For the entire exam, solutions are aqueous and T = 25 °C unless stated otherwise.

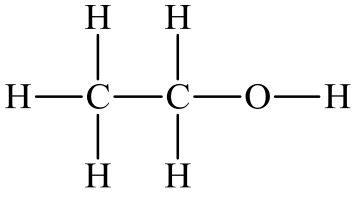
Questions 1–15 cover material from Exam 1.

1. What state of matter is described as follows?

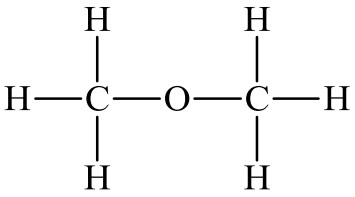
   On the molecular level, the distances between the molecules are far greater than the sizes of the molecules. Therefore, the density of this state of matter is very low compared to the other states.

   A. Gas
   C. Liquid
   B. Solid
   D. Solid and liquid

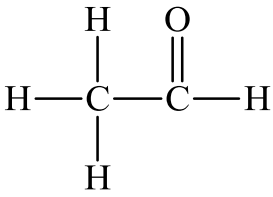
2. Consider the following three substances in the liquid state:



ethanol



dimethyl ether



ethanal

   Which statement is true about these substances?

   A. All three substances can hydrogen bond because all substances contain hydrogen atoms.

   B. Both ethanol and ethanal can hydrogen bond because both substances contain oxygen close to hydrogen.

   C. Ethanol is the only substance of the three that can hydrogen bond.

   D. None of the substances meet the criteria for hydrogen bonding.

3. The surface tension of a liquid _____ and the viscosity of a liquid _____ with increasing intermolecular forces.

   A. decreases, decreases
   C. decreases, increases
   B. increases, increases
   D. increases, decreases

4. The rate of evaporation of a liquid _____ as the temperature increases and _____ as the surface area increases.

A. decreases, decreases
C. decreases, increases
B. increases, increases
D. increases, decreases

5. Methanol has a normal boiling point of 64.7 °C and a heat of vaporization (ΔH_{vap}) of 35.29 kJ/mol. What is the vapor pressure of methanol at 25.0 °C?

A. 395 torr
C. 892 torr
B. 4.30 torr
D. 143 torr

6. How much heat is required to sublime 2.00 mol $I_2(s)$?

ΔH_{fus} = 7.76 kJ/mol

ΔH_{vap} = 20.9 kJ/mol

A. 57.3 kJ
C. 11.6 kJ
B. 124 kJ
D. 30.8 kJ

7. How much heat is required to convert 100. g of water at 75.0 °C to steam at 100. °C?

Specific heat, ice = 2.09 J/g·°C
Specific heat, water = 4.18 J/g·°C
Specific heat, steam = 2.01 J/g·°C
Heat of vaporization, water = 40.7 kJ/mol
Heat of fusion, water = 6.02 kJ/mol
Molar mass H_2O = 18.015 g/mol

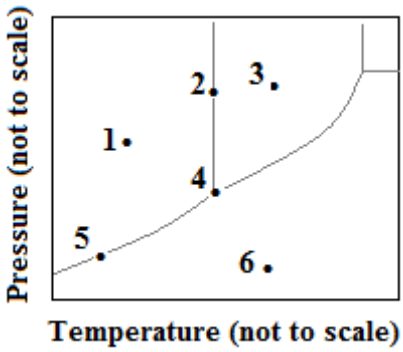
A. 1.10×10^4 kJ

B. 367 kJ

C. 236 kJ

D. 10.9 kJ

8.



Examine the phase diagram above. Determine which of the following correctly identifies the points.

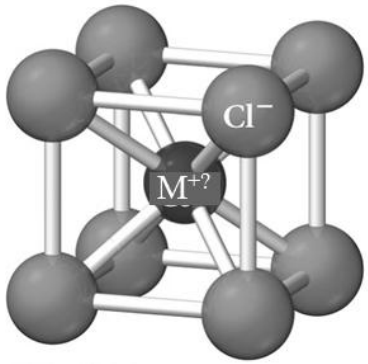
A. Point 3 is in the liquid region. Point 4 is the triple point.

B. Point 6 is in the solid region. Point 2 is on the liquid-gas phase boundary.

C. Point 3 is in the solid region. Point 5 is on the liquid-gas phase boundary.

D. Point 1 is in the liquid region. Point 4 is the critical point.

9. The following image is the unit cell of a metal chloride. The metal ion (of unknown charge) is at the center of the unit cell and the chloride ions are located on the corners. Determine the empirical formula of the metal chloride.



