, its adverse impacts.

### 16.2: Chemistry and the Environment

2. What is the definition of the environment?

**Answer**

Our surroundings which affect us and which we may affect.

3. What are the five spheres of the environment? What is each sphere comprised of?

**Answer**

Atmosphere: atmospheric gases within a few kilometers of sea level

Hydrosphere: Earth's water

Geosphere: all rocks and minerals

Biosphere: all living organisms

Anthrosphere: the part of the environment made and operated by humans

4. What is the definition of environmental chemistry?

**Answer**

The branch of chemistry that studies the sources, reactions, transport, effects, and fates of chemical species in water, soil, air, and living environments and the effects of technology on them.

5. What are the categories of environmental chemistry that correspond to each of the five spheres of the environment?

**Answer**

Atmospheric chemistry, aquatic chemistry, geochemistry, environmental biochemistry, and industrial ecology

### 16.3: The Air We Breathe

6. In what respect are elemental nitrogen and oxygen green elements?

**Answer**

They are naturally present in the atmosphere in large quantities.

7. Why is there essentially no atmospheric chemistry involving elemental nitrogen gas in the atmosphere?

**Answer**

Nitrogen is very stable and has a low reactivity. It can absorb excess energy from atmospheric chemical reactions.

8. Cite an atmospheric chemical condition or phenomenon that shows that the  $O_2$  molecule is easier to break apart than the  $N_2$  molecule.

**Answer**

It will react with sulfur dioxide and pollutant hydrocarbons through a hydroxyl radical. It is involved in making stratospheric ozone. It is consumed in burning hydrocarbons and chemical weathering of minerals.

### 16.4: Air Pollution

9. What is the definition of air pollution?

**Answer**

The introduction into the atmosphere of substances that have harmful effects on humans, other living organisms, and the environment.

10. What are two types of pollutants? Where do they come from?

**Answer**

Primary pollutants are released directly from the source into the air. Secondary pollutants are produced through reactions between primary pollutants and normal atmospheric compounds.

11. What are the two types of standards used to set limits for air pollutants? What is each of them based on?

**Answer**

Primary standards based on human health and secondary standards based on environmental and property damage

12. What are the six criteria pollutants monitored by the EPA?

**Answer**

Carbon monoxide, ground-level ozone, nitrogen dioxide, sulfur dioxide, lead, and particulate matter

13. Which of the six criteria pollutants is a secondary pollutant?

**Answer**

## Ground-level ozone

14. Suggest why lead has become less of a problem as an atmospheric pollutant in recent years.

**Answer**

It is no longer allowed to be in gasoline.

15. What are two types of particulate material?

**Answer**

Coarse particles (2.5 to 10 micrometers) and fine particles (up to 2.5 micrometers)

16. Why are very small particles especially dangerous to breathe?

**Answer**

They are small enough to pass through the throat and nose and enter the lungs and possibly the blood.

17. What are some natural and human-made sources of volatile organic compounds?

**Answer**

Natural sources include plants and gut bacteria. Human-made sources paints, varnishes, cleaning agents, and fuels.

18. What is the major health effect of carbon monoxide?

**Answer**

It reduces the amount of oxygen that reaches the body's organs and tissues.

19. What are two classifications of outdoor pollutants? How do they differ?

**Answer**

Mobile and stationary sources. They differ in mobility. Mobile sources move from place to place such as cars. Stationary sources are in a fixed location such as a power plant.

20. What are two types of stationary sources? How do they differ?

**Answer**

Point sources and nonpoint sources. They differ in size. Point sources are larger emitters such as an industrial facility. Nonpoint sources are abundant and small such as individual homes in a community.

21. What is exhaust gas? What types of pollutants does it contain?

**Answer**

Exhaust gas is emitted as a result of combustion of fuels. As such, it will contain CO, NO<sub>x</sub>, and possibly SO<sub>2</sub>. It can include unreacted fuel vapors or particulate matter.

