ANSWERS TO END-OF-CHAPTER QUESTIONS

CHAPTER 3: Radiation from the Sun

Emphasizing Essentials

1. Answer:

The chemical formulas of ozone and oxygen are O_3 and O_2, respectively. Both are gases, but they differ in their properties. Oxygen has no odor; ozone has a very sharp odor. Although both are reactive, ozone is much more highly so. Oxygen is necessary for many forms of life; in contrast, ozone is a harmful air pollutant in the troposphere. However, ozone in the stratosphere helps to protect us from the harmful ultraviolet rays of the sun.

2. Answer:

a. Yes, this is over the detection minimum of 10 ppb.

$$\frac{0.118 \text{ parts } O_3}{1{,}000{,}000 \text{ parts air}} = \frac{118 \text{ parts } O_3}{1{,}000{,}000{,}000 \text{ parts air}} \text{ or 118 ppb}$$

b. Yes, this is well over the detection minimum of 10 ppb.

$$\frac{25 \text{ parts } O_3}{1{,}000{,}000 \text{ parts air}} = \frac{25{,}000 \text{ parts } O_3}{1{,}000{,}000{,}000 \text{ parts air}} \text{ or 25,000 ppb}$$

3. **Answer:**

a. The size of the ozone "hole" varies each year, but has been estimated to be as large as 28 million km^2 in area.

b. $$10 \text{ miles} \times \frac{\text{km}}{0.621 \text{ miles}} = 16.1 \text{ km}$$

Yes, the figure is correct, as the stratosphere extends between 15 and 30 km above the Earth's surface.

c. Ozone absorbs UV-B and UV-C radiation.

4. **Answer:**

The term *ozone layer*, while in widespread use, brings to mind an incorrect image of a blanket-like layer. In fact, even in the stratospheric region of highest concentration, ozone's concentration is typically less than 1 ppm and is not even the most abundant species in that region. The ozone does not completely block all UV radiation, such as a blanket might block all visible light. The ozone that is present, however, serves the essential function of absorbing some wavelengths of UV-B and reducing its intensity before it reaches the surface of the Earth, making the screen analogy more useful.

5. Answer:

The air in the troposphere is simply denser than the stratosphere; the number of atoms and compounds in a given volume will be far higher. Also, the troposphere has a lower concentration of the gases like oxygen and ozone than the stratosphere. These gases are formed in the stratosphere and too reactive to mix downward. The opposite is also true, many gases formed in the troposphere, such as the NO_X or SO_X described in Chapter 2, are not common in the stratosphere.

6. Answer:

a. The Dobson unit (or DU) measures the ozone in a column above a specific location on Earth. If this ozone were compressed at specified conditions of temperature and pressure, it would form a layer. A layer 3 mm thick corresponds to 300 DU. Similarly, a 1 mm layer corresponds to 100 DU.

b. 320 DU > 275 DU Thus, 320 DU indicates more total ozone overhead.

7. Answer:

a. A neutral atom of oxygen has 8 protons and 8 electrons.
b. A neutral atom of nitrogen has 7 protons and 7 electrons.
c. A neutral atom of magnesium has 12 protons and 12 electrons
d. A neutral atom of sulfur has 16 protons and 16 electrons

8. **Answer:**

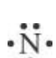
a. Group 2A
b. beryllium, Be; magnesium, Mg; calcium, Ca; strontium, Sr; barium, Ba; radium, Ra
c. Be 4, Mg 12, Ca 20, Sr 38, Ba 56, Ra 88.
d. Each element in Group 2A has 2 outer electrons.

9. Answer:

a. helium, He
b. potassium, K
c. copper, Cu

10. Answer:

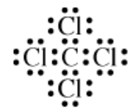
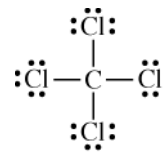
a. 

b. 

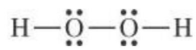
c. 

d. 

