CANADIAN CHEMISTRY CONTEST

CHEMISTRY

TOPIC QUESTIONS

King

CANADIAN CHEMISTRY OLYMPIAD | OLYMPIADE DE CHIMIE DU CANADA

2. Acids and Bases

KingCh

12) For the titration of a weak base with a strong acid, which of the following indicators would be best to visualize the equivalence point?

A) Cresol red (pKa = 1.0)
B) Methyl red (pKa = 5.0)
C) Thymol blue (pKa = 8.9)
D) Phenolphthalein (pKa = 9.4)
E) Alizarin yellow (pKa = 11.2)

13) Methylamine is a weak base with a pKb of 3.36. What is the pH of a 0.500 M solution of methylamine?

A) 1.84 B) 10.08 C) 12.16 D) 12.32 E) 13.70

14) An acid-base titration is performed using formic acid (HCOOH) and sodium hydroxide (NaOH) as the titrant, according to the equation below:

$$HCOOH\ (aq) + NaOH\ (aq) \rightarrow H_2O\ (\ell) + NaHCOO\ (aq)$$

If 15.00 mL of 0.400 M sodium hydroxide solution was required to neutralize a 30.00 mL sample of formic acid, what will be the pH at the equivalence point of this titration? The K_a of formic acid is 1.77×10^{-4}.

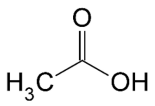
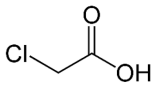
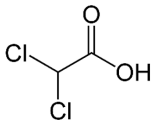
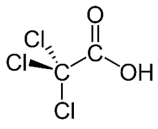
A) 5.562 B) 7.000 C) 8.438 D) 11. 686 E) 13.651

15) Tums® tablets contain the active ingredient calcium carbonate, which eases the symptoms of acid-indigestion by neutralizing hydrochloric acid in the stomach and inhibiting peptic activity. The standard dose for the treatment of acid-indigestion with Tums® is two tablets, which each contain 1000 mg of calcium carbonate. Suppose an individual with a stomach volume of 1 L and pH of 1.64 ingests the recommended dose of Tums®. What will be the resulting pH of the contents of the stomach once the reaction is complete?

A) 2.53 B) 1.78 C) 2.87 D) 2.72 E) 1.89

CCC 2021

19) Consider the structures and associated pKa values in the table below. Which statement below the table best explains the pKa values observed?

			
acetic acid	chloroacetic acid	dichloroacetic acid	trichloroacetic acid
$pK_a = 4.76$	$pK_a = 2.85$	$pK_a = 1.35$	$pK_a = 0.66$

A) The electron density on the ionizable proton is diminished by induction, which increases the strength of the acid
B) The presence of electron-donating alkyl groups increases the stability of the conjugate base, increasing the strength of the acid
C) Resonance stabilization of the conjugate base increases the strength of the acid
D) The presence of electronegative atoms decreases the stability of the conjugate base, decreasing the strength of the acid
E) Resonance stabilization of the conjugate base decreases the strength of the acid

20) $H_2PO_4^-(aq) + H_2O(l) \rightleftharpoons HPO_4^{2-}(aq) + H_3O^+(aq)$ $K_a = 6.2 \times 10^{-8}$

$H_3PO_4(aq) + H_2O(l) \rightleftharpoons H_2PO_4^-(aq) + H_3O^+(aq)$ $K_a = 7.9 \times 10^{-3}$

$CH_3COOH(aq) + H_2O(l) \rightleftharpoons CH_3COO^-(aq) + H_3O^+(aq)$ $K_a = 1.8 \times 10^{-5}$

Using the equilibria above, determine which of the following combinations of solutions will generate a buffer with a pH of approximately 5?

