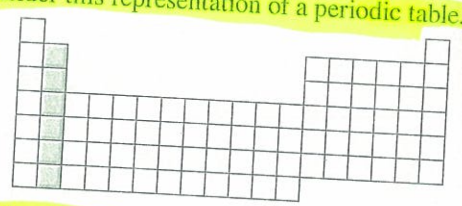
- Understand how the stratospheric ozone layer protects against harmful ultraviolet radiation (2.6, 2.7)
- Compare and contrast UV-A, UV-B, and UV-C radiation along several different lines (2.6, 2.7)
- Discuss the interaction of radiation with matter and changes caused by such interactions, including biological sensitivity (2.6, 2.7)
- Relate the meaning and the use of the UV Index (2.7)
- Write Lewis structures for chlorine and bromine atoms, as well as for some other free radicals. Be able to explain why these free radicals are so reactive (2.8)
- Recognize the complexities of collecting accurate data for stratospheric ozone depletion and interpreting them correctly (2.8, 2.9)
- Understand the chemical nature and role of CFCs in stratospheric ozone depletion (2.9, 2.10)
- Explain the unique circumstances responsible for seasonal ozone depletion in the Antarctic (2.10)
- Summarize the outcomes of the Montreal Protocol and its amendments (2.11, 2.12)
- Evaluate articles on green chemistry alternatives to stratospheric ozone-depleting compounds (2.12)
- Discuss factors that will help lead to the recovery of the ozone layer (2.11, 2.12)

Questions

Emphasizing Essentials

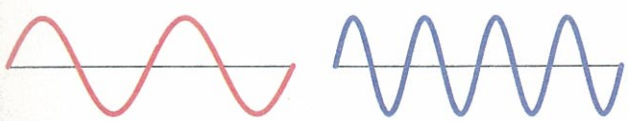
1. How does ozone differ from oxygen in its chemical formula? In its properties?
2. Explain why it is possible to detect the pungent odor of ozone after a lightning storm or around electrical transformers.
3. The text states that the odor of ozone can be detected in concentrations as low as 10 ppb. Would you be able to smell ozone in either of these air samples?
   a. 0.118 ppm of ozone, a concentration reached in an urban area
   b. 25 ppm of ozone, a concentration measured in the stratosphere
4. A journalist wrote "Hovering 10 miles above the South Pole is a sprawling patch of stratosphere with disturbingly low levels of radiation-absorbing ozone."
   a. How big is this sprawling patch?
   b. Is the figure of 10 miles correct? Express this value in kilometers.
   c. What type of radiation does ozone absorb?
5. It has been suggested that the term *ozone screen* would be a better descriptor than *ozone layer* to describe ozone in the stratosphere. What are the advantages and disadvantages to each term?
6. Assume there are 2×10^{20} CO molecules per cubic meter in a sample of tropospheric air. Furthermore, assume there are 1×10^{19} O_3 molecules per cubic meter at the point of maximum concentration of the ozone layer in the stratosphere.
   a. Which cubic meter of air contains the larger number of molecules?
   b. What is the ratio of CO to O_3 molecules in a cubic meter?
7. a. What is a Dobson unit?
   b. Does a reading of 320 DU or 275 DU indicate more total column ozone overhead?
8. Using the periodic table as a guide, specify the number of protons and electrons in a neutral atom of each of these elements.
   a. oxygen (O)
   b. nitrogen (N)
   c. magnesium (Mg)
   d. sulfur (S)
9. Consider this representation of a periodic table.



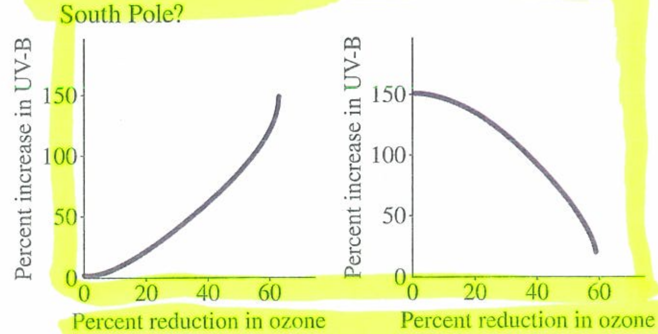
   a. What is the group number of the shaded column?
   b. Which elements make up this group?
   c. What is the number of electrons for a neutral atom of each element in this group?
   d. What is the number of outer electrons for a neutral atom of each element of this group?
10. Give the name and symbol for the element with this number of protons.
   a. 2
   b. 19
   c. 29
11. Give the number of protons, neutrons, and electrons in each of these neutral atoms.
   a. oxygen-18 ($^{18}_{8}O$)
   b. sulfur-35 ($^{35}_{16}S$)
   c. uranium-238 ($^{238}_{92}U$)
   d. bromine-82 ($^{82}_{35}Br$)
   e. neon-19 ($^{19}_{10}Ne$)
   f. radium-226 ($^{226}_{88}Ra$)
12. Give the symbol showing the atomic number and the mass number for the isotope that has:
   a. 9 protons and 10 neutrons (used in nuclear medicine).
   b. 26 protons and 30 neutrons (the most stable isotope of this element).
   c. 86 protons and 136 neutrons (the radioactive gas found in some homes).
13. Draw the Lewis structure for each of these atoms.
   a. calcium
   b. nitrogen
   c. chlorine
   d. helium