A. MCl_8

B. MCl_2

C. MCl_4

D. MCl

10. Chromium crystallizes in a body-centered cubic unit cell with a mass of 1.73×10^{-22} g. The edge length of the unit cell is 2.89×10^{-8} cm. Select the value that is closest to the density of chromium.

A. 0.1 g/cm^3

B. 1 g/cm^3

C. 10 g/cm^3

D. 20 g/cm^3

11. Which of the following is the **<u>least</u>** soluble in benzene (C_6H_6)?

A. $CH_3CH_2CH_2CH_2CH_3$

B. H_2O

C. $CH_3CH_2CH_2CH_2CH_2OH$

D. $CH_3CH_2CH_2CH_2OH$

12. Which statement best describes the unique property of a supersaturated solution?

A. A supersaturated solution must have more solute than solvent.

B. A supersaturated solution can dissolve more solute.

C. A supersaturated solution has more solute dissolved than predicted by the solubility.

D. A supersaturated solution has a precipitated solute in equilibrium with the dissolved solute.

13. A solution is prepared by dissolving 0.025 g $O_2(g)$ in 2.5 kg of water. What is the molality of the solution?

A. $6.9 \times 10^{-4}\ m$

B. $1.0 \times 10^{-2}\ m$

C. $3.4 \times 10^{-1}\ m$

D. $3.1 \times 10^{-4}\ m$

14. A solution is prepared by dissolving 14.20 g NaCl in enough water to produce 150.0 mL of solution. The density of the solution is 1.008 g/mL. Determine the percent by mass of the solution.

A. 9.489 %

B. 9.123 %

C. 9.392 %

D. 9.266 %

15. A sample of seawater is 0.428 M in NaCl with a density of 1.018 g/mL at 25.0 °C. What is the molality of NaCl in this sample?

A. 0.431 *m*
C. 0.321 *m*
B. 0.493 *m*
D. 0.784 *m*

Questions 16–30 cover material from Exam 2.

16. Which of the following has the correct van't Hoff factor indicated?

A. Na_3PO_4, $i = 4$
C. $CH_3CH_2CH_3$, $i = 3$
B. KOH, $i = 3$
D. $Mg(C_2H_3O_2)_2$, $i = 2$

17. The osmotic pressure of 250.0 mL of a solution of an unknown nonelectrolyte is 452 torr at 348 K. Determine the molarity of the solution.

A. 0.0633 M
C. 0.0208 M
B. 2.56 M
D. 15.2 M

18. Which solution would you expect to experience the **greatest** boiling point elevation?

A. 0.05 M $Al_2(SO_4)_3$
C. 0.05 M K_2SO_4
B. 0.10 Na_2CO_3
D. 0.15 M $C_6H_{12}O_6$

19. Use the data in the table provided to determine the rate law of the reaction

$$2\ A(g) + 2\ B(g) \rightarrow 2\ C(g) + D(g)$$

Experiment	[A], (M)	[B], (M)	Initial Rate (M/s)
1	0.100	0.100	0.014
2	0.200	0.100	0.057
3	0.200	0.200	0.115
4	0.400	0.400	0.920

A. Rate = $k[A][B]^2$

B. Rate = $k[A]^2[B]$

C. Rate = $k[A]^2[B]^2$

D. Rate = $k[A][B]$

20. For a certain first-order reaction, the half-life is 2.55 s. What percent of the reactant will **remain** after 5.95 seconds?

A. 19.8 %

B. 25.0 %

C. 22.3 %

D. 73.2 %

21. Which statement correctly explains what occurs on the molecular level that leads to an increase of reaction rate with temperature?

A. As the temperature increases, the reactants turn into gases and gases have the fastest rates of reactions.

B. As the temperature increases, the kinetic energy of the molecules increases. Therefore, more molecules have the minimum energy necessary to initiate the reaction.

C. As the temperature increases, the distance between molecules decreases. This gives rise to more frequent collisions and more frequent collisions gives rise to a faster rate.

D. There is **not** an increase in reaction rate with temperature. The rate usually decreases with temperature.

22. A certain chemical reaction has an activation energy of 96.8 kJ/mol and a rate constant of 0.00329 s^{-1} at 295 K. If the temperature is increased to 350 K, what is the new rate constant?

