electron: The basic constituent of atoms that has a negative charge.

electron volt: A unit of energy equal to the kinetic energy acquired by an electron or proton falling through an electric potential difference of 1 volt. Equal to 1.6×10^{-19} joule.

emission spectrum: The collection of discrete wavelengths emitted by atoms that have been excited by heating or electric currents.

ion: An atom with missing or extra electrons.

nucleus: The central part of an atom containing the positive charges.

photoelectric effect: The ejection of electrons from metallic surfaces by illuminating light.

photon: A particle of light. The energy of a photon is given by the relationship $E = hf$, where f is the frequency of the light and h is Planck's constant.

quantum (pl., *quanta*)**:** The smallest unit of a discrete property. For instance, the quantum of charge is the charge on the proton.

quantum number: A number giving the value of a quantized quantity. For instance, a quantum number specifies the angular momentum of an electron in an atom.

shell: A collection of electrons in an atom that have approximately the same energy.

X ray: A high-energy photon with a range of frequencies in the electromagnetic spectrum lying between the ultraviolet and the gamma rays.

CONCEPTUAL QUESTIONS

1. Today, we think of the periodic table as being arranged in order of increasing proton (or electron) number. Why did Mendeleev not use this approach?

2. If Mendeleev was ordering the elements according to their masses, why did he not produce a table with only one row?

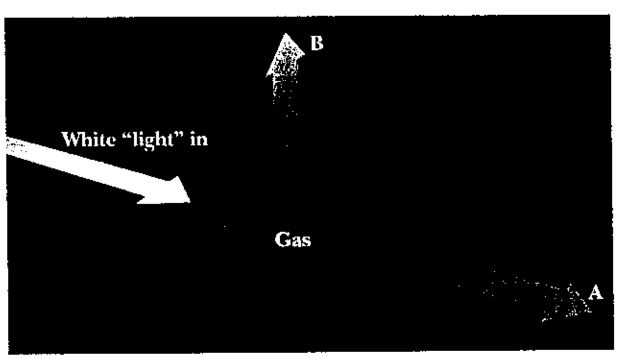
3. What element in Mendeleev's periodic table is most similar to silicon (Si)?

4. What elements would you expect to have chemical properties similar to chlorine (Cl)?

5. Why are the spectral lines for elements sometimes called "atomic fingerprints"?

6. How could you determine if there is oxygen in the Sun?

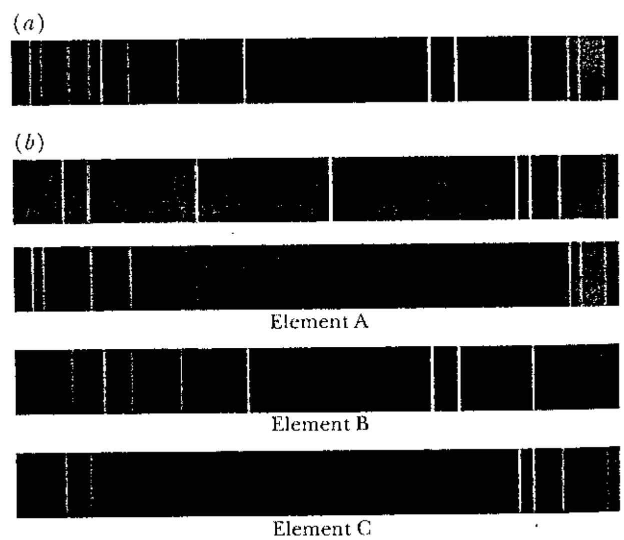
7. Would you obtain an emission or an absorption spectrum at location A in the setup shown in the figure?



Questions 7 and 8

8. Would you obtain an emission or an absorption spectrum at location B in the setup shown in the figure?

9. The emission spectra shown in the figure were all obtained with the same apparatus. What element(s) can you identify in sample (a)? Are there any that you cannot identify?



Questions 9 and 10

10. What element(s) can you identify in sample (b) of the figure? Are there any that you cannot identify?

11. How does the number of lines in the absorption spectrum for an element compare with the number in the emission spectrum?

12. What are the differences between an emission spectrum and an absorption spectrum?

13. When your authors were students, their textbooks did not have color. Could the spectra in Figure 23-3 still be used to identify atoms if they were in black and white? Explain.