22. Based on [Figure 16.4.3](#), rank the different pollutants emitted in 2017 from greatest to least.

**Answer**

CO > VOC > NO<sub>x</sub> > NH<sub>3</sub> > PM<sub>10</sub> > SO<sub>2</sub> > PM<sub>2.5</sub>

23. Based on [Figure 16.4.3](#), what is the largest anthropogenic source of each pollutant?

**Answer**

CO: highway vehicles

NH<sub>3</sub>: industrial and other processes

NO<sub>x</sub>: stationary fuel combustion and highway vehicles

PM<sub>2.5</sub>: stationary fuel combustion and industrial and other processes

PM<sub>10</sub>: industrial and other processes

SO<sub>2</sub>: stationary fuel combustion

VOC: industrial and other processes

24. What is an example of a stationary fuel combustion source?

**Answer**

Coal-burning power plant

## 16.5: Photochemical Smog

25. What are the ingredients and conditions leading to the formation of photochemical smog?

**Answer**

The ingredients are nitrogen oxides from combustion products, oxygen gas in the atmosphere, and VOCs. The conditions necessary are dry, stagnant air that allows the gases to accumulate and provides UV light to initiate the reactions.

26. What is an important health effect of nitrogen dioxide? Why is it particularly important in atmospheric chemistry?

**Answer**

It aggravates respiratory diseases. It is important in atmospheric chemistry as it is a precursor and intermediate in the formation of photochemical smog.

27. What substances are found in a smoggy atmosphere?

**Answer**

Ozone is the main component. Oxygen-rich organic compounds. Nitrogen oxides. VOCs.

28. What are some harmful effects of smog?

**Answer**

Difficulty in breathing and irritation to eyes and respiratory tract. Damage to plants and materials attacked by oxidants. The formation of visibility-reducing atmospheric particles.

29. What is a serious air pollution phenomenon resulting from an atmospheric reaction of sulfur dioxide?

**Answer**

Industrial smog

30. What are the major constituents of industrial smog?

**Answer**

Soot, fly ash, sulfur dioxide, sodium chloride, and calcium sulfate particles

31. What is a secondary environmental problem that can arise from industrial smog?

**Answer**

Formation of acid rain

32. What is a method used to separate sulfur dioxide from furnace stack gas?

**Answer**

Scrubbers that react  $\text{SO}_2$  with  $\text{CaO}$  to produce a solid precipitate that is collected

## 16.6: Clean Air

33. What are two major classes of atmospheric particles, or aerosols, based upon how they are produced?

**Answer**

Dispersion aerosols formed by grinding solids and dispersing dusts; condensation aerosols formed by the condensation of gases or vapors

34. List five means of controlling particle emissions.

**Answer**

Sedimentation, inertial mechanisms, baghouses, scrubbers, and electrostatic precipitators

35. What have been some of the effects of the Clean Air Acts on pollutant levels? What have been some benefits experienced in the US over the same time? You may wish to reference [Figure 16.6.2](#) and [Figure 16.6.3](#).

**Answer**

Answers can include percent declines for different pollutants, steady energy consumption, and increases in vehicular travel and GDP.

36. What are some of the ways that green chemistry can help prevent air pollution?

**Answer**

Answers can include scrubbers to eliminate SO<sub>2</sub> emissions, catalytic converters to minimize nitrogen oxides, limiting release of VOCs, reformulating gasoline to allow for better combustion, etc.

## 16.7: Global Warming

37. What is the definition of global warming?

**Answer**

The increase in the average temperature of the Earth's atmosphere due to elevated greenhouse gas concentrations.

38. What is the definition of climate change? How does it differ from global warming?

**Answer**

It includes global warming and the resulting large-scale shifts in weather patterns. It differs in that it looks at the effects of the increased temperatures on other areas of the Earth (like the weather).

39. What chemical species in the stratosphere is essential for life on Earth? Why is it important?

**Answer**

Ozone. It blocks UV light which would cause severe damage to biological species.

40. In what respect does the radiation by which Earth loses energy differ from that by which it gets energy from the sun?

**Answer**

The Earth gets its energy from the sun as UV and visible light. It radiates it back to the atmosphere as infrared radiation (heat).

