31. Positronium is an atom formed by an electron and a positron (antielectron). It is similar to the hydrogen atom, with the positron replacing the proton. If a positronium atom makes a transition from the state with \( n = 3 \) to a state with \( n = 1 \), the energy of the photon emitted in this transition is closest to

(A) 6.0 eV
(B) 6.8 eV
(C) 12.2 eV
(D) 13.6 eV
(E) 24.2 eV

\( \text{53\%} \)

30. Given that the binding energy of the hydrogen atom ground state is \( E_0 = 13.6 \text{ eV} \), the binding energy of the \( n = 2 \) state of positronium (positron-electron system) is

(A) \( 8 E_0 \)
(B) \( 4 E_0 \)
(C) \( E_0 \)
(D) \( E_0 / 4 \)
(E) \( E_0 / 8 \)

\( \text{31\%} \)

59. The ground state of the helium atom is a spin

(A) singlet
(B) doublet
(C) triplet
(D) quartet
(E) quintuplet

\( \text{29\%} \)

21. In the hydrogen spectrum, the ratio of the wavelengths for Lyman-\( \alpha \) radiation (\( n = 2 \) to \( n = 1 \)) to Balmer-\( \alpha \) radiation (\( n = 3 \) to \( n = 2 \)) is

(A) 5/48
(B) 5/27
(C) 1/3
(D) 3
(E) 27/5

\( \text{60\%} \)

31. In a \( ^3S \) state of the helium atom, the possible values of the total electronic angular momentum quantum number are

(A) 0 only
(B) 1 only
(C) 0 and 1 only
(D) 0, \( \frac{1}{2} \), and 1
(E) 0, 1, and 2

\( \text{16\%} \)

17. The ground state electron configuration for phosphorus, which has 15 electrons, is

(A) \( 1s^2 2s^2 2p^6 3s^1 3p^4 \)
(B) \( 1s^2 2s^2 2p^6 3s^2 3p^3 \)
(C) \( 1s^2 2s^2 2p^6 3s^3 3d^3 \)
(D) \( 1s^2 2s^2 2p^6 3s^1 3d^4 \)
(E) \( 1s^2 2s^2 2p^6 3p^3 3d^3 \)

\( \text{81\%} \)

84. An energy-level diagram of the \( n = 1 \) and \( n = 2 \) levels of atomic hydrogen (including the effects of spin-orbit coupling and relativity) is shown in the figure above. Three transitions are labeled \( A, B, \) and \( C \). Which of the transitions will be possible electric-dipole transitions?

(A) \( B \) only
(B) \( C \) only
(C) \( A \) and \( C \) only
(D) \( B \) and \( C \) only
(E) \( A, B, \) and \( C \)

\( \text{26\%} \)

90. The spacing of the rotational energy levels for the hydrogen molecule \( \text{H}_2 \) is most nearly

(A) \( 10^{-9} \text{ eV} \)
(B) \( 10^{-3} \text{ eV} \)
(C) \( 10 \text{ eV} \)
(D) \( 10 \text{ MeV} \)
(E) \( 100 \text{ MeV} \)

\( \text{29\%} \)
76. The configuration of three electrons $ls^2p^3p$ has which of the following as the value of its maximum possible total angular momentum quantum number?

A. $\frac{7}{2}$
B. 3
C. $\frac{5}{2}$
D. 2
E. $\frac{3}{2}$

25%

58. The ground state configuration of a neutral sodium atom ($Z = 11$) is

A. $ls^22s^22p^53s^2$
B. $ls^22s^22p^5$
C. $ls^22s^22p^53s^3$
D. $ls^22s^22p^53p$
E. $ls^22s^22p^5$

82%

77. Consider a heavy nucleus with spin $\frac{1}{2}$. The magnitude of the ratio of the intrinsic magnetic moment of this nucleus to that of an electron is

A. zero, because the nucleus has no intrinsic magnetic moment
B. greater than 1, because the nucleus contains many protons
C. greater than 1, because the nucleus is so much larger in diameter than the electron
D. less than 1, because of the strong interactions among the nucleons in a nucleus
E. less than 1, because the nucleus has a mass much larger than that of the electron

25%

79. The energy required to remove both electrons from the helium atom in its ground state is 79.0 eV. How much energy is required to ionize helium (i.e., to remove one electron)?