A) 50 mL of 0.10 mol L^{-1} Na_2HPO_4 + 100 mL of 0.10 mol L^{-1} NaH_2PO_4
B) 100 mL of 0.10 mol L^{-1} $NaCH_3COO$ + 100 mL of 0.10 mol L^{-1} NaOH
C) 100 mL of 0.10 mol L^{-1} NaH_2PO_4 + 100 mL of 0.10 mol L^{-1} HCl
D) 100 mL of 0.10 mol L^{-1} NaH_2PO_4 + 100 mL of 0.10 mol L^{-1} NaOH
E) 100 mL of 0.10 mol L^{-1} CH_3COOH + 50 mL of 0.10 mol L^{-1} NaOH

CCC 2020

8) Vinegar used as a cooking ingredient, or in pickling, is a solution of 5% acetic acid (CH_3COOH) by mass in solution with water. The pKa= 4.76 for acetic acid at 25°C. Evaluate the **pH** of vinegar at 25 °C.

A) 4.80 B) 4.15 C) 2.92 D) 2.42 E) 2.24

13) A student combines 75 mL of 0.500 mol L^{-1} hydrochloric acid with 55 mL of 0.125 M KOH. What is the pH of the resulting solution?

A) 0.30 B) 0.39 C) 0.63 D) 1.51 E) 7.00

CCC 2019

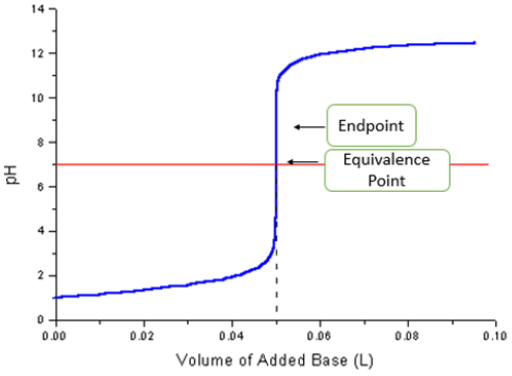
8) Hydrofluoric acid reacts with potassium hydroxide according to the net ionic equation:

$$HF\ (aq) + OH^-\ (aq) \rightarrow F^-\ (aq) + H_2O\ (l)$$

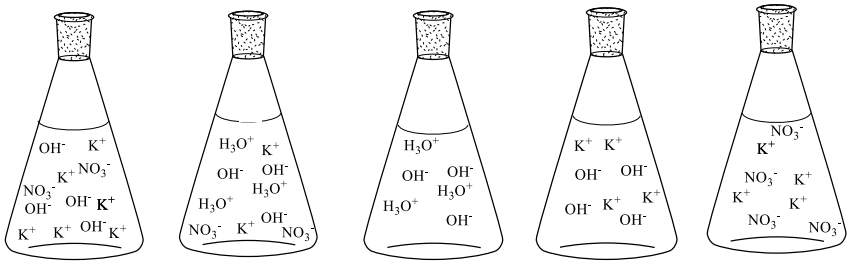
If 5.0 mL of 1.0 M KOH are added to 25.0 mL of 2.0 M HF, what is the pH of the resulting solution? The K_a of HF is 7.2×10^{-4}.

A) 1.42 B) 1.48 C) 1.66 D) 2.19 E) 2.84

14) For the titration of HNO_3 with KOH, which of the following receiving flasks best depicts the ions present at the **endpoint** as indicated on this titration curve?



A) B) C) D) E)

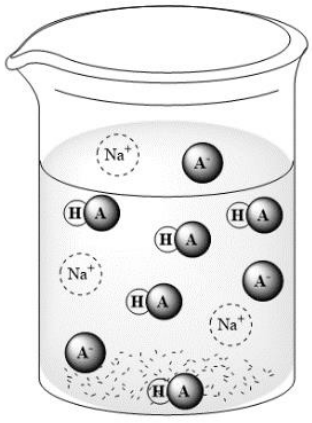


15) What is the pH of a solution created by mixing 1000.0 mL of 0.120 M HNO_3 (aq) with 250.0 mL of 0.750 M HBr (aq)?

