Section 30.1 Rutherford Scattering and the Nuclear Atom

1. Which model of atomic structure was developed to explain the results of the experiment shown?
   (a) Bohr model
   (b) nuclear atom
   (c) billiard ball atom
   (d) plum-pudding model
   (e) quantum mechanical atom

2. Which one of the following statements concerning the plum-pudding model of the atom is false?
   (a) There is no nucleus at the center of the plum-pudding model atom.
   (b) The plum-pudding model was proven correct in experiments by Ernest Rutherford.
   (c) The plum-pudding model was proposed by Joseph J. Thomson.
   (d) Positive charge is spread uniformly throughout the plum-pudding model atom.
   (e) Negative electrons are dispersed uniformly within the positively charged “pudding” within the plum-pudding model atom.

3. In the planetary model of the atom where electrons orbit a centralized nucleus, what is the approximate ratio of the radius of the nucleus to that of the electron orbits, \( r_n/r_e \)?
   (a) 10^5
   (b) 10^{-3}
   (c) 10^7
   (d) 10^{-5}

4. The nucleus of a certain atom has a radius of 4.0 \times 10^{-15} m. An electron orbits the nucleus at a radius of 1.5 \times 10^{-10} m. Imagine the electron orbit is on the surface of a sphere and that the shape of the nucleus is spherical. Approximately how many nuclei would fit into the sphere on which the electron orbits?
   (a) 5.3 \times 10^{13}
   (b) 4.9 \times 10^{11}
   (c) 1.4 \times 10^{9}
   (d) 7.5 \times 10^{7}
   (e) 3.8 \times 10^{4}

Section 30.2 Line Spectra

Section 30.3 The Bohr Model of the Hydrogen Atom

Section 30.4 De Broglie’s Explanation of Bohr’s Assumption about Angular Momentum

5. Each atom in the periodic table has a unique set of spectral lines. Which one of the following statements is the best explanation for this observation?
   (a) Each atom has a dense central nucleus.
   (b) The electrons in atoms orbit the nucleus.
   (c) Each atom has a unique set of energy levels.
   (d) The electrons in atoms are in constant motion.
   (e) Each atom is composed of positive and negative charges.

6. Each atom in the periodic table has a unique set of spectral lines. The model of atomic structure that provides the best explanation for this observation was proposed by
   (a) Balmer.
   (b) Bohr.
   (c) Einstein.
   (d) Rutherford.
   (e) Thomson.
7. Which one of the following pairs of characteristics of light is best explained by assuming that light can be described in terms of photons?
   (a) photoelectric effect and the effect observed in Young’s experiment
   (b) diffraction and the formation of atomic spectra
   (c) polarization and the photoelectric effect
   (d) existence of line spectra and the photoelectric effect
   (e) polarization and the formation of line spectra

8. Which one of the following statements is the assumption that Niels Bohr made about the angular momentum of the electron in the hydrogen atom?
   (a) The angular momentum of the electron is zero.
   (b) The angular momentum can assume only certain discrete values.
   (c) Angular momentum is not quantized.
   (d) The angular momentum can assume any value greater than zero because it’s proportional to the radius of the orbit.
   (e) The angular momentum is independent of the mass of the electron.

9. Why was it necessary for Bohr to require that electrons remain in stationary orbits?
   (a) An electron must travel in a circular path.
   (b) It was required by the Heisenberg uncertainty principle.
   (c) No two electrons can be in the same region in the atom.
   (d) It was required by the Pauli exclusion principle.
   (e) Classical physics predicts that the electron should spiral into the nucleus.

10. Complete the following statement: For the ground state of the hydrogen atom, the Bohr model correctly predicts
    (a) only the energy.
    (b) only the angular momentum.
    (c) only the angular momentum and the spin.
    (d) the angular momentum and the energy.
    (e) the energy, the angular momentum, and the spin.

11. Complete the following statement: An individual copper atom emits electromagnetic radiation with wavelengths that are
    (a) evenly spaced across the spectrum.
    (b) unique to that particular copper atom.
    (c) the same as other elements in the same column of the periodic table.
    (d) unique to all copper atoms.
    (e) the same as those of all elements.