41. What is the definition of albedo? What types of surfaces have beneficial albedos?

**Answer**

Albedo is the percentage of radiation that is reflected off of the Earth's surface and thus is less effective in warming the surface. Beneficial albedos have high percentages and lighter colors such as snow grass. Poor albedos have lower percentages and are darker colors such as dirt and asphalt.

42. What are two catastrophic events that could cause a sudden cooling of Earth's atmosphere?

**Answer**

Volcanic eruptions and asteroid hits

43. In what respect is atmospheric carbon dioxide essential to life on Earth? Why may it end up being the "ultimate air pollutant"?

**Answer**

It is needed to provide the blanket which allows the Earth to be warm enough for life to exist. However, it is being produced in levels that is leading to temperature levels that will upset the balance of processes on Earth.

44. What is a greenhouse gas other than carbon dioxide that is produced by microorganisms?

**Answer**

Methane, and to a lesser extent nitrous oxide.

45. Rank the greenhouse gases from the greatest global warming potential to least.

**Answer**

Fluorinated gases ( $\text{SF}_6 > \text{HFCs} > \text{PFCs}$ )  $> \text{N}_2\text{O} > \text{CH}_4 > \text{CO}_2$

46. Based on the information in [Figure 16.7.5](#), which areas of the US have had the greatest rate of temperature change over the last century? Why do you think that is? Why has the US warmed at a faster rate than the global rate since the late 1970s?

**Answer**

Areas of greatest rate include the west, Florida, the Northeast and upper Midwest. Reasons will vary but could include increased manufacturing and weather patterns.

## 16.8: Climate Change: Effects of Global Warming

47. Distinguish between the terms weather and climate.

**Answer**

Weather is short term variations in the state of the atmosphere as seen in temperatures, cloud cover, precipitation, humidity, atmospheric pressure, and wind. Climate looks at long-term trends over the whole of Earth's surface.

48. How is water vapor involved in moving energy through the atmosphere?

**Answer**

Water absorbs significant amounts of heat energy as it evaporates. This gaseous water can then move the energy to other parts of the Earth and condense to form rain. As it condenses, it releases the energy as heat to warm the area where the rain falls.

49. What are some of the more harmful effects projected if global warming occurs to a significant extent?

**Answer**

Increased temperatures in many areas, changes in precipitation which can affect water availability, rising sea levels, and ocean acidification.

50. Based on the information in [Figure 16.8.1](#), which season is most responsible for the increase in temperature in the upper Midwest? How is this manifested during the season?

**Answer**

Winter has the biggest increase in temperature. This is seen in fewer record lows, later fall frost and earlier last spring frost.

51. Based on the information in [Figure 16.8.2](#), which areas of the US are expected to have an increase in precipitation? Which are expected to have a decrease in precipitation? What types of challenges could these changes cause economically?

**Answer**

Increases in precipitation are expected on the East Coast. Decreases are expected in the South, the lower Midwest, and the West Coast. Increased precipitation can affect manufacturing and infrastructure. Decreased precipitation can affect water availability, both for drinking and for agriculture which are prevalent in the lower Midwest and California.

52. What are two factors related to global warming which are causing the sea levels to rise?

**Answer**

Increased temperatures are causing land ice to melt and runoff to oceans. Increased temperatures also cause water to expand and take up a greater volume.

53. Based on the information in [Figure 16.8.6](#), what is the main type of land that has been affected by sea level rise? Why is the loss of this type of land particularly harmful in the face of changing weather patterns?

**Answer**

Wetlands. Wetlands provide buffers to flooding which results from increased precipitation or hurricanes. They are also a habitat for many species of plants and animals.

## 16.9: Climate Mitigation Strategies

54. How do adaptation strategies work?

**Answer**

They provide ways to deal with changing environments. Examples would be conservation of water or improved methods of water purification.

55. How can green chemistry be used to implement adaptation strategies for dealing with climate change?

**Answer**

Answers can vary but may include development of fertilizers and crops that will grow under drought conditions or with saline water.

56. What contributed to the increased use of coal in the early 1800s?

**Answer**

The invention of the steam engine.

57. Describe a combined power cycle. How may it be tied with district heating?

**Answer**

A combined power cycle uses waste heat energy from a primary electricity generator (like coal or gas combustion) to generate additional electricity by heating water and using the steam in a steam turbine. The steam can then be used to heat buildings in the vicinity before returning to the boiler for reheating.