A) 1.268 B) 0.000 C) 0.060 D) 0.512 E) 0.609

25) A chemist creates one litre of buffer solution by mixing **unequal** volumes of 1.0 M acetic acid ($K_a = 1.74 \times 10^{-5}$) and 1.0 M sodium hydroxide to obtain a solution with the ratio of solution particles in the diagram to the right. What is the pH of the buffer solution?

A) 4.33 B) 4.54 C) 4.76
D) 4.98 E) 5.19



HA = acetic acid
A^- = acetate anion
Na^+ = sodium cation

End of the contest Go back and check your work

CCC 2018

19) When you do extreme exercise, your body converts glucose to lactic acid ($HCH_3H_5O_3$). Lactic acid has a K_a= 1.38 x 10^{-4}. Buffer systems maintain the pH of your blood at 7.4 during exercise. Without buffers, what would your blood pH range be at equilibrium if 4.00 x 10^{-3} mol L^{-1} of lactic acid dissociated according to the equation:

$$HCH_3H_5O_3\,(aq) + H_2O(l) \rightleftharpoons CH_3H_5O_3^-(aq) + H_3O^+(aq)$$

A) 2<pH<3 B) 3<pH<4 C) 4<pH<5 D) 5<pH<6 E) 6<pH<7

23) *Hypophosphatemia* is a condition of abnormally low phosphate concentration in the human blood stream, occurring in 2% of hospitalized patients. The treatment includes administration of intravenous phosphate buffer to increase blood phosphate concentration. However, since phosphoric acid is a weak acid, care needs to be taken to maintain blood pH at 7.4. Given the data below, and assuming similar concentrations of both species of the acid-base conjugate pair, determine the most effective buffer combination to achieve a pH of 7.4.

$H_3PO_4^-$; K_a = 7.2 x 10^{-3} $H_2PO_4^-$; K_a = 6.3 x 10^{-8} HPO_4^{2-}; K_a = 4.2 x 10^{-13}

A) H_3PO_4 and $H_2PO_4^-$ B) H_3PO_4 and HPO_4^{2-} C) $H_2PO_4^-$ and HPO_4^{2-}
D) $H_2PO_4^-$ and PO_4^{3-} E) HPO_4^{2-} and PO_4

CCC 2017

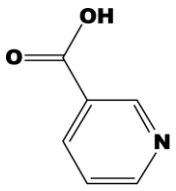
15) Canadian cities began adding fluoride to their drinking water in the mid-1950s, as a means to reducing dental caries (cavities) in children. Sodium fluorosilicate (Na_2SiF_6), a by-product of the industrial processing of phosphate minerals, can be added to drinking water to produce free fluoride ions. A drinking water analysis for a Canadian city revealed the following data:

pH = 7.60 $[F^-]$ = 3.2 x 10^{-5} mol L^{-1}

Given that the pKa of hydrofluoric acid (HF) is 3.17, determine the concentration of HF in the drinking water of this Canadian city. Assume a water temperature of 25°C.

A) 5.4 x 10^{-2} mol L^{-1} B) 3.2 x 10^{-5} mol L^{-1} C) 6.4 x 10^{-5} mol L^{-1}
D) 1.9 x 10^{-8} mol L^{-1} E) 1.2 x 10^{-9} mol L^{-1}

20) Vitamin-B3, or Niacin, is an essential nutrient for humans. Its molecular structure is shown on the right. A 0.0050 mol L^{-1} solution of Niacin in water has a pH of 3.56. What is the percentage ionization of niacin in water?