12. Electrons have been removed from a beryllium atom (Z = 4) until only one remains. Determine the energy of the photon that can be emitted if the remaining electron is in the n = 2 level.
    (a) 13.6 eV
    (b) 54.4 eV
    (c) 122 eV
    (d) 164 eV
    (e) 218 eV

13. Determine the wavelength of incident electromagnetic radiation required to cause an electron transition from the n = 6 to the n = 8 level in a hydrogen atom.
    (a) $1.2 \times 10^3$ nm
    (b) $2.2 \times 10^3$ nm
    (c) $3.4 \times 10^3$ nm
    (d) $5.9 \times 10^3$ nm
    (e) $7.5 \times 10^3$ nm
14. The second ionization energy (the energy required to remove the second outermost electron) of calcium is 11.9 eV. Determine the maximum wavelength of incident radiation that can be used to remove the second electron from a calcium atom?
(a) 16.6 nm  
(b) 52 nm  
(c) 104 nm  
(d) 208 nm  
(e) 416 nm

15. Which one of the following will result in an electron transition from the $n = 4$ level to the $n = 7$ level in a hydrogen atom?
(a) emission of a 0.28 eV photon  
(b) emission of a 0.57 eV photon  
(c) emission of a 0.85 eV photon  
(d) absorption of a 0.28 eV photon  
(e) absorption of a 0.57 eV photon

16. Determine the maximum wavelength of incident radiation that can be used to remove the remaining electron from a singly ionized helium atom He$^+$ ($Z = 2$). Assume the electron is in its ground state.
(a) 6.2 nm  
(b) 12.4 nm  
(c) 22.8 nm  
(d) 45.6 nm  
(e) 54.4 nm

17. What is the longest wavelength in the Paschen series of atomic spectra?
(a) $8.204 \times 10^{-7}$ m  
(b) $1.875 \times 10^{-6}$ m  
(c) $2.216 \times 10^{-6}$ m  
(d) $5.522 \times 10^{-6}$ m  
(e) $6.756 \times 10^{-5}$ m

18. Determine the energy of the photon emitted when the electron in a hydrogen atom undergoes a transition from the $n = 8$ level to the $n = 6$ level.
(a) 0.17 eV  
(b) 0.21 eV  
(c) 0.36 eV  
(d) 0.57 eV  
(e) 13.4 eV

19. The kinetic energy of the ground state electron in hydrogen is +13.6 eV. What is its potential energy?
(a) -13.6 eV  
(b) +27.2 eV  
(c) -27.2 eV  
(d) +56.2 eV  
(e) zero eV

20. An electron is in the ground state of a hydrogen atom. A photon is absorbed by the atom and the electron is excited to the $n = 2$ state. What is the energy in eV of the photon?
(a) 13.6 eV  
(b) 10.2 eV  
(c) 3.40 eV  
(d) 1.51 eV  
(e) 0.54 eV

21. According to the Bohr model, what is the radius of a hydrogen atom when its electron is excited to the $n = 9$ state?
(a) $5.87 \times 10^{-12}$ m  
(b) $5.29 \times 10^{-11}$ m  
(c) $4.76 \times 10^{-10}$ m  
(d) $4.28 \times 10^{-9}$ m  
(e) $1.51 \times 10^{-8}$ m

22. Determine the kinetic energy of an electron that has a de Broglie wavelength equal to twice the diameter of the hydrogen atom. Assume that the hydrogen atom is a sphere of radius $5.3 \times 10^{-11}$ m.
(a) 13.6 eV  
(b) 27.2 eV  
(c) 33.6 eV  
(d) 48.9 eV  
(e) 65.2 eV

23. What is the shortest possible wavelength in the Lyman series for atomic hydrogen?
(a) 91.3 nm  
(b) 104 nm  
(c) 122 nm  
(d) 364 nm  
(e) 820 nm
24. The electron in a hydrogen atom is in the $n = 3$ state. What is(are) the possible value(s) for an emitted photon?
   (a) 1.89 eV or 12.09 eV        (c) 0.66 eV or 13.6 eV        (e) 1.51 eV only
   (b) 1.89 eV or 13.6 eV        (d) 0.66 eV or 12.09 eV