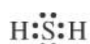
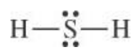
11. Answer:

a. There are 4 + 4(7) = 32 outer electrons  or 

b. There are 2(1) + 2(6) = 14 outer electrons. The Lewis structure is:

 or 

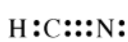
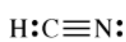
c. There are 2(1) + 6 = 8 outer electrons. The Lewis structure is:

 or 

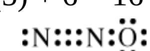
d. There are 2(5) = 10 outer electrons. The Lewis structure is:

 or 

e. There are 1 + 4 + 5 = 10 outer electrons. The Lewis structure is:

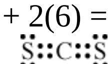
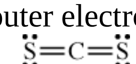
 or 

f. There are 2(5) + 6 = 16 outer electrons. One possible Lewis structure is:

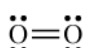
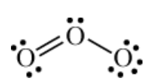
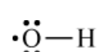
 or 

Other resonance structures are possible for N_2O as well.

g. There are 4 + 2(6) = 16 outer electrons. The Lewis structure is:

 or 

12. Answer:

The Lewis structures for the oxygen molecule and the ozone molecule both follow the octet rule. In contrast, the oxygen atom has only 6 outer electrons and does not follow the octet rule. The hydroxyl radical also does not follow the octet rule and has an unpaired electron. Another resonance structure for the ozone molecule may be drawn; the other molecules do not have resonance structures.

13. Answer:

a. Wave 1 has a longer wavelength than wave 2.
b. Wave 1 has a lower frequency than wave 2.
c. Both waves travel at the same speed.

14. Answer:

a. This wavelength is in the microwave region of the spectrum.
b. This wavelength is in the range of violet light in the visible region.
c. This wavelength is in the infrared region of the spectrum.
d. This wavelength is in the UHF/microwave region of the spectrum.

15. Answer:

Colors of visible light differ in their energy, frequency, and wavelength. Orange light is lower in energy, lower in frequency, and longer in wavelength than violet light.

16. Answer:

Note: $c = 3.0 \times 10^8$ m·s^{-1} and $E = h \cdot v$, in which $h = 6.63 \times 10^{-34}$ J·s.

a. $E = (6.63 \times 10^{-34}\ \text{J·s})(1.5 \times 10^{10}\ \text{s}^{-1}) = 1.0 \times 10^{-24}$ J
b. $E = (6.63 \times 10^{-34}\ \text{J·s})(8 \times 10^{14}\ \text{s}^{-1}) = 5 \times 10^{-19}$ J
c. $E = (6.63 \times 10^{-34}\ \text{J·s})(6 \times 10^{12}\ \text{s}^{-1}) = 4 \times 10^{-21}$ J
d. $E = (6.63 \times 10^{-34}\ \text{J·s})(2.0 \times 10^{9}\ \text{s}^{-1}) = 1.3 \times 10^{-24}$ J

The most energetic photon corresponds to the shortest wavelength, 400 nm.

17. **Answer:**

Yes, the speed of light in a vacuum is a constant.

18. Answer:

In order of increasing energy per photon: radiowaves < infrared < visible < gamma rays

19. Answer:

$$c = v \cdot \lambda \text{ and } \lambda = \frac{c}{v};\ c = 3.0 \times 10^8 \text{ m/s}$$

$$\lambda = \frac{3.0 \times 10^8 \text{ m/s}}{2.45 \times 10^9 \text{ /s}} = 1.2 \times 10^{-1} \text{ m}$$

At 1.2 × 10^{-1} m, this microwave radiation has a longer wavelength (and lower energy) than X-rays (at ~10^{-10} m), but a shorter wavelength (and higher energy) than radio waves
(at ~10^{3} m).

20. **Answer:**

a. In order of increasing wavelength: UV-C < UV-B < UV-A
b. In order of increasing energy: UV-A < UV-B < UV-C
c. In order of increasing potential for biological damage: UV-A < UV-B < UV-C

21. **Answer:**

a. $\boldsymbol{\lambda = \frac{c}{v} = 3.00 \times 10^{8}\ \frac{m}{s} \times \frac{s}{6.79 \times 10^{14}} \times \frac{10^{9}\ nm}{m} = 442\ nm}$

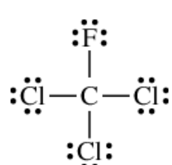
b. $\boldsymbol{\lambda = \frac{c}{v} = 3.00 \times 10^{8}\ \frac{m}{s} \times \frac{s}{4.44 \times 10^{12}} \times \frac{10^{9}\ nm}{m} = 67,600\ nm}$

22. Answer:

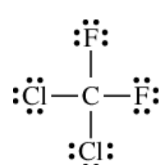
$$1.5 \times 10^{8}\ km \times \frac{1000\ m}{km} \times \frac{s}{3.00 \times 10^{8}\ m} = 500\ seconds$$

23. **Answer:**

Answers will vary. To qualify as CFCs, the compounds should contain only carbon, chlorine, and fluorine. Possibilities include:



CCl_3F
trichlorofluoromethane
Freon 11



CCl_2F_2
dichlorodifluoromethane
Freon 12

24. Answer:

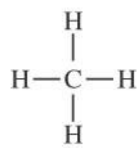
All of these make use of the fact that CFCs are inert non-toxic gases that do not burn. Hair sprays, refrigerators, and air conditioners also make use of property that their boiling points are in a range useful for a refrigerant gas or propellant.