Niacin

A) 1.4 % B) 2.8 % C) 3.6 % D) 5.5 % E) 7.8%

CCC 2016

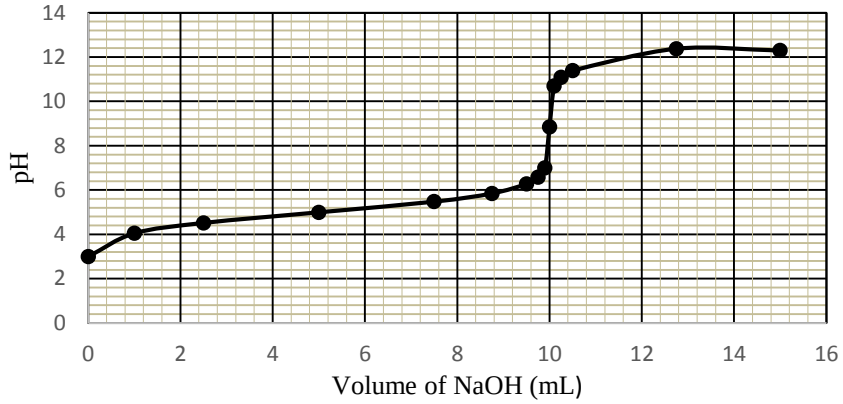
4. When dissolved in aqueous solution, Al^{3+} forms a six coordinate complex with water that can undergo dissociation according to the following equation:

$Al(OH_2)_6^{3+}(aq) + H_2O\ (l) \rightleftharpoons Al(OH_2)_5(OH)^{2+}(aq) + H_3O^+(aq)\quad K_a = 1.0 \times 10^{-5}$

If the initial concentration of $Al(OH_2)_6^{3+}$ is 0.10 mol L^{-1}, what is the approximate pH of the solution?

A) 1.00 B) 3.00 C) 4.00 D) 5.00 E) 7.00

18. A student titrated aqueous ethanoic acid with sodium hydroxide and recorded the change in pH on the graph below. Using the curve, estimate the pH at the equivalence point for this titration.



A) 3.0 B) 7.0 C) 8.8 D) 11.0 E) 12.5

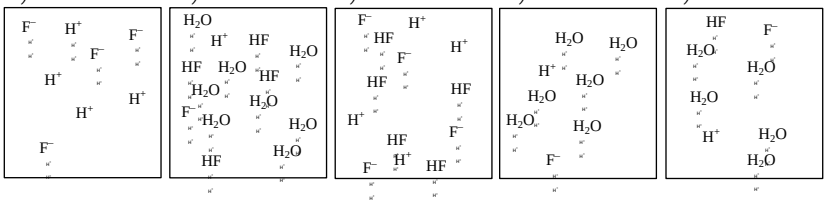
CCC 2015

23. To determine the concentration of 10.00 mL of a solution of H_2SO_3 of unknown concentration, a 10.00 mL sample of the unknown H_2SO_3 is diluted to 100.00 mL and 25.00 mL of the diluted H_2SO_3 is titrated with 0.1178 mol L^{-1} sodium hydroxide. The complete neutralization of the unknown H_2SO_3 requires 32.45 mL of the NaOH solution. What is the concentration of the original H_2SO_3 solution?

A) 0.01529 mol L^{-1} B) 0.07645 mol L^{-1} C) 0.1529 mol L^{-1}
D) 0.7645 mol L^{-1} E) 1.529 mol L^{-1}

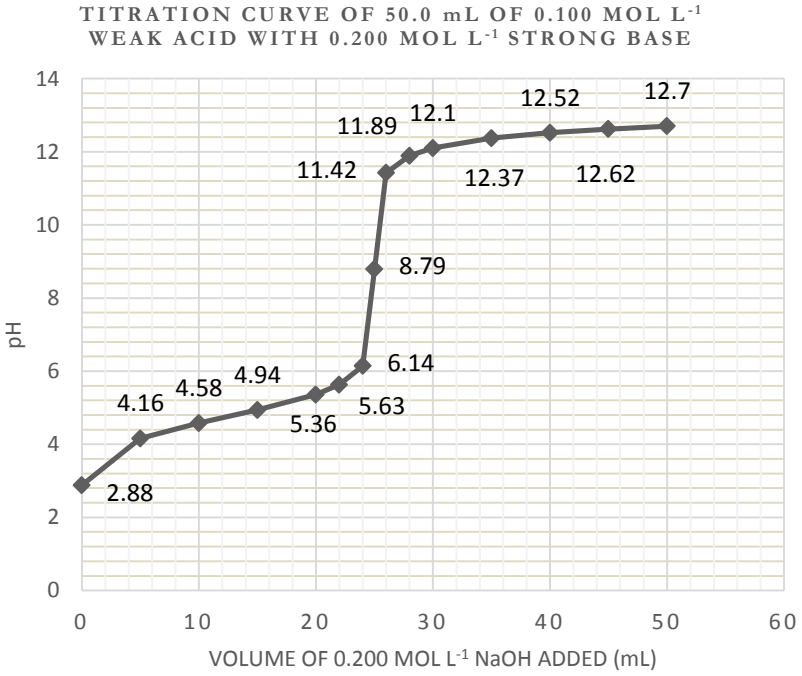
24. Which diagram best depicts an aqueous solution of dilute hydrofluoric acid?