25. What energy (in eV) is required to remove the remaining electron from a singly ionized helium atom, He$^+$ ($Z = 2$)?
   (a) 3.40 eV                  (c) 27.2 eV                  (e) 76.9 eV
   (b) 13.6 eV                  (d) 54.4 eV

Section 30.5 The Quantum Mechanical Picture of the Hydrogen Atom

26. According to the quantum mechanical picture of the atom, which one of the following is a true statement concerning the ground state electron in a hydrogen atom?
   (a) The ground state electron has zero kinetic energy.
   (b) The ground state electron has zero binding energy.
   (c) The ground state electron has zero ionization energy.
   (d) The ground state electron has zero spin angular momentum.
   (e) The ground state electron has zero orbital angular momentum.

27. A hydrogen atom is in a state for which the principle quantum number is $n = 3$. How many possible such states are there for which the magnetic quantum number is $m_l = 0$?
   (a) 2                          (c) 6                          (e) 10
   (b) 4                          (d) 8

28. According to the quantum mechanical picture of the atom, which one of the following statements is true concerning the magnitude of the angular momentum $L$ of an electron in the $n = 3$ level of the hydrogen atom?
   (a) $L$ is 0.318$h$.
   (b) $L$ is 0.477$h$.
   (c) $L$ could be 0.159$h$ or 0.318$h$.
   (d) $L$ could be 0.225$h$ or 0.276$h$.
   (e) $L$ could be 0.225$h$ or 0.390$h$.

29. An electron in a hydrogen atom is described by the quantum numbers: $n = 8$ and $m_l = 4$. What are the possible values for the orbital quantum number $\ell$?
   (a) only 0 or 4
   (b) only 4 or 7
   (c) only 5 or 8
   (d) only 5, 6, 7, or 8
   (e) only 5, 6, 7, or 8

30. Which one of the following sets of quantum numbers is not possible?

<table>
<thead>
<tr>
<th>$n$</th>
<th>$\ell$</th>
<th>$m_\ell$</th>
<th>$m_s$</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>2</td>
<td>3</td>
<td>−2</td>
</tr>
<tr>
<td>b</td>
<td>4</td>
<td>3</td>
<td>+2</td>
</tr>
<tr>
<td>c</td>
<td>3</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>d</td>
<td>6</td>
<td>2</td>
<td>−1</td>
</tr>
<tr>
<td>e</td>
<td>5</td>
<td>4</td>
<td>−4</td>
</tr>
</tbody>
</table>

31. The principle quantum number for the electron in a hydrogen atom is $n = 4$. According to the quantum mechanical picture of the atom, what is the maximum possible value for the magnitude of the $z$-component of the angular momentum of the electron?
   (a) 3.17 $\times 10^{-34}$ kg $\cdot$ m$^2$/s
   (b) 4.22 $\times 10^{-34}$ kg $\cdot$ m$^2$/s
   (c) 1.99 $\times 10^{-34}$ kg $\cdot$ m$^2$/s
   (d) 1.06 $\times 10^{-34}$ kg $\cdot$ m$^2$/s
   (e) 2.11 $\times 10^{-33}$ kg $\cdot$ m$^2$/s
32. Which quantum number applies to most of the electrons in a collection of hydrogen atoms at room temperature?
(a) \( n = 1 \)  
(b) \( n = 2 \)  
(c) \( n = 3 \)  
(d) \( n = 4 \)  
(e) \( n = 5 \)

33. How many electron states (including spin states) are possible in a hydrogen atom if its energy is \(-3.4\) eV?
(a) 2  
(b) 4  
(c) 6  
(d) 8  
(e) 10

34. Determine the maximum number of electron states with principal quantum number \( n = 3 \)?
(a) 2  
(b) 3  
(c) 6  
(d) 9  
(e) 18

35. Which one of the following values of \( m_l \) is not possible for \( \ell = 2 \)?
(a) zero  
(b) \(-1\)  
(c) \(+1\)  
(d) \(+2\)  
(e) \(+3\)

