Part I—Multiple Choice. All questions here are from old AP Chemistry exams. Remember that no calculators are allowed on the multiple choice so you need to be able to do these questions without a calculator.

1) Which of the following acids can be oxidized to form a stronger acid?
   a. H₃PO₄
   b. HNO₃
   c. H₂CO₃
   d. H₃BO₃
   e. H₂SO₃

2) HSO₄⁻ + H₂O ⇌ SO₄²⁻ + H₃O⁺
   In the equilibrium represented here, the species that act as bases include which of the following?
   I. HSO₄⁻
   II. H₂O
   III. SO₄²⁻
   a. II only
   b. III only
   c. I and II
   d. I and III
   e. II and III

3) A molecule or ion is classified as a Lewis acid if it
   a. accepts a proton from water
   b. accepts a pair of electrons to form a bond
   c. donates a pair of electrons to form a bond
   d. donates a proton to water
   e. has resonance Lewis electron-dot structures

4) The reaction shown here has an equilibrium constant equal to 3.7 x 10⁴. Which of the following can be concluded from this information?
   HC₂H₃O₂ + CN⁻ ⇌ HCN + C₂H₃O₂⁻
   a. CN⁻ is a stronger base than C₂H₃O₂⁻.
   b. HCN is a stronger acid than HC₂H₃O₂.
   c. The conjugate base of CN⁻ is C₂H₃O₂⁻.
   d. The equilibrium constant will increase with an increase in temperature.
   e. The pH of a solution containing equimolar amounts of CN⁻ and HC₂H₃O₂ is 7.0.

5) The volume of distilled water that should be added to 10.0 mL of 6.00 M HCl in order to prepare a 0.500 M HCl solution is approximately
   a. 50.0 mL
   b. 60.0 mL
   c. 100. mL
   d. 110. mL
   e. 120. mL
6) Each of the following can act as both a Bronsted acid and a Bronsted base EXCEPT
   a. HCO$_3^-$
   b. H$_3$PO$_4^-$
   c. NH$_4^+$
   d. H$_2$O
   e. HS$^-$

7) Which, if any, of the following species is in the greatest concentration in a 0.100-molar solution of H$_2$SO$_4$ in water?
   a. H$_2$SO$_4$ molecules
   b. H$_3$O$^+$ ions
   c. HSO$_4^-$ ions
   d. SO$_4^{2-}$ ions
   e. All species are in equilibrium and therefore have the same concentration.

8) The pH of 0.1-molar ammonia is approximately
   a. 1
   b. 4
   c. 7
   d. 11
   e. 14

9) As the number of oxygen atoms increases in any series of oxygen acids, such as HXO, HXO$_2$, HXO$_3$, which of the following is generally true?
   a. The acid strength varies unpredictably.
   b. The acid strength decreases only if X is a nonmetal.
   c. The acid strength decreases only if X is a metal.
   d. The acid strength decreases whether X is a nonmetal or a metal.
   e. The acid strength increases.

10) Oxalic acid, H$_2$C$_2$O$_4$, is a diprotic acid with K$_1 = 5 \times 10^{-2}$ and K$_2 = 5 \times 10^{-5}$. Which of the following is equal to the equilibrium constant for the reaction represented above?
    a. $5 \times 10^{-2}$
    b. $5 \times 10^{-5}$
    c. $2.5 \times 10^{-6}$
    d. $5 \times 10^{-7}$
    e. $2.5 \times 10^{-8}$

11) A 1-molar solution of which of the following salts has the highest pH?
    a. NaNO$_3$
    b. Na$_2$CO$_3$
    c. NH$_4$Cl
    d. NaHSO$_4$
    e. Na$_2$SO$_4$

12) What is the pH of a $1.0 \times 10^{-2}$-molar solution of HCN? (For HCN, K$_a = 4.0 \times 10^{-10}$)
    a. 10
    b. between 7 and 10
    c. 7
    d. between 4 and 7
    e. 4

13) A solution of calcium hypochlorite, a common additive to swimming-pool water, is
    a. basic because of the hydrolysis of the OCI$^-$ ion
    b. basic because Ca(OH)$_2$ is a weak and insoluble base
    c. neutral if the concentration is kept below 0.1 molar
    d. acidic because of the hydrolysis of the Ca$^{2+}$ ions
    e. acidic because the acid HOCl is formed
Part II—Short Answer. Please show your work on separate paper.