A) B) C) D) E)



25. The following is a titration curve of a weak acid by a strong base. What is the [H_3O^+] in mol L^{-1} at equivalence?

A) 1.6×10^{-9} B) 8.8×10^{-8} C) 1.0×10^{-7} D) 0.010 E) 0.94



CCC 2014

5. Which of the following is a Lewis acid but is not a Brønsted acid?

A) H_2O B) BF_3 C) H_3O^+ D) NH_3 E) HF

8. Fluoride salts can be added to municipal water supplies to help reduce tooth decay among the population. Given that the pK_a of hydrofluoric acid, HF(aq), is 3.17 at 25.0°C, calculate the pH of a 0.00500 mol L^{-1} sodium fluoride solution at this temperature.

A) pH = 2.74 B) pH = 3.50 C) pH = 6.57
D) pH = 7.43 E) pH = 10.50

12. A 100.0 mL sample of 0.0875 mol L^{-1} HOCl, a weak monoprotic acid with a $K_a = 3.0 \times 10^{-8}$, reacts with solid sodium hydroxide. If 0.0656 g of solid NaOH are added to the initial sample, calculate the final pH in this neutralization reaction. Assume there are no volume changes in the solution.

A) pH = 4.79 B) pH = 6.89 C) pH =7.00
D) pH = 7.11 E) pH = 8.16

22. A solution labelled "concentrated sulfuric acid" is found to be a 65.0% solution of H_2SO_4 by mass and has a density of 1.55 g mL^{-1} at 20°C. The pK_b = 4.74 for ammonia (NH_3), and a concentrated solution of ammonia is 28.0 % ammonia by mass and has a density of 0.898 g mL^{-1} at 20°C. What is the maximum volume of the concentrated solution of ammonia that can be completely neutralized by 10.0 mL of the concentrated solution of sulfuric acid?

A) 6.98 mL B) 10.7 mL C) 14.0 mL D) 20.9 mL E) 21.4 mL

CCC 2013

12. Which of the following statements is true for a 0.010 mol L^{-1} aqueous solution of the weak base ethylamine ($C_2H_5NH_2$) if the K_a = 1.78 x 10^{-11} for the conjugate acid?

A. The pH is equal to 2
B. The pH is between 2 and 7
C. The pH is equal to 7
D. The pH is between 7 and 12
E. The pH is equal to 12

13. The sour taste of vinegar is due to acetic acid, CH_3COOH. When aqueous acetic acid reacts with aqueous sodium hydroxide in a titration, the products of the net ionic equation are:

A. $CH_3COOH_2^+$, Na_2O
B. CH_3COOH, H_2O, Na^+
C. CH_3COO^-, Na^+
D. CH_3COO^-, H_2O
E. CH_3COOH, NaOH

23. 25.0 mL of 0.100 mol L^{-1} NaOH are added to 50.0 mL of a 0.100 mol L^{-1} solution of acetic acid (K_a = 1.8 x 10^{-5}) at 25°C. Select the pH value that most closely describes the pH after the addition has taken place.