36. Two possible states for the hydrogen atom are labeled A and B. The maximum magnetic quantum number for state A is \(+3\). For state B, the maximum value is \(+1\). What is the ratio of the magnitudes of the orbital angular momenta, \( L_A/L_B \), of an electron in these two states?
(a) 1.22  
(b) 1.73  
(c) 2.00  
(d) 2.45  
(e) 3.46

Section 30.6 The Pauli Exclusion Principle and the Periodic Table of the Elements

37. To which model of atomic structure does the Pauli exclusion principle apply?
(a) the nuclear atom  
(b) the quantum mechanical atom  
(c) the billiard ball atom  
(d) the plum-pudding model  
(e) the planetary model

38. Which one of the following factors best explains why the six electrons of a carbon atom are not all in the 1s state?
(a) electron spin  
(b) Coulomb's law  
(c) Pauli exclusion principle  
(d) Heisenberg uncertainty principle  
(e) Rutherford model of atomic structure

39. Which one of the following statements concerning the electrons specified by the notation 3p\(^4\) is true?
(a) The electrons are in the M shell.  
(b) The electrons are in the \( \ell = 2 \) subshell.  
(c) The electrons are necessarily in an excited state.  
(d) They have principal quantum number 4.  
(e) There are 3 electrons in the specified subshell.

40. How many electrons could be accommodated in a \( g \) subshell?
(a) 4  
(b) 5  
(c) 8  
(d) 9  
(e) 18

41. Which one of the following subshells is not compatible with a principle quantum number of \( n = 4 \)?
(a) \( s \)  
(b) \( p \)  
(c) \( d \)  
(d) \( f \)  
(e) \( g \)
42. Which one of the following electronic configurations corresponds to an atomic ground state?
   (a) $1s^2 2s^1 2p^6$  (c) $1s^1 2s^2 3p^1$  (e) $1s^1 2s^2 2p^1$
   (b) $1s^1 2s^1 2p^1$  (d) $1s^2 2s^2 2p^1$

43. An $h$ subshell refers to orbital quantum number
   (a) $\ell = 1$  (c) $\ell = 3$  (e) $\ell = 5$
   (b) $\ell = 2$  (d) $\ell = 4$

44. What is the total number of subshells in the $n = 3$ level?
   (a) 3  (c) 7  (e) 18
   (b) 6  (d) 9

45. Name the physicist credited with the following statement: No two electrons in an atom can have the same set of values for the four quantum numbers.
   (a) Werner Heisenberg  (c) Arthur Compton  (e) Erwin Schrödinger
   (b) Wolfgang Pauli  (d) Niels Bohr

46. The ground state electronic configuration of a neon atom is $1s^2 2s^2 2p^6$. How many of these electrons have magnetic quantum number $m_l = 0$?
   (a) 2  (c) 6  (e) 10
   (b) 4  (d) 8

Questions 47 through 49 pertain to the statement below:
A neutral atom has the following electronic configuration: $1s^2 2s^2 2p^6 3s^2 3p^5$

47. How many electrons are in the M shell?
   (a) 2  (c) 6  (e) 8
   (b) 5  (d) 7

48. How many protons are in the atomic nucleus?
   (a) 4  (c) 12  (e) 34
   (b) 7  (d) 17

49. To which group of the periodic table does this element belong?
   (a) I  (c) III  (e) VII
   (b) II  (d) VI

Questions 50 through 52 pertain to the statement below:
An electron in an atom has the following set of quantum numbers: $n = 3$, $\ell = 2$, $m_\ell = +1$, $m_s = +1/2$.