58. What are two major problems with reliance upon coal and petroleum for energy?

**Answer**

They generate substantial amounts of greenhouse gases and are not renewable energy sources.

59. Cite two examples of vastly increased efficiency of energy utilization that took place during the 1900s.

**Answer**

Increased automobile fuel economy as a result of the energy crisis in the 1970s and improved efficiency of engines in general. Combined power cycles.

60. What is the biggest problem with nuclear energy?

**Answer**

High-level nuclear wastes which last for centuries

61. Describe two ways to use solar energy.

**Answer**

Heating and converting to electricity with photovoltaic cells

62. Using internet resources for information, list some possible means for storing energy generated from solar radiation?

**Answer**

Answers will vary but may include a variety of storage batteries.

63. In what respects is wind both one of the oldest, as well as one of the newest, sources of energy?

**Answer**

Wind has been used for centuries for sailing and windmills. They are new based on technologically advanced wind turbines.

64. Why does the burning of biomass not contribute to an increase in greenhouse gases?

**Answer**

The carbon dioxide released during the burning is the same carbon dioxide that was captured during the biomass growth. Thus, there is a net zero change in the amount of carbon dioxide over time.

65. What are concerns in growing biomass for fuel? How can these concerns be addressed?

**Answer**

Not enough can be grown and its use as fuel will mean a food shortage. Only a small amount of the widely grown grain crops goes to food. A lot of the waste can be used for energy production. Biomass can be used which is not a food source. Cultivation of less than 10% of the land area of the US would be sufficient to provide for energy needs.

66. What are benefits of using biomass for energy and electricity generation?

**Answer**

Burning does not lead to global warming. Can use perennial plants to prevent erosion.

67. How can technology and green chemistry be used to mitigate climate change?

**Answer**

Carbon dioxide can be injected deep into the ground to capture it and prevent it from entering the atmosphere. Unreacted coal can be converted to carbon dioxide (which can be sequestered) and hydrogen gas which is a clean fuel. New compounds can be developed which do not lead to greenhouse gases.

68. Go to the [EPA's Carbon Footprint Calculator](#). What is your carbon footprint? What are ways that you can minimize this footprint?

**Answer**

Answers will vary.

## 16.10: Water

69. What are some special properties of water related to its polarity and hydrogen bonding?

**Answer**

High heat capacity, high latent heat of fusion, high heat of vaporization, excellent solvent for ionic compounds, and high surface tension

70. Where is most of the freshwater on the Earth located?

**Answer**

Snowpack, ice and glaciers

71. What is an aquifer?

**Answer**

A body of rock which contains appreciable quantities of water

72. What are desirable properties of an aquifer that is used for water wells?

**Answer**

High permeability and high porosity

73. What is a watershed?

**Answer**

Areas of land upon which precipitation falls to provide flows of surface water

74. What is desalination? What are benefits and drawbacks to using desalination to provide potable water?

**Answer**

Desalination is a means of removing salt from sea water to make it potable. It is often done by reverse osmosis. Benefits are that it provides potable water, especially in areas near seas and oceans. Drawbacks are the expense of purification.

75. What are some minerals which are present in natural water?

**Answer**

Calcium carbonate from calcite and aragonite, magnesium salts

76. What makes water hard?

**Answer**

The presence of dissolved minerals resulting in the presence of metal cations, especially  $\text{Ca}^{2+}$  and  $\text{Mg}^{2+}$ .

77. What are some drawbacks of using hard water?

**Answer**

Minerals present in hard water can affect color and taste. Mineral deposits in pipes and heaters, lowering efficiency. Soap is less effective and scum can form.

78. Look up proposals to restore the Hetch-Hetchy Valley in Yosemite National Park to its former state. How might this affect water supply to parts of California? What might be some benefits of restoration of this valley to its former state?

**Answer**

Answers will vary.

79. Look up and explain the significance of the name Mulholland in relationship to water. How did Mulholland affect history?

**Answer**

Mulholland was a civil engineer who designed the water system for LA. Answers will vary.