A. 0.945 s^{-1}

B. 2.03 s^{-1}

C. 1.62 s^{-1}

D. 0.00265 s^{-1}

23. Initially the following reaction mixture contains 1.0 atm each of SO_2, O_2 and SO_3.

$$2\ SO_2(g) + O_2(g) \rightleftharpoons 2\ SO_3(g) \qquad K_p = 6.9 \times 10^6 \text{ (at 298 K)}$$

What is **<u>true</u>** about the system at equilibrium?

A. $2P_{O_2} = P_{SO_3}$

B. $P_{SO_3} > P_{SO_2}$

C. $2P_{SO_2} + P_{O_2} = P_{SO_3}$

D. $P_{O_2} > P_{SO_3}$

24. Which statement is **<u>false</u>** about the following reaction mechanism?

$ClO^-(aq) + H_2O(l) \rightleftharpoons HClO(aq) + OH^-(aq)$ Fast

$I^-(aq) + HClO(aq) \rightleftharpoons HIO(aq) + Cl^-(aq)$ Slow

$OH^-(aq) + HIO(aq) \rightleftharpoons H_2O(l) + IO^-(aq)$ Fast

$ClO^-(aq) + I^-(aq) \rightleftharpoons Cl^-(aq) + IO^-(aq)$ Overall

A. H_2O is a catalyst.

B. I^- is a reactant.

C. HClO is an intermediate.

D. HIO is a catalyst.

25. What is K_p for the overall reaction that converts propane (C_3H_8) and steam to carbon dioxide and hydrogen gas (H_2) at 1200 K given the following information?

$C_3H_8(g) + 3\ H_2O(g) \rightleftharpoons 3\ CO(g) + 7\ H_2(g)$ $\quad K_p = 8.175 \times 10^{15}$

$CO(g) + H_2O(g) \rightleftharpoons CO_2(g) + H_2(g)$ $\quad K_p = 0.6944$

A. 3.473×10^{16}

B. 8.268×10^{15}

C. 1.229×10^{14}

D. 2.737×10^{15}

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26. Ethanol can be produced according to the following equation:

$$C_2H_4(g) + H_2O(g) \rightleftharpoons C_2H_5OH(g) \qquad K_c = ? \text{ at } 250\ K$$

When the **initial** concentrations of C_2H_4 and H_2O are both 1.000 M, the **equilibrium** concentration of C_2H_4 is 0.036 M. What is the value of K_c?

A. 9.6×10^{-1}

B. 2.8×10^{1}

C. 7.4×10^{2}

D. 3.9×10^{3}

---

27. For the following reaction at 298 K, $K_p = 6.70$.

$$2\ NO_2(g) \rightleftharpoons N_2O_4(g)$$

At equilibrium, the partial pressure of NO_2 is 0.250 atm. Determine the partial pressure of N_2O_4 at equilibrium.

A. 0.419 atm

B. 1.50 atm

C. 1.22 atm

D. 1.63 atm

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28. Given the following reaction, initially at equilibrium, which change will cause the greatest shift in the equilibrium to favor product formation?

$$3\ C(s) + 4\ H_2(g) \rightleftharpoons C_3H_8(g) \qquad \Delta H_{rxn} = -105\ kJ/mol$$

A. Double the mass of C
B. Decrease the pressure of the container
C. Lower the temperature
D. Remove H_2

29. In the following reaction, NH_3 is behaving as a(n) _____.

$$H_2PO_4^-(aq) + NH_3(aq) \rightarrow HPO_4^{2-}(aq) + NH_4^+(aq)$$

A. Arrhenius base
B. Arrhenius acid
C. Brønsted-Lowry base
D. Brønsted-Lowry acid

30. Calculate $[OH^-]$ at 25 °C for a solution with $[H_3O^+] = 3.25 \times 10^{-4}$ M and indicate whether the solution is acidic, basic, or neutral.

A. $[OH^-] = 3.08 \times 10^{-11}$ M, acidic
B. $[OH^-] = 3.08 \times 10^{-11}$ M, basic
C. $[OH^-] = 1.28 \times 10^{-3}$ M, acidic
D. $[OH^-] = 1.28 \times 10^{-3}$ M, basic

Questions 31–45 cover material from Exam 3.