25. **Answer:**

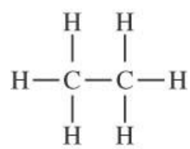
a. No, a CFC molecule can contain only chlorine, fluorine, and carbon atoms.
b. HCFC molecules must contain hydrogen, carbon, fluorine, and chlorine atoms, and no other atoms In order for a molecule to be classified at an HFC, it must contain hydrogen, fluorine, and carbon (but no other atoms).

26. Answer:

a. Methane, CH_4



Ethane, C_2H_6

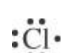


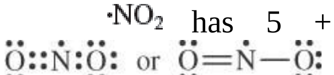
b. Three different CFCs are based on methane. They are: CF_3Cl, CCl_3F, and CCl_2F_2.

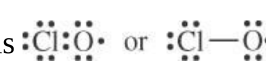
c. The most successful CFCs were $CFCl_3$ and CF_2Cl_2. These Freon® compounds were widely used in the U.S. as refrigerant gases.

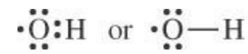
d. Although many compounds are synthesized and tested for appropriate properties, only a few have the boiling points to serve as refrigerant gases.

27. **Answer:**

a.
has 7 outer electrons. Its Lewis structure is 

$\cdot NO_2$ has 5 + 2(6) = 17 outer electrons. Its Lewis structure is 

$ClO\cdot$ has 7 + 6 = 13 outer electrons. Its Lewis structure is 

•OH has 6 + 1 = 7 outer electrons. Its Lewis structure is: 

b. They all contain an unpaired electron.

28. Answer:

a. The original measurements were obtained during flights of NASA's ER-2 research airplanes carrying measuring instruments over the Antarctic region.

b. Today these measurements are usually gathered via instruments in satellites.

29. Answer:

The first graph is a more realistic representation of the relationship between the percent *reduction* in the concentration of ozone and the percent *increase* in UV-B radiation. As the ozone layer is depleted, the concentration of UV-B that can penetrate into the atmosphere rises. The second graph shows a type of inverse relationship, which is not substantiated by experimental facts.

Concentrating on Concepts

30. **Answer:**

The message is that ground-level ozone is a harmful air pollutant. Ozone in the stratosphere, on the other hand, is beneficial because it can absorb harmful UV-B before it reaches the surface of the Earth.

31. Answer:

According to legend, Achilles was a man of mighty strength with one weak point - the heel of his foot. As the story goes, his downfall was caused by an arrow, possibly poisoned, shot to his heel. Similarly, our planet is robust and has great strengths. But it has a weak point – its atmosphere. If you damage the atmosphere, you may cause the downfall of the planet.

32. Answer:

a. The most energetic fraction of solar UV radiation is the UV-C light.

b. Up in the stratosphere where the air is very thin, UV-C splits oxygen molecules, O_2, into two oxygen atoms, O. These in turn react with other oxygen molecules to produce ozone, O_3. See the reactions of the Chapman Cycle. Without the UV-C light (which does not reach the surface of our planet), the ozone layer would not form.

33. Answer:

The solution proposed in the cartoon will not work for several reasons. One is that the amount of ozone required is too large to ship up to the stratosphere (and of course we don't have a series of freight planes heading up there anyhow). More importantly, if the mechanism for ozone destruction remains in place, any new ozone will be destroyed as well.

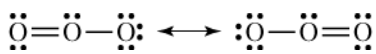
34. Answer:

a. HFCs are being used to replace HCFCs.
b. HFCs are greenhouse gases!

35. **Answer:**

Each Lewis structure has 3 × 6 = 18 electrons, and each oxygen atom has an octet of electrons. The triangular structure is not reasonable because the bond angles (60°) are much smaller than the usual bond angles.

36. Answer:

Here are the resonance structures for ozone: 
Both contain 1 double bond (expected length of 121 pm) and 1 single bond (expected length of 132 pm). But in reality, the bonds are neither single nor double. Rather, the length of each bond is intermediate between the single and double bond lengths. A reasonable prediction would be 126 or 127 pm for both O-to-O bonds, midway between the two lengths.