A. 24.6 eV
B. 39.5 eV
C. 51.8 eV
D. 54.4 eV
E. 65.4 eV

45%

19. The primary source of the Sun’s energy is a series of thermonuclear reactions in which the energy produced is $c^2$ times the mass difference between

A. two hydrogen atoms and one helium atom
B. four hydrogen atoms and one helium atom
C. six hydrogen atoms and two helium atoms
D. three helium atoms and one carbon atom
E. two hydrogen atoms plus two helium atoms and one carbon atom

36%

20. In the production of X rays, the term “bremsstrahlung” refers to which of the following?

A. The cut-off wavelength, $\lambda_{\text{min}}$, of the X-ray tube
B. The discrete X-ray lines emitted when an electron in an outer orbit fills a vacancy in an inner orbit of the atoms in the target metal of the X-ray tube
C. The discrete X-ray lines absorbed when an electron in an inner orbit absorbs a vacancy in an outer orbit of the atoms in the target metal of the X-ray tube
D. The smooth, continuous X-ray spectra produced by high-energy blackbody radiation from the X-ray tube
E. The smooth, continuous X-ray spectra produced by rapidly decelerating electrons in the target metal of the X-ray tube

49%

75. A uranium nucleus decays at rest into a thorium nucleus and a helium nucleus, as shown above. Which of the following is true?

A. Each decay product has the same kinetic energy.
B. Each decay product has the same speed.
C. The decay products tend to go in the same direction.
D. The thorium nucleus has more momentum than the helium nucleus.
E. The helium nucleus has more kinetic energy than the thorium nucleus.

61%
67. The $^{238}\text{U}$ nucleus has a binding energy of about 7.6 MeV per nucleon. If the nucleus were to fission into two equal fragments, each would have a kinetic energy of just over 100 MeV. From this, it can be concluded that

(A) $^{238}\text{U}$ cannot fission spontaneously 19%
(B) $^{238}\text{U}$ has a large neutron excess
(C) nuclei near $A = 120$ have masses greater than half that of $^{238}\text{U}$
(D) nuclei near $A = 120$ must be bound by about 6.7 MeV/nucleon
(E) nuclei near $A = 120$ must be bound by about 8.5 MeV/nucleon

78. The muon decays with a characteristic lifetime of about $10^{-6}$ second into an electron, a muon neutrino, and an electron antineutrino. The muon is forbidden from decaying into an electron and just a single neutrino by the law of conservation of

(A) charge 52%
(B) mass
(C) energy and momentum
(D) baryon number
(E) lepton number

97. Lattice forces affect the motion of electrons in a metallic crystal, so that the relationship between the energy $E$ and wave number $k$ is not the classical equation $E = \frac{\hbar^2 k^2}{2m}$, where $m$ is the electron mass. Instead, it is possible to use an effective mass $m^*$ given by which of the following?

(A) $m^* = \frac{1}{2} \frac{\hbar^2 k \left( \frac{dk}{dE} \right)}{rac{dE}{dk}}$
(B) $m^* = \frac{\hbar^2 k \left( \frac{dk}{dE} \right)}{\frac{dE}{dk}}$ 9%
(C) $m^* = \hbar^2 k \left( \frac{d^2 k}{dE^2} \right)^{\frac{1}{2}}$
(D) $m^* = \frac{\hbar^2}{\frac{d^2 E}{dk^2}}$
(E) $m^* = \frac{1}{2} \hbar^2 m^2 \left( \frac{d^2 E}{dk^2} \right)$

91. The particle decay $\Lambda \rightarrow p + \pi^-$ must be a weak interaction because

(A) the $\pi^-$ is a lepton
(B) the $\Lambda$ has spin zero
(C) no neutrino is produced in the decay
(D) it does not conserve angular momentum
(E) it does not conserve strangeness 29%

52. The conventional unit cell of a body-centered cubic Bravais lattice is shown in the figure above. The conventional cell has volume $a^3$. What is the volume of the primitive unit cell?

(A) $a^3/8$
(B) $a^3/4$
(C) $a^3/2$
(D) $a^3$
(E) $2a^3$ 12%

24. Solid argon is held together by which of the following bonding mechanisms?

(A) Ionic bond only
(B) Covalent bond only
(C) Partly covalent and partly ionic bond
(D) Metallic bond
(E) van der Waals bond

23. The Fermi temperature of Cu is about 80,000 K. Which of the following is most nearly equal to the average speed of a conduction electron in Cu?

(A) $2 \times 10^{-1}$ m/s
(B) 2 m/s
(C) $2 \times 10^2$ m/s
(D) $2 \times 10^4$ m/s
(E) $2 \times 10^6$ m/s

29%