14) A chemical reaction occurs when 100. milliliters of 0.200-molar HCl is added dropwise to 100. milliliters of 0.100-molar Na₃PO₄ solution.
   a. Write the two net ionic equations for the formation of the major products.
   b. Identify the species that acts as both a Bronsted acid and as a Bronsted base in the equation in (a). Draw the Lewis electron-dot diagram for this species.
   c. Sketch a graph using the axes provided, showing the shape of the titration curve that results when 100. milliliters of the HCl solution is added slowly from a buret to the Na₃PO₄ solution. Account for the shape of the curve.

   ![Graph](image)

   d. Write the equation for the reaction that occurs if a few additional milliliters of the HCl solution are added to the solution resulting from the titration in (c).

15) A 0.682 gram sample of an unknown weak monoprotic organic acid, HA was dissolved in sufficient water to make 50 milliliters of solution and was titrated with a 0.135 molar NaOH solution. After the addition of 10.6 milliliters of base, a pH of 5.65 was recorded. The equivalence point (end point) was reached after the addition of 27.4 milliliters of the 0.135 molar NaOH.
   a. Calculate the number of moles of acid in the original sample.
   b. Calculate the molecular weight of the acid HA.
   c. Calculate the number of moles of unreacted HA remaining in solution when the pH was 5.65.
   d. Calculate the [H₃O⁺] at pH = 5.65
   e. Calculate the value of the ionization constant, $K_a$, of the acid HA.

16) Hypochlorous acid, HOCl, is a weak acid commonly used as a bleaching agent. The acid-dissociation constant, $K_a$, for the reaction represented above is $3.2 \times 10^{-8}$.
   a. Calculate the [H⁺] of a 0.14-molar solution of HOCl.
   b. Write the correctly balanced net ionic equation for the reaction that occurs when NaOCl is dissolved in water and calculate the numerical value of the equilibrium constant for the reaction.
   c. Calculate the pH of a solution made by combining 40.0 milliliters of 0.14-molar HOCl and 10.0 milliliters of 0.56-molar NaOH.
   d. How many millimoles of solid NaOH must be added to 50.0 milliliters of 0.20-molar HOCl to obtain a buffer solution that has a pH of 7.49? Assume that the addition of the solid NaOH results in a negligible change in volume.
   e. Household bleach is made by dissolving chlorine gas in water, as represented below.

   $\text{Cl}_2(g) + \text{H}_2\text{O} \rightarrow \text{H}^+ + \text{Cl}^- + \text{HOCl}(aq)$

   Calculate the pH of such a solution if the concentration of HOCl in the solution is 0.065 molar.
HF(aq) + H₂O(l) ⇌ H₃O⁺(aq) + F⁻(aq)  \quad K_a = 7.2 \times 10^{-4}

17) Hydrofluoric acid, HF(aq), dissociates in water as represented by the equation above.
   a. Write the equilibrium constant expression for the dissociation of HF in water.
   b. Calculate the molar concentration of H₃O⁺ in a 0.40 M HF solution.

HF(aq) reacts with NaOH(aq) according to the reaction represented below.

HF(aq) + OH⁻(aq) → H₂O(l) + F⁻(aq)

A volume of 15 mL of 0.40 M NaOH(aq) is added to 25 mL of 0.40 M HF(aq) solution. Assume that the volumes are additive.

   c. Calculate the number of moles of HF remaining in the solution.
   d. Calculate the molar concentration of F⁻(aq) in the solution.
   e. Calculate the pH of the solution.

C₆H₅NH₂(aq) + H₂O(l) ⇌ C₆H₅NH₃⁺(aq) + OH⁻(aq)

18) Aniline, a weak base, reacts with water according to the reaction represented above.
   a. Write the equilibrium constant expression, K_b, for the reaction represented above.
   b. A sample of aniline is dissolved in water to produce 25.0 mL of a 0.10 M solution. The pH of the solution is 8.82. Calculate the equilibrium constant, K_b, for the reaction.
   c. The solution prepared in part (b) is titrated with 0.10 M HCl. Calculate the pH of the solution when 5.0 mL of the acid has been added.
   d. Calculate the pH at the equivalence point of the titration in part (c).
   e. The pKₐ values for several indicators are given below. Which of the indicators is most suitable for this titration? Justify your answer.

<table>
<thead>
<tr>
<th>Indicator</th>
<th>pK_b</th>
</tr>
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<tbody>
<tr>
<td>Erythrosine</td>
<td>3</td>
</tr>
<tr>
<td>Litmus</td>
<td>7</td>
</tr>
<tr>
<td>Thymolphthalein</td>
<td>10</td>
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</tbody>
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