50. What shell is this electron occupying?
   (a) K shell  (c) M shell  (e) O shell
   (b) L shell  (d) N shell

51. In which subshell can the electron be found?
   (a) s  (c) d  (e) g
   (b) p  (d) f
52. According to the quantum mechanical picture of the atom, which quantum number(s) could be different for electrons in this same atom that have exactly the same energy?
(a) \( n, \ell, m_\ell \) and \( m_s \)  
(b) only \( \ell, m_\ell \) and \( m_s \)  
(c) only \( \ell \) and \( m_\ell \)  
(d) only \( m_\ell \) and \( m_s \)

Questions 53 through 57 pertain to the statement below

Consider the following list of electron configurations:

\[ \begin{align*}
1 & \quad \text{(1)} \quad 1s^2 \ 2s^2 \ 3s^2 \\
2 & \quad \text{(2)} \quad 1s^2 \ 2s^2 \ 2p^6 \\
3 & \quad \text{(3)} \quad 1s^2 \ 2s^2 \ 2p^6 \ 3s^1
\end{align*} \]

53. Which one of the above lists represents the electronic configuration for the ground state of the atom with \( Z = 11 \)?
(a) 1  
(b) 2  
(c) 3  
(d) 4  
(e) 5

54. Which electronic configuration is characteristic of noble gases?
(a) 1  
(b) 2  
(c) 3  
(d) 4  
(e) 5

55. Which one of the above configurations represents a neutral atom that readily forms a singly charged positive ion?
(a) 1  
(b) 2  
(c) 3  
(d) 4  
(e) 5

56. Which one of the above configurations represents an excited state of a neutral atom?
(a) 1  
(b) 2  
(c) 3  
(d) 4  
(e) 5

57. Which one of the above configurations represents a transition element?
(a) 1  
(b) 2  
(c) 3  
(d) 4  
(e) 5

Section 30.7 X-rays

58. Which one of the following statements concerning the cutoff wavelength typically exhibited in X-ray spectra is true?
(a) The cutoff wavelength depends on the target material.  
(b) The cutoff wavelength depends on the potential difference across the X-ray tube.  
(c) The cutoff wavelength is independent of the energy of the incident electrons.  
(d) The cutoff wavelength occurs because of the mutual shielding effects of K-shell electrons.  
(e) The cutoff wavelength occurs because an incident electron cannot give up all of its energy.

59. In an X-ray tube, electrons with energy 35 keV are incident on a cobalt (\( Z = 27 \)) target. Determine the cutoff wavelength for X-ray production.
(a) \( 1.4 \times 10^{-11} \) m  
(b) \( 1.8 \times 10^{-11} \) m  
(c) \( 2.8 \times 10^{-11} \) m  
(d) \( 3.2 \times 10^{-11} \) m  
(e) \( 3.6 \times 10^{-11} \) m

60. Which electron energy will produce the lowest cutoff wavelength for X-ray production from a nickel (\( Z = 28 \)) surface?
(a) 25 keV  
(b) 30 keV  
(c) 35 keV  
(d) 40 keV  
(e) 45 keV
61. Calculate the $K_{\alpha}$ X-ray wavelength for a gold atom ($Z = 79$).

(a) $5.13 \times 10^{-10}$ m  
(b) $8.54 \times 10^{-10}$ m

(c) $2.00 \times 10^{-11}$ m  
(d) $3.60 \times 10^{-11}$ m

(e) $2.47 \times 10^{-13}$ m

62. Electrons in an X-ray tube are accelerated through a potential difference of 40 kV. The electrons then strike a zirconium ($Z = 40$) target. Determine the cutoff frequency for X-ray production.

(a) $4.7 \times 10^{19}$ Hz  
(b) $9.7 \times 10^{18}$ Hz

(c) $3.2 \times 10^{18}$ Hz  
(d) $6.7 \times 10^{17}$ Hz

(e) $1.1 \times 10^{16}$ Hz

63. What is the operating voltage of a medical X-ray machine that has a cut-off wavelength of $2.20 \times 10^{-11}$ m?

(a) 83 800 V  
(b) 10 900 V

(c) 30 700 V  
(d) 44 900 V

(e) 56 500 V

---

Section 30.8 The Laser

Section 30.9 Medical Applications of the Laser

Section 30.10 Holography

64. Complete the following sentence: In the condition known as population inversion,

(a) the amount of one type of gas atoms is larger than that of another in a mixture.

(b) the number of energy levels that are populated is larger than that of unpopulated levels.

(c) there are more electrons occupying lower energy levels than occupying higher energy levels.