14. Assuming that the octet rule applies, draw the Lewis structure for each of these molecules.
    a. CCl_4 (carbon tetrachloride, a substance formerly used as a cleaning agent)
    b. H_2O_2 (hydrogen peroxide, a mild disinfectant; the atoms are bonded in this order: H–O–O–H)
    c. H_2S (hydrogen sulfide, a gas with the unpleasant odor of rotten eggs)
    d. N_2 (nitrogen gas, the major component of the atmosphere)
    e. HCN (hydrogen cyanide, a molecule found in space and a poisonous gas)
    f. N_2O (nitrous oxide, "laughing gas"; the atoms are bonded N–N–O)
    g. CS_2 (carbon disulfide, used to kill rodents; the atoms are bonded S–C–S)
15. Several oxygen species play important chemical roles in the stratosphere, including oxygen atoms, oxygen molecules, ozone molecules, and hydroxyl radicals. Draw Lewis structures for each.
16. Consider these two waves representing different parts of the electromagnetic spectrum. How do they compare in terms of:

Wave 1 Wave 2



    a. wavelength b. frequency c. speed of travel
17. Use Figure 2.7 to specify the region of the electromagnetic spectrum where radiation of each wavelength is found. *Hint:* Change each wavelength to meters before making the comparison.
    a. 2.0 cm b. 400 nm
    c. 50 μm d. 150 mm
18. Arrange the wavelengths in question 17 in order of *increasing* energy. Which wavelength possesses the most energetic photons?
19. Arrange these types of radiation in order of *increasing* energy per photon: gamma rays, infrared radiation, radio waves, visible light.
20. The microwaves in home microwave ovens have a frequency of $2.45 \times 10^9\ s^{-1}$. Is this radiation more or less energetic than radio waves? Than X-rays?
21. Ultraviolet radiation is categorized as UV-A, UV-B, or UV-C. Arrange these types in order of increasing:
    a. wavelength
    b. energy
    c. potential for biological damage
22. Draw Lewis structures for any three different CFCs.
23. CFCs were used in hair sprays, refrigerators, air conditioners, and plastic foams. Which properties of CFCs made them desirable for these uses?
24. a. Can a molecule that contains hydrogen be classified as a CFC?
    b. What is the difference between an HCFC and an HFC?
25. a. Most CFCs are based either on methane, CH_4, or ethane, C_2H_6. Use structural formulas to represent these two compounds.
    b. Substituting chlorine atoms, fluorine atoms, or both for all of the hydrogen atoms on a methane molecule, you obtain CFCs. How many possibilities exist?
    c. Which of the substituted CFC compounds in part **b** has been the most successful?
    d. Why weren't all of these compounds equally successful?
26. These free radicals all play a role in catalyzing ozone depletion reactions: Cl•, •NO_2, ClO•, and •OH.
    a. Count the number of outer electrons available and then draw a Lewis structure for each free radical.
    b. What characteristic is shared by these species that makes them so reactive?
27. a. How were the original measurements of increases in chlorine monoxide and the stratospheric ozone depletion over the Antarctic obtained?
    b. How are these measurements made today?
28. Which graph shows how measured increases in UV-B radiation correlate with percent reduction in the concentration of ozone in the stratosphere over the South Pole?