31. A 0.20 M solution of a monoprotic acid has a percent ionization of 3.9%. Determine K_a of the acid.

A. 3.9×10^{-2}
C. 3.2×10^{-4}
B. 6.5×10^{-4}
D. 1.8×10^{-5}

32. Calculate the pH of a solution that contains 0.060 M HNO_3 and 0.40 M HOCl (hypochlorous acid, $K_a = 2.9 \times 10^{-8}$).

A. 2.45
C. 1.05
B. 6.00
D. 1.22

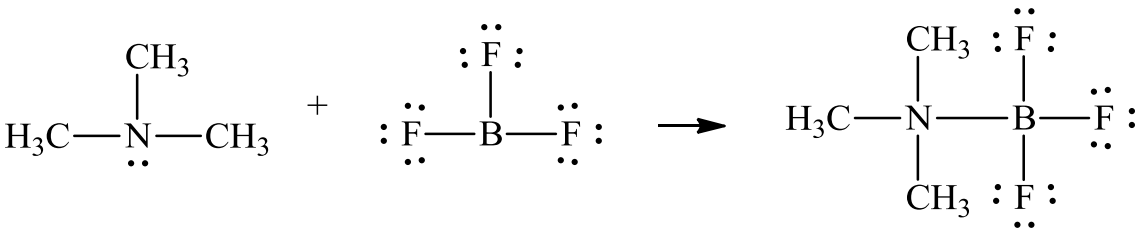
33. Which salt will be neutralized by the addition of HBr?

A. NaF
C. CaI_2
B. $LiNO_3$
D. NH_4Cl

34. Select the **strongest** of these oxyacids.

A. HClO
C. HBrO
B. $HClO_2$
D. $HBrO_2$

35. Which statement is **<u>true</u>** for the reaction given below?



A. $(CH_3)_3N$ is a Lewis base; it is an electron pair donor.

B. $(CH_3)_3N$ is a Lewis acid; it is an electron pair acceptor.

C. BF_3 is a Lewis base; it is an electron pair donor.

D. BF_3 is a Lewis base; it is an electron pair acceptor.

36. A buffer made of hypochlorous acid (HClO, $K_a = 2.9 \times 10^{-8}$) and sodium hypochlorite (NaClO) has a pH of 8.38. What is true about the ratio of base to acid for this buffer?

A. $[ClO^-] = [HClO]$

B. $[ClO^-] = 10[HClO]$

C. $[ClO^-] > [HClO]$

D. $[ClO^-] < [HClO]$

37. A few milliliters of 0.10 M NaOH are added to 100 mL of a buffer containing 0.10 M $HC_2H_3O_2$ (acetic acid) and 0.15 M $NaC_2H_3O_2$ (sodium acetate). Which of the following reactions represents the neutralization of the strong base?

A. $H_2O(l) + HC_2H_3O_2(aq) \rightarrow C_2H_3O_2^-(aq) + OH^-(aq)$

B. $H_3O^+(aq) + C_2H_3O_2^-(aq) \rightarrow HC_2H_3O_2(aq) + H_2O(l)$

C. $OH^-(aq) + HC_2H_3O_2(aq) \rightarrow C_2H_3O_2^-(aq) + H_2O(l)$

D. $H_3O^+(aq) + OH^-(aq) \rightarrow 2\ H_2O(l)$

38. Calculate the pH of a solution when 10.10 mL of 0.10 M HCl is titrated with 10.10 mL of 0.10 M CH_3NH_2. $K_b(CH_3NH_2) = 4.4 \times 10^{-4}$, $K_a(CH_3NH_3^+ = 2.3 \times 10^{-11})$.

A. 8.23
C. 4.26
B. 5.97
D. 9.77

39. Calculate the pH after 27.5 mL of 0.350 M HNO_3 has been added to 50.0 mL of a 0.160 M codeine solution. K_b(codeine) $= 1.6 \times 10^{-6}$.

A. 3.892
C. 1.678
B. 2.739
D. 0.224

40. Calculate the molar solubility of $PbBr_2$ in pure water. K_{sp} ($PbBr_2$) $= 4.67 \times 10^{-6}$.

A. 1.37×10^{-6} M
C. 2.19×10^{-3} M
B. 1.39×10^{-2} M
D. 1.05×10^{-2} M

41. A solution is 1.50×10^{-3} M in $Ca(NO_3)_2$ and 3.40×10^{-3} M in NaF. K_{sp} (CaF_2) $= 1.46 \times 10^{-10}$. Which of the following statements is true?