(d) there are more electrons occupying higher energy levels than occupying lower energy levels.

(e) there are more photons than electrons in a given system.

65. An argon-ion laser emits a blue-green beam of light with a wavelength of 488 nm in a vacuum. What is the difference in energy in joules between the two energy states for the atomic transition that produces this light?

(a) $4.08 \times 10^{-19}$ J  
(b) $1.05 \times 10^{-20}$ J

(c) $6.18 \times 10^{-20}$ J  
(d) $4.76 \times 10^{-24}$ J

(e) $5.10 \times 10^{-28}$ J

66. A pulsed laser has an average output power of 4.0 W. Each pulse consists of light at wavelength $5.0 \times 10^{-7}$ m and has a 25 ms duration. How many photons are emitted in a single pulse?

(a) $1.0 \times 10^{17}$  
(b) $2.5 \times 10^{17}$

(c) $3.7 \times 10^{17}$  
(d) $5.0 \times 10^{17}$

(e) $7.4 \times 10^{17}$

67. An electron makes a transition from a higher energy state to a lower one without any external provocation. As a result of the transition, a photon is emitted and moves in a random direction. What is the name of this emission process?

(a) stationary emission  
(b) stimulated emission

(c) spectral emission  
(d) spontaneous emission

(e) specular emission

68. Complete the following statement: In the laser-based medical procedure known as photorefractive keratectomy (PRK), nearsightedness and farsightedness can be treated using the laser to

(a) remove small amounts of tissue from the lens and change its curvature.

(b) remove small amounts of tissue from the cornea and change its curvature.

(c) change the index of refraction of the aqueous humor.

(d) alter the fluid pressure within the eye.

(e) stimulate unused rods and cones on the retina.
69. Complete the following sentence: Holography is
(a) the projection of an image produced by a combination of mirrors and lenses.
(b) a photograph of the light produced by a laser.
(c) a process for producing three dimensional images using the interference of laser light beams.
(d) the name for an imaging process that occurs within a camera when a photograph is taken.
(e) the production of a two dimensional image of the three dimensional object.

Additional Problems

70. An atom will emit photons when one of its electrons goes from
(a) the K shell to the L shell.  
(b) the M shell to the N shell.  
(c) the K shell to the M shell.  
(d) the N shell to the L shell.  
(e) the K shell to the N shell.

71. Which one of the following statements best explains why a neon sign does not emit visible light after it is turned off?
(a) All of the neon atoms are ionized.
(b) Most of the neon atoms are in the ground state.
(c) None of the neon atoms are in the \( n = 2 \) state.
(d) All of the neon atoms have principle quantum number \( n = 0 \).
(e) Only some of the neon atoms have returned to the \( n = 1 \) state.

Questions 72 through 78 pertain to the statement and diagram below.

The figure shows an energy level diagram for the hydrogen atom. Several transitions are shown and are labeled by letters.

Note: The diagram is not drawn to scale.

72. In which transition is a Balmer series photon absorbed?
(a) A  
(b) B  
(c) C  
(d) D  
(e) E

73. Which transition corresponds to the absorption of the photon with the longest wavelength?
(a) A  
(b) B  
(c) C  
(d) D  
(e) E

74. Determine the energy of the photon involved in transition E.
(a) 1.5 eV  
(b) 1.9 eV  
(c) 3.4 eV  
(d) 10.2 eV  
(e) 12.1 eV

75. Determine the wavelength of the radiation involved in transition B.
(a) 291 nm  
(b) 364 nm  
(c) 487 nm  
(d) 652 nm  
(e) 1910 nm
76. Which transition will occur when a hydrogen atom is irradiated with radiation of wavelength 103 nm?
   (a) A  (b) B  (c) C  (d) D  (e) E

77. Which transition will occur when a hydrogen atom is irradiated with radiation of frequency $1.60 \times 10^{14}$ Hz?
   (a) A  (b) B  (c) C  (d) D  (e) E

78. Which transition involves the longest wavelength line in the visible portion of the hydrogen spectrum?
   (a) A  (b) B  (c) C  (d) D  (e) E