(a) (b)

Concentrating on Concepts

29. The EPA has used the slogan "*Ozone: Good Up High, Bad Nearby*" in some of its publications for the general public. Explain the message.
30. Nobel laureate W. Sherwood Rowland referred to the ozone layer as the Achilles heel of our atmosphere. Explain the metaphor.
31. In the abstract of a talk he gave in 2007, Nobel laureate W. Sherwood Rowland wrote "Solar UV radiation creates an ozone layer in the atmosphere which in turn completely absorbs the most energetic fraction of this radiation."
    a. What is the most energetic fraction? *Hint:* See Figure 2.8.
    b. How does solar UV radiation "create an ozone layer"?

32. In the conclusion of this chapter, we reported the words that Georgios Souflias spoke at the Symposium for the 20th Anniversary of the Montreal Protocol: "*We all, breathing on this planet today and having the potential, must guarantee its future, rapidly and decisively. We have no right to delay; we have no luxury of losing time.*"
    a. What danger in delaying was he referring to?
    b. Look back at the definitions of sustainability in the prologue. How do his words connect to these definitions?

33. Consider the Chapman cycle in Figure 2.10.
    a. Explain the source of the oxygen atoms.
    b. Can this cycle take place in the troposphere as well? Explain.

34. What are some of the reasons that the solution to ozone depletion proposed in this Sydney Harris cartoon will not work?

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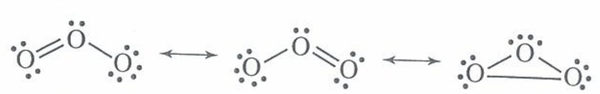
35. "*We risk solving one global environmental problem while possibly exacerbating another unless other alternatives can be found.*" The date of this quote by a U.S. official is 2009, and the context is phasing out the use of HCFCs.
    a. What compounds were HCFCs being replaced with in 2009?
    b. What is the risk of this replacement?

36. It is possible to write three resonance structures for ozone, not just the two shown in the text. Verify that all three structures satisfy the octet rule and offer an explanation of why the triangular structure is not reasonable.



37. The average length of an O–O single bond is 132 pm. The average length of an O–O double bond is 121 pm. What do you predict the O–O bond lengths will be in ozone? Will they all be the same? Explain your predictions.

38. Consider the Lewis structures for SO_2. How do they compare with the Lewis structures for ozone?

39. Even if you have skin with little pigment, you cannot get a tan from standing in front of a radio. Why?

40. The morning newspaper reports a UV Index Forecast of 6.5. Given the amount of pigment in your skin, how might this affect how you plan your daily activities?

41. All the reports of the damage caused by UV radiation focus on UV-A and UV-B radiation. Why is there no attention on the damaging effects of UV-C radiation?

42. If all 3×10^8 tons of stratospheric ozone that are formed every day are also destroyed every day, how is it possible for stratospheric ozone to offer any protection from UV radiation?

43. How does the chemical inertness of CCl_2F_2 (Freon-12) relate both the usefulness and the problems associated with this compound?

44. Explain how the small changes in concentrations (measured in parts per billion) can cause the much larger changes in O_3 concentrations (measured in parts per million).

45. Development of the stratospheric ozone hole has been most dramatic over Antarctica. What set of conditions exist over Antarctica that help to explain why this area is well-suited to studying changes in stratospheric ozone concentration? Are these same conditions not operating in the Arctic? Explain.

46. The free radical $CF_3O\cdot$ is produced during the decomposition of HFC-134a.
    a. Propose a Lewis structure for this free radical.
    b. Offer a possible reason why $CF_3O\cdot$ does not cause ozone depletion.

47. One mechanism that helps break down ozone in the Antarctic region involves the $BrO\cdot$ free radical. Once formed, it reacts with $ClO\cdot$ to form BrCl and O_2. BrCl, in turn, reacts with sunlight to break into $Cl\cdot$ and $Br\cdot$, both of which react with O_3 and form O_2.
    a. Represent this information with a set of equations similar to those shown for the Chapman cycle.
    b. What is the net equation for this cycle?

48. Polar stratospheric clouds (PSCs) play an important role in stratospheric ozone depletion.
    a. Why do PSCs form more often over Antarctica than in the Arctic?
    b. Reactions occur more quickly on the surface of PSCs than in the atmosphere. One such reaction is the reaction of hydrogen chloride and chlorine nitrate ($ClONO_2$), two species that do not deplete ozone, to produce a chlorine molecule and nitric acid (HNO_3). Write the chemical equation.
    c. The chlorine molecule produced does not deplete ozone either. However, when the Sun returns to the Antarctic in the springtime, it is converted to a species that does. Show how with a chemical equation.