A. $Q = 1.73 \times 10^{-8}$ and **a precipitate** will form.
B. $Q = 5.10 \times 10^{-6}$ and **a precipitate** will form.
C. $Q = 1.73 \times 10^{-8}$ and **no precipitate** will form.
D. $Q = 5.10 \times 10^{-6}$ and **no precipitate** will form.

42. An aqueous solution is 0.100 M in Ca^{2+}, Mg^{2+}, and Zn^{2+}. When sufficient $C_2O_4^{2-}$ is added to the solution, CaC_2O_4 ($K_{sp} = 2.32 \times 10^{-9}$), MgC_2O_4 ($K_{sp} = 4.83 \times 10^{-6}$), and ZnC_2O_4 ($K_{sp} = 2.70 \times 10^{-8}$) will precipitate from the solution. What minimum concentration of $C_2O_4^{2-}$ is needed to begin precipitation of the salt that precipitates first?

A. 2.32×10^{-8}

B. 4.83×10^{-5}

C. 2.70×10^{-9}

D. 2.08×10^{-3}

43. Which of the following processes is accompanied by an **increase** in entropy of the system?

A. Freezing of water.

B. Evaporation of water.

C. Condensation of methanol vapor.

D. Crystallization of a supersaturated solution of fructose.

44. Which balanced chemical equation shows the **greatest decrease** in entropy for the reaction?

A. $2\ NO_2(g) \rightarrow N_2O_4(g)$

B. $CO(g) + 2\ H_2(g) \rightarrow CH_3OH(g)$

C. $SnO_2(s) + H_2(g) \rightarrow Sn(s) + H_2O(g)$

D. $2\ H_2S(g) + 3\ O_2(g) \rightarrow 2\ H_2O(l) + 2\ SO_2(g)$

45. What is the change in entropy of the surroundings for the following reaction at 15.0°C?

$C_3H_8(g) + 5\ O_2(g) \rightarrow 3\ CO_2(g) + 4\ H_2O(g)$ $\Delta H_{rxn} = -2044$ kJ

A. 7.10 kJ/K

B. 183 kJ/K

C. 27.4 kJ/K

D. 2.63 kJ/K

Questions 46–60 cover material after Exam 3.

46. For a spontaneous process, which of the following must be **true**?

A. $\Delta S_{rxn} < 0$

B. $\Delta S_{rxn} > 0$

C. $\Delta G_{rxn} < 0$

D. $\Delta G_{rxn} > 0$

47. Given the table of ΔG_f^o below, determine the standard Gibbs free energy change of the following reaction.

$$2\ CO(g) + 2\ NO\ (g) \rightarrow 2\ CO_2(g) + N_2(g)$$

Substance	ΔG_f^o (kJ/mol)
$CO(g)$	–137.2
$CO_2(g)$	–394.4
$NO(g)$	87.6

A. –689.6 kJ

B. –344.2 kJ

C. –426.1 kJ

D. More information is needed.

48. Find ΔG_{rxn}^o for $Cu_2O(s) + C(s) \rightarrow 2\ Cu(s) + CO(g)$ at 375 K, given

$Cu_2O(s) \rightarrow 2\ Cu(s) + ½\ O_2(g)$ $\quad \Delta G_{rxn}^o = 140.0$ kJ at 375 K

$CO(g) \rightarrow C(s) + ½\ O_2(g)$ $\quad \Delta G_{rxn}^o = 143.8$ kJ at 375 K.

A. 14.1 kJ

B. 317.2 kJ

C. –3.8 kJ

D. –7.2 kJ

49. Consider the following reaction at 298 K.

$$2\ H_2S(g) + SO_2(g) \rightarrow 3\ S(s, \text{rhombic}) + 2\ H_2O(g) \qquad \Delta G^{o}_{rxn} = -102\ kJ$$

Calculate ΔG_{rxn} when

$$P_{H_2S} = 1.50\ atm;\ P_{SO_2} = 2.50\ atm;\ \text{and}\ P_{H_2O} = 0.0150\ atm.$$

A. –78 kJ
C. –152 kJ
B. –102 kJ
D. –127 kJ

50. The equilibrium constant, $K_c = 9.90 \times 10^3$ at 327 °C for the following reaction:

$$C_2H_4(g) + H_2O(g) \rightleftharpoons C_2H_5OH(g)$$

Calculate ΔG^{o}_{rxn} at 327 °C.