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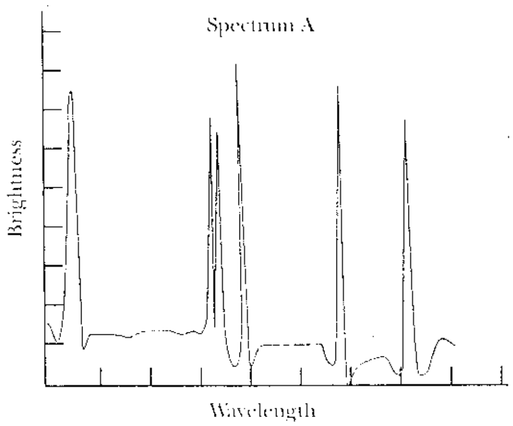
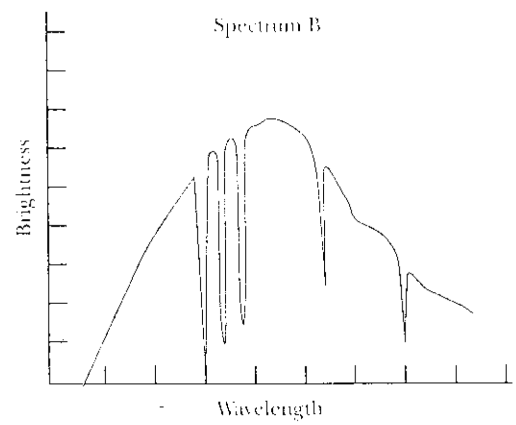
14. Two graphs of brightness versus wavelength are shown in the figure. Identify which is an absorption spectrum and which is an emission spectrum.





15. To which of the brightness versus wavelength graphs in Question 14 does the line spectrum in the figure correspond?

16. Sketch the brightness versus wavelength graph for the hydrogen spectrum shown in Figure 23-3.

17. Suppose you were a nineteenth-century scientist who had just discovered a new phenomenon known as Zeta rays (yes, we're making this up). What experiment could you perform to determine whether Zeta rays were charged particles or an electromagnetic wave? Could this experiment distinguish between neutral particles and an electromagnetic wave?

18. Imagine that you determined that the Zeta rays from Question 17 were charged particles. How would you determine the sign of the charge?

19. In the Millikan oil-drop apparatus shown in Figure 23-8, an electric field provides a force that balances the gravitational force on charged oil drops. Millikan found that he needed the electric field to point down toward the floor. Was the net charge on the oil drops a result of an excess or a deficit of electrons?

20. Why was it not necessary for Millikan to use oil drops charged to only one electron charge to determine the charge of a single electron?

21. Millikan's oil-drop experiment was used to determine the charge on a single electron. Why should Millikan also get credit for determining the electron's mass?

22. What do we mean when we say that a certain physical quantity is quantized?

23. How does Rutherford's model of an atom explain why most alpha particles pass right through a thin gold foil? How does it account for why some alpha particles are scattered backward?

24. In Rutherford's model of the atom, nothing separates the negative electrons from the positively charged nucleus but empty space. Why don't the electrons just rush right into the nucleus?

25. Rutherford's model predicted that atoms should be unstable (the electrons should spiral into the nucleus) over very short time periods. What caused this instability in Rutherford's model?

26. Rutherford's model provided an explanation for the emission of light from atoms. What was this mechanism and why was it unsatisfactory?

27. Why can the curves for the intensities of the colors emitted by hot solid objects not serve as "atomic fingerprints" of the materials?

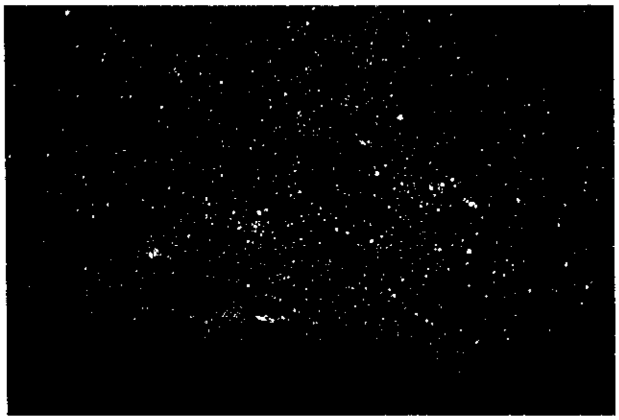
28. If all objects emit radiation, why don't we see most of them in the dark?

29. As you move to the right along the horizontal axis of Figure 23-14, is the frequency increasing or decreasing? Explain your reasoning.

30. For an object at a temperature of 8000 K, use Figure 23-14 to determine whether the light intensity is greater for light in the ultraviolet or in the infrared.

31. You measure the brightness of two different hot objects; first with a blue filter and then with a red filter. You find that object A has a brightness of 25 in the blue and 20 in the red. Object B has a brightness of 12 in the blue and 3 in the red. The brightness units are arbitrary but the same for all measurements. Which is the hotter of the two objects?

32. The curves in Figure 23-14 show the intensities of the various wavelengths emitted by an object at three different temperatures. The region corresponding to visible light is indicated. How would the color of the object at 8000 K compare to the color of the object at 4000 K?



Questions 33 and 34

33. Why do astronomers often use the terms *color* and *temperature* interchangeably when referring to stars?

34. Why are blue stars thought to be hotter than red stars?

35. What assumption(s) did Planck make that enabled him to obtain the correct curve for the spectrum of light emitted by a hot object?

36. What assumption(s) did Einstein make that enabled him to account for the experimental observations of the photoelectric effect?