### 16.11: Groundwater Contamination

80. According to the WHO, how many people lived in water-stressed communities in 2020?

**Answer**

2 billion

81. What is water pollution?

**Answer**

The contamination of water by an excess amount of a substance that can cause harm to human beings and/or the ecosystem.

82. What are examples of point sources of water pollution? What are examples of nonpoint sources of water pollution?

**Answer**

Point sources are small locations such as farms or pipes from factories or sewage treatment plants. Nonpoint sources are large and more diffuse areas such as agricultural runoff.

83. What are sources of biochemical oxygen demand as pollutants?

**Answer**

Sewage, food wastes, and fertilizer runoff

84. How does BOD act as a pollutant?

**Answer**

BOD removes oxygen from the water which kills fish and aquatic insects.

85. Why do some cities have fountains in the middle of ponds or small lakes?

**Answer**

The fountains agitate the water allowing for more contact with oxygen in the air and increasing its concentration in the water.

86. Tests can be performed on water that show the presence of biochemical demand (BOD) and other tests that react with organic matter to produce CO<sub>2</sub> can show total organic carbon (TOC). Applied to a particular sample of water, these two tests showed relatively high TOC and relatively low BOD. What does this say about the nature of the organic pollutants in the water?

**Answer**

The organic pollutants are probably industrial chemicals which are not easily broken down by microbes utilizing oxygen.

87. Agricultural fertilizer normally adds nitrogen, phosphorus, and potassium to soil. Explain how fertilizer runoff into a body of water can lead eventually to increased biochemical oxygen demand pollution.

**Answer**

The fertilizer causes rapid growth of aquatic plants like algae. When the algae dies, it becomes a source of oxygen-demanding waste.

88. How do pharmaceuticals and personal care products enter groundwater and surface water?

**Answer**

They are excreted by patients and enter the waste water which then leaks into the groundwater. Some pharmaceuticals are improperly disposed of by manufacturers and consumers and it will runoff into groundwater.

89. Why are pharmaceuticals in groundwater an area of concern?

**Answer**

Low levels may affect the life cycles and reproductive cycles of various fish and aquatic organisms. Pollutants can become concentrated in larger species as various smaller ones are consumed.

90. By doing some search on the internet, gather information regarding the use of wastewater for irrigation. Is this a practice that is used and if so where does it usually take place? What are some of the benefits? What are some of the risks?

**Answer**

Answers will vary.

### 16.12: Water Purification

91. How does water softening work? What are ways it can be accomplished on large and small scales?

**Answer**

Water softening replaces "hard" ions such as  $\text{Ca}^{2+}$  and  $\text{Mg}^{2+}$  with "soft" ions like  $\text{Na}^+$ . The  $\text{Na}^+$  does not precipitate out of the water as easily and so the effects of hard water are reduced. Large scale softening can be accomplished with lime-soda softening. Small scale softening is done with water softeners.

92. Membrane filtration processes can be very effective in removing residual BOD from secondary wastewater effluent. What does this suggest regarding the nature of contaminants responsible for the BOD?

**Answer**

The contaminants are large enough to be contained by the membranes. Thus they are suspended solids and not dissolved solids.

93. Phosphate in the form of  $\text{H}_2\text{PO}_4^-$  and  $\text{HPO}_4^{2-}$  ions is the substance usually removed from secondary sewage effluent to prevent excessive algal growth and eutrophication in receiving waters. Of several possible algal nutrients, why is phosphate chosen? Show with a chemical reaction the most common means of removal.

**Answer**

Phosphates tend to make insoluble solids. Thus it is relatively easy to precipitate the various phosphates out of the waste water.

### 16.13: Acid Rain

94. What is acid rain?

**Answer**

A mixture of wet and dry deposited material from the atmosphere with higher than normal amounts of nitric and sulfuric acids.

95. What is the typical pH of acid rain in the US?

**Answer**

Between 4.2 and 4.4.

96. What are five adverse effects from acid rain and its precursors?

**Answer**

Acidification of lakes and streams

Damage of trees and sensitive forest soils

Accelerates the decay of building materials and paints

Visibility degradation

Harmful to public health

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