A. –45.9 kJ
C. –0.455 kJ
B. –25.9 kJ
D. –248 kJ

51. What is the coefficient **a** when the equation below is balanced in acid with the smallest possible integers?

$$\mathbf{a}\ Al(s) + \mathbf{b}\ MnO_4^-(aq) \rightarrow \mathbf{c}\ Al^{3+}(aq) + \mathbf{d}\ Mn^{2+}(aq)$$

A. 2
C. 5
B. 3
D. 12

52. A voltmeter connected to the following cell under standard-state conditions reads 0.34 V. Which statement is true?

$$Pt(s) \mid H_2(g, 1\ atm) \mid H^+(aq, 1.0\ M) \parallel Cu^{2+}(aq, 1.0\ M) \mid Cu(s)$$

A. The reduction half-cell potential of $Cu^{2+} + 2\ e^- \rightarrow Cu$ is –0.34 V

B. The reduction half-cell potential of $Cu^{2+} + 2\ e^- \rightarrow Cu$ is 0.34 V

C. The reduction half-cell potential of $Cu^{2+} + 2\ e^- \rightarrow Cu$ is –0.17 V

D. The reduction half-cell potential of $Cu^{2+} + 2\ e^- \rightarrow Cu$ is 0.17 V

53. Calculate E^o for the following reaction at 298 K:

$$Ca^{2+}(aq) + 2\ Cu(s) \rightarrow Ca(s) + 2\ Cu^+(aq)$$

$Ca^{2+}(aq) + 2\ e^- \rightarrow Ca(s)$ $\quad E^o = –2.76$ V
$Cu^+(aq) + e^- \rightarrow Cu(s)$ $\quad E^o = 0.52$ V

A. –3.80 V

B. –2.24 V

C. –3.28 V

D. 3.28 V

54. A voltaic cell is constructed that uses the following reaction:

$$Al(s) + Au^{3+}(aq) \rightarrow Al^{3+}(aq) + Au(s)$$

What is E_{cell} when $[Au^{3+}] = 0.0250$ M and $[Al^{3+}] = 0.850$ M at 25 °C? The standard cell potential for the reaction is 3.16 V.

A. 3.13 V

B. 2.65 V

C. 3.98 V

D. 2.02 V

55. Which reaction occurs **<u>at the anode</u>** during the electrolysis of molten Al_2O_3?

A. Al^{3+} is oxidized to Al.

B. Al^{3+} is reduced to Al.

C. O^{2-} is oxidized to O_2.

D. O^{2-} is reduced to O_2.

56. Silver can be plated out of a solution containing Ag^+ ions according to the half-reaction:

$$Ag^+(aq) + e^- \rightarrow Ag(s).$$

How long would it take to plate 15 g of silver using a current of 2.5 A?

A. 6.0 min

B. 38 min

C. 3.3×10^4 min

D. 89 min

57. Which type of radioactive decay emits high-energy electromagnetic waves, often in conjunction with other types of radiation?

A. α decay

B. β decay

C. γ emission

D. $^{0}_{+1}e$ emission

58. The elements below lie in the region of the *Valley of Stability* where N/Z ≈ 1. Select the nuclide that undergoes positron emission to achieve stability.

A. $^{28}_{12}\text{Mg}$

B. $^{22}_{12}\text{Mg}$

C. $^{31}_{10}\text{Ne}$

D. $^{25}_{10}\text{Ne}$

59. A radioactive sample contains 1.40 g of an isotope that decays with a rate constant of 0.182 day^{-1}. What mass of the isotope **remains** after 6.5 days?

A. 0.25 g

B. 1.02 g

C. 0.75 g

D. 0.43 g

60. How many half-lives must pass for the radioactivity of a technetium-99m sample to decrease to **below** 5.0% of its initial level?

A. 2 half-lives

B. 3 half-lives

C. 5 half-lives

D. 8 half-lives

Answer Key:

1. A
2. C
3. B
4. B
5. D
6. A
7. C
8. A
9. D
10. C
11. B
12. C
13. D
14. C
15. A
16. A
17. C
18. B
19. B
20. ?
21. B
22. C
23. B
24. D
25. D
26. C
27. A
28. C
29. C
30. A
31. C
32. D
33. A
34. B
35. A
36. C
37. C
38. B
39. C

40. D
41. A
42. A
43. B
44. D
45. A
46. C
47. A
48. C
49. D
50. A
51. C
52. B
53. C
54. A
55. C
56. D
57. C
58. B
59. D
60. C