37. What property of the emitted photoelectrons depends on the intensity of the incident light?

38. What property of the emitted photoelectrons depends on the frequency of the incident light?

39. If a metal surface is illuminated by light at a single frequency, why don't all the photoelectrons have the same kinetic energy when they leave the metal's surface?

40. How is it possible that ultraviolet light can cause sunburn but no amount of visible light will?

41. You find that if you shine ultraviolet light on a negatively charged electroscope, the electroscope discharges even if the intensity of the light is low. Red light, however, will not discharge the electroscope even at high intensities. How do you account for this?

42. You find that if you shine ultraviolet light on a negatively charged electroscope, the electroscope discharges. Can you discharge a positively charged electroscope the same way? Why or why not?

43. What are the three assumptions of Bohr's model of the atom?

44. Why did Bohr assume that the electrons do not radiate when they are in the allowed orbits?

45. An electron in the $n = 3$ energy level can drop to the ground state by emitting a single photon or a pair of photons. How does the total energy of the pair compare with the energy of the single photon?

46. If electrons in hydrogen atoms are excited to the fourth Bohr orbit, how many different frequencies of light may be emitted?

47. How can the spectrum of hydrogen contain so many spectral lines when the hydrogen atom only has one electron?

48. What determines the frequency of a photon emitted by an atom?

49. Why does the spectrum of lithium (element 3) resemble that of hydrogen?

50. How does Bohr's model explain that there are more lines in the emission spectrum than in the absorption spectrum?

51. How many electrons would you expect to find in each shell for chlorine (Cl)?

52. Radon (element 86) is a gas. Would you expect the molecules of radon to consist of a single atom or a pair of atoms? Why?

53. Sodium does not naturally occur as a free element. Why?

54. What effective charge do the outer electrons in aluminum "see"? (Aluminum is element 13.)

55. What type of electromagnetic wave has a wavelength about the size of an atom? (The electromagnetic spectrum is given in Figure 22-24.)

56. Are X rays deflected by electric or magnetic fields? Explain.

57. How does an X ray differ from a photon of visible light?

58. Why would you not expect an X-ray photon to be emitted every time an inner electron is removed from an atom?

EXERCISES

1. What is the charge-to-mass ratio for a cathode ray?

2. What is the charge-to-mass ratio for a hydrogen ion (an isolated proton)?

3. Given that the radius of a hydrogen atom is 5.29×10^{-11} m and that its mass is 1.682×10^{-27} kg, what is the average density of a hydrogen atom? How does it compare with the density of water?

4. What is the average density of the hydrogen ion (an isolated proton) given that its radius is 1.2×10^{-15} m and that its mass is 1.673×10^{-27} kg? It is interesting to note that such densities also occur in neutron stars.

5. If you were helping your younger brother build a scale model of an atom for a science fair and wanted it to fit in a box 1 m on each side, how big would the nucleus be?

6. A student decides to build a physical model of an atom. If the nucleus is a rubber ball with a diameter of 1 cm, how far away would the outer electrons be?

7. What is the energy of a photon of red light with a frequency of 4.5×10^{14} Hz?

8. What is the energy of the most energetic photon of visible light?

9. A photon of green light has energy 3.6×10^{-19} J. What is its frequency?

10. An X-ray photon has energy 1.5×10^{-15} J. What is its frequency?

11. A microwave photon has an energy of 2×10^{-23} J. What is its wavelength?

12. A photon of yellow light has a wavelength of 6.0×10^{-7} m. What is its energy?

13. What is the angular momentum of an electron in the ground state of hydrogen?

14. What is the angular momentum of an electron in the $n = 4$ level of hydrogen?

15. What is the radius of the $n = 4$ level of hydrogen?

16. What is the quantum number of the orbit in the hydrogen atom that has 36 times the radius of the smallest orbit?

17. What is the frequency of a photon of energy 3 eV?

18. What is the energy, in electron volts, of a yellow photon of wavelength 6.0×10^{-7} m?

19. According to Figure 23-20, it requires a photon with an energy of 10.2 eV to excite an electron from the $n = 1$ energy level to the $n = 2$ energy level. What is the frequency of this photon? Does it lie in, above, or below the visible range?

20. When a proton captures an electron, a photon with an energy of 13.6 eV is emitted. What is the frequency of this photon? Does it lie in, above, or below the visible range?

21. What is the ratio of the volumes of the hydrogen atom in the $n = 1$ state compared with those in the $n = 2$ state?

***22.** The diameter of the hydrogen atom is 10^{-10} m. In Bohr's model this means that the electron travels a distance of about 3×10^{-10} m in orbiting the atom once. If the orbital frequency is 7×10^{15} Hz, what is the speed of the electron? How does this speed compare with that of light?

23. What difference in energy between two atomic levels is required to produce an X ray with a frequency of 2×10^{18} Hz?

24. What is the frequency of the X ray that is emitted when an electron drops down to the ground state from an excited state with 1000 eV more energy?

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