37. Answer:

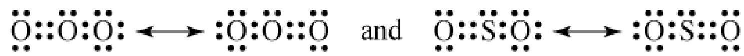
Ozone is very reactive and quickly dissipates in the troposphere. Ozone in the stratosphere is regenerated by UV-C sunlight reacting with oxygen molecules.

38. **Answer:**

The O – O bond in ozone is longer and weaker than the O=O double bond in oxygen gas, so the ozone bond is easier to break.

39. **Answer:**

With respect to valence electron distribution, the Lewis structures of SO_2 and ozone are identical. This should not be surprising, as sulfur and oxygen are in the same group on the periodic table, and thus have the same number of outer electrons. However, the atoms present in the two Lewis structures differ:



40. **Answer:**
The energy of a photon of a radio wave is only about one ten-millionth of the energy of a photon of UV radiation. While UV radiation has sufficient energy to interact with melanin in skin pigments, radio waves do not.

41. **Answer:**
The UV Index, typically a number between 1 and 15, helps people to gauge how intense the sunlight is predicted to be on a particular day. A value of 6.5 (color-coded orange) indicates that there is high risk of harm and that you should protect your eyes and skin. A value of 8-10 indicates a very high risk and above 11 is an extreme risk.

42. Answer:
Although UV-C radiation causes damage to both animals and plants, it is completely absorbed by the O_2 in our atmosphere before it can reach the surface of the Earth.

43. Answer:
Stratospheric ozone is both formed and broken down in a dynamic system called the Chapman Cycle. Unless there are disturbances to this system, the system remains in balance and there is no net change in the concentration of stratospheric ozone.

44. **Answer:**
See the answer to question #24. These compounds are useful because they are colorless, odorless, tasteless and generally inert. However, compounds such as these have long atmospheric lifetimes. They persist in the environment and make their way up to the stratosphere where they cause harm to the ozone layer.

45. **Answer:**
NO in the stratosphere can act as a catalyst for the destruction of ozone. ClO• acts as a catalyst in the series of reactions in which stratospheric O_3 molecules are changed to O_2 molecules.

46. Answer:
Cl• acts as a catalyst in the series of reactions in which stratospheric O_3 molecules react to produce O_2 molecules. As it is not consumed in the reaction, Cl• can continue to catalyze the breakdown of O_3.

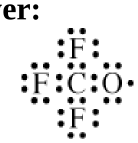
Exploring Extensions

47. **Answer:**
The smaller wavelength of the Blu-ray laser allows the laser beam to etch pits in the storage material that are smaller and closer together, therefore allowing more data to be stored.

48. Answer:
There are wide seasonal fluctuations in the temperatures and wind patterns in Antarctica. Development of polar stratospheric clouds of ice crystals during the long, dark, and still winter months provides reaction sites for the conversion of non-ozone depleting particles to reactive species. When the sun appears in Antarctica in late September and early October, the UV radiation releases Cl· from CFCs, initiating the destruction of ozone. The depletion in the Northern Hemisphere is not as severe as in the Southern Hemisphere. Scientists have not classified the ozone depletion over the North Pole as a "hole." The main reason for the observed difference between the total ozone changes in the two hemispheres is that the atmosphere above the North Pole usually is not as cold. Although polar stratospheric clouds have been observed in the Arctic, the air trapped over the Arctic generally begins to diffuse out of the region before the Sun gets bright enough to trigger as much ozone destruction as has been observed in Antarctica.

49. Answer:

a.



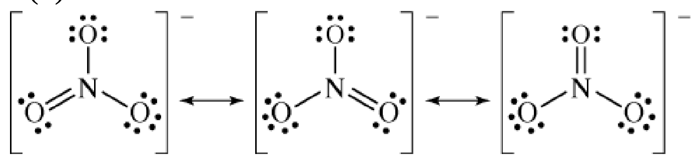
b. This free radical is very reactive in the troposphere, so it does not last long enough to reach the stratosphere.

50. Answer:
These compounds once were manufactured as fire suppressants. They are not water-based, so are excellent for specialized uses such as libraries, aircraft, and electronics. However, their production has been halted because they have high ozone depleting potentials (ODPs).
The two Halons have different atmospheric lifetimes. According to data from the U.S. EPA, http://www.epa.gov/Ozone/science/ods/classone.html (accessed August 2013), the values are 65 years and 16 years, respectively, for Halon-1301 and Halon-1211. A more interesting question is why the different lifetimes, which is beyond the scope of this text.