A. 7.00 B. 4.75 C. 2.89 D. 3.12 E. 8.72

CCC 2012

15. In the following reaction, which are the Brønsted-Lowry acids?

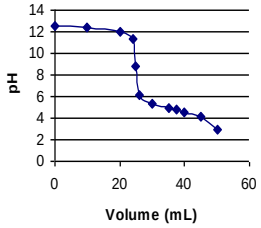
$$HCO_3^-(aq) + H_2O(l) \rightleftharpoons H_3O^+(aq) + CO_3^{2-}(aq)$$

A. HCO_3^- (aq) and H_3O^+(aq)
B. HCO_3^- (aq) and CO_3^{2-}(aq)
C. H_2O(l) and H_3O^+(aq)
D. H_2O(l) and CO_3^{2-} (aq)
E. HCO_3^- (aq) and H_2O(l)

E. II and III

21. The following graph shows the titration curve of:

A. a dilute strong base titrated with a strong acid
B. a concentrated weak base with a strong acid
C. a concentrated strong base with a weak acid
D. a dilute weak base with a weak acid
E. a dilute strong base with a weak acid



8. What is the pH of a solution in which 35.0 mL of 0.067 mol L^{-1} of $Ba(OH)_2$ is mixed with 50.0 mL of 0.050 mol L^{-1} HBr?

A. 1.59 B. 1.89 C. 7.00 D. 12.11 **E. 12.41**

9. At 100°C, the ionic product K_w for water is 5.13×10^{-13}. Which statement best describes pure water at its boiling point?

A. pH = 7.0; the water is neither basic nor acidic.
B. **pH = 6.14; the water is neither basic nor acidic.**
C. pH = 6.14; the water is acidic.
D. pH = 6.14; the water is basic.
E. the value of K_w decreases when water temperature increases.

18. What is the pH of a solution at 25°C if the concentration of OH^- ion is 100 times greater than the concentration of H_3O^+ ion?

A. 2 B. 6 C. 8 D. 12 E. 14

19. Buffer solutions contain a weak acid together with its conjugate base. If the ionization constant (K_a) of acetic acid is 1.8×10^{-5}, what mass of sodium acetate ($NaC_2H_3O_2$) must be dissolved in 400 mL of 0.20 mol L^{-1} acetic acid to obtain a buffer with a pH of 5.0?

A. 30 g B. 12 g C. 8.6 g D. 3.6 g E. 2.7 g

20. The ionization constant (K_b) of ethylamine ($C_2H_5NH_2$) is 4.3×10^{-4}, while that of aniline ($C_6H_5NH_2$) is 7.4×10^{-10}. The conjugate acids of these bases are the ethylammonium ion and the anilinium ion. It follows that:

A. Ethylamine is a stronger base than aniline and the ethylammonium ion is a stronger acid than the anilinium ion.
B. Ethylamine is a stronger base than aniline and the anilinium ion is a stronger acid than the ethylammonium ion.
C. The two acids are of equal strength and the two bases are of equal strength.
D. Aniline is a stronger base than ethylamine and the ethylammonium ion is a stronger acid than the anilinium ion.
E. Aniline is a stronger base than ethylamine and the anilinium ion is a stronger acid than the ethylammonium ion.

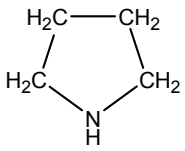
CCC 2010

13. Which of the following aqueous solutions has the highest numerical value of pH?

A. Pure water B. 0.01 M KBr C. 0.01 M HBr

D. 0.01 M NH_4Br E. 0.01 M CH_3COOK

19. Pyrrolidine is a weak base found in carrot leaves, with formula C_4H_9N and structure as shown below.



Pyrrolidine

The pH of a 1.00×10^{-3} mol/L solution of pyrrolidine in water is measured to be 10.82. The value of the ionization constant K_b of this base is

A. 1.3×10^{-3} B. 4.4×10^{-4} C. 2.3×10^{-19} D. 6.7×10^{-19} E. 1.9

18. In aqueous solution the Fe^{3+} ion is bound to six water molecules and forms the hydrated ion $Fe(H_2O)_6^{3+}$. Many salts of this ion form acidic solutions, for example in red iron-containing soils. The cause of this acidity is that the hydrated ion