At the time this graph was drawn, it was thought that no substitutes would be found for some uses of methyl bromide. However, it now is looking more likely that substitutes will be found.

51. **Answer:**

5 + 3(6) + 1 = 24 electrons



52. **Answer:**

Large amounts of smog can scatter UV radiation and cause poor breathing conditions.

53. Answer:

This is not likely to be a reasonable solution, as ozone released into the troposphere will be destroyed by reactions with other atomospheric constituents before it can rise to the stratosphere.

54. Answer:

O_2, O_3, and N_2 all have an even number of valence electrons. In contrast, N_3 would have 15 valence electrons. Molecules with odd numbers of electrons cannot follow the octet rule and are more reactive.

55. Answer:

a. 90 + 12 = 102. The compound contains one carbon atom, no hydrogen atoms, and two fluorine atoms. The chemical formula for CFC-12 is CCl_2F_2.

b. CCl_4 contains 1 carbon atom, 0 hydrogen atoms, and 0 fluorine atoms. Therefore, the code number for CCl_4 is 100 or 90 + 10. The name is CFC-10.

c. Yes, the “90” method will work for HCFCs. 90 + 22 = 112, so HCFC-22 would be composed of 1 carbon atom, 1 hydrogen atom, and 2 fluorine atoms and its chemical formula would be CHF_2Cl.

d. No, this method will not work for halons as there is no guideline for handling bromine.

56. **Answer:**

Ozonators typically produce ozone either via an electrical discharge or with UV light. The former is similar to the process that produces ozone in a thunderstorm. A bolt of lightning can split O_2 molecules to form O atoms. The latter uses UV-C light to split O_2 molecules. In either case, the O atoms then react with another oxygen molecule to produce ozone. The ozone produced works as an effective disinfectant. It can react with many biological molecules, thereby being effective against undesired microbes and viruses. It also can react with many molecules that produce odors.

a. Search the web for examples. Claims include that ozonators can:

• destroy odors; tobacco, smoke, pet, cooking, and chemical
• kill bacteria and airborne viruses
• remove allergy causing pollen and microbes
• prevent mold and mildew, the leading cause of Legionnaires Disease
• eliminate toxic fumes from printing, plating processes, hair and nail salons
• purify water in holding tanks and emergency storage water tanks
• purify drinking water from well sources or city water supplies
• remove undesirable tastes, odors, and colors.

b. Ozone can be a harmful pollutant causing both damage to plants and animals. Any device that creates the gas must carefully contain it.

57. **Answer:**

a. Factors include (1) the reactivity of the compound, because this in turn affects the length of time it will remains in the atmosphere, and (2) the presence of Cl or Br in the compound, because Cl• and Br•, formed in the stratosphere from chlorine- and bromine- containing compounds, deplete ozone.

b. Most HCFCs, developed as replacements for CFCs, would be expected to have ODP values lower than those of the CFCs. HCFCs tend to be somewhat more reactive in the troposphere and thus do not accumulate in the stratosphere. Their ODP values range from 0.01 to 0.11.

c. HFCs were also developed as CFC substitutes. Without chlorine or bromine present, they generally do not have the potential to deplete stratospheric ozone. Their ODP values are 0.0.

58. **Answer:**

Depending on location, the generation of electricity may rely on the combustion of fossil fuels such as coal.

59. Answer:

a. $BrO\bullet + ClO\bullet \rightarrow BrCl + O_2$

$BrCl + \text{sunlight} \rightarrow Br\bullet + Cl\bullet$

$Br\bullet + O_3 \rightarrow BrO\bullet + O_2$

$Cl\bullet + O_3 \rightarrow ClO\bullet + O_2$

b. The net equation is $2\ O_3 \rightarrow 3\ O_2$

60. Answer:

a. See Figure 2.17. Most months of the year, it is not cold enough in the Arctic for PSCs to form.

b. $HCl + ClONO_2 \rightarrow Cl_2 + HNO_3$

The nitric acid remains bound to the ice, but the chlorine gas is released to the atmosphere.

c. In the atmosphere in the presence of sunlight, $Cl_2 \rightarrow 2Cl•$

61. Answer:

a. This is a possible Lewis structure. 

b. If Cl_2O_2 is the actual molecule, then it will have to be broken down by UV photons to ClO· free radicals before it can react with oxygen atoms as shown in equations 2.8 and 2.9. This would add one additional decomposition reaction in the catalytic destruction of ozone.