A. can add a water molecule to form $Fe(H_2O)_7^{3+}$
B. can lose a water molecule to form $Fe(H_2O)_5^{3+}$
C. can lose a hydroxide ion from a water molecule to form $FeH(H_2O)_5^{4+}$
D. can lose a proton from a water molecule to form $FeOH(H_2O)_5^{2+}$
E. can lose a proton from the iron nucleus to form $Mn(H_2O)_6^{2+}$

CCC 2009

14. In the titration of 25.00 mL of vinegar to find the concentration of ethanoic acid (Mr = 60.1) in a commercial sample, a student needed 22.50 mL of 0.0944 mol L^{-1} sodium hydroxide to reach the end point colour change. What is the concentration of ethanoic acid in the sample being analyzed? (The density of the solution is 1.00 g mL^{-1} at 25°C.)

A. 0.0650 mol L^{-1} B. 0.0850 mol L^{-1} C. 0.1049 mol L^{-1}
D. 4.50 % E. 5.00 %

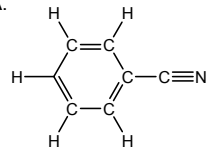
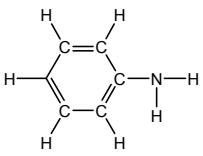
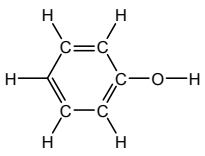
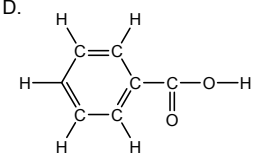
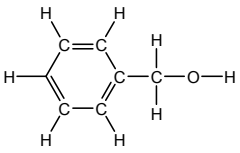
8. At low temperatures ammonia is a liquid that boils at –33°C. This liquid is used as a solvent for some chemical reactions and can autoionize in a manner analogous to liquid water. In liquid ammonia the conjugate base of NH_3 is:

A. NH_2^- B. NH_3 C. NH_4^+ D. OH^- E. H_2O

9. Adipic acid, $HOOC(CH_2)_4COOH$, is an important chemical product used primarily to manufacture nylon. It is a diprotic acid with $K_{a1} = 3.9 \times 10^{-5}$ and $K_{a2} = 3.9 \times 10^{-6}$. If a saturated solution (approx. 0.1 mol L^{-1}) of adipic acid is titrated with 0.1 mol L^{-1} NaOH, which of the following values is closest to the pH when 1.5 mole NaOH have been added for each mole of adipic acid?

A. 4.4 B. 4.9 C. 5.4 D. 7.0 E. 12.3

10. Which of the following derivatives of benzene is the most acidic?

A. 
B. 
C. 
D. 
E. 

CCC 2008

7. Magnesium hydroxide, $Mg(OH)_2$, is used in antacid tablets. It is a strong base, which is completely dissociated in water. What is the pH of a solution of $Mg(OH)_2$ with a concentration of 0.0001 mol L^{-1} at 25°C?

A. 3.7 B. 4.0 C. 8.0 D. 10. 0 E. 10.3

8. The ionic product of water, K_w, is 1.0×10^{-14} at 298 K. Given that the **neutralisation** of a strong acid with a strong base is an exothermic reaction, which one of the following is likely to be the value of K_w at 273 K?

A. -1.2×10^{-15} B. 1.2×10^{-13} C. 1.0×10^{-14}
D. 1.2×10^{-14} E. 1.2×10^{-15}

11. Vitamin C is ascorbic acid, which is a monoprotic acid of formula $C_6H_8O_6$. When a 500-mg tablet of pure vitamin C is dissolved in 100 mL of water, the pH of the solution is measured as 2.83. The acid dissociation constant, K_a, of ascorbic acid is therefore:

A. 1.0×10^{-14} B. 2.2×10^{-6} C. 8.1×10^{-5}
D. 1.5×10^{-3} E. 5.5×10^{-2}