UNIT 3 REVIEW

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Understanding Concepts

1. Solutions are important to the study of chemistry because solutions make it easy to:
   handle chemicals — solids or gases are dissolved in water for ease of use or transportation.
   react chemicals — some chemicals do not react until they are in a homogeneous state with increased contact between the reacting entities.
   control reactions — the rate, extent, and type of reactions are much more easily controlled when one or more reactants are in solution.
2. (a) Cloudy water is not a solution because it is not homogeneous: it blocks light.
   (b) Hard water is a solution because it is homogeneous: it is clear.
   (c) Pure water is not a solution because it is only one substance.
   (d) Soft water is a solution because it is homogeneous: it is clear.
   (e) Water with high iron content is a solution because it is homogeneous: it is clear.
3. (a) Electrolytes are compounds that dissolve to form conducting solutions.
   (b) Nonelectrolytes are compounds that dissolve to form nonconducting solutions.
4. (a) glucose $C_6H_{12}O_{6(s)}$ molecular
   (b) citric acid $H_3C_3H_4(COO)_{3(s)}$ acid
   (c) sodium citrate $Na_3C_3H_4(COO)_{3(s)}$ ionic
   (d) sodium benzoate $NaC_6H_5COO_{(s)}$ ionic
   (e) carbon dioxide $CO_{2(g)}$ molecular
5. (a) The two properties of solutions that Arrhenius studied to develop his theory of dissociation of electrolytes were conductivity and freezing-point depression.
   (b) According to Arrhenius' theory, the ions responsible for the acidic and the basic properties of solutions are hydrogen and hydroxide ions, respectively.
   (c) The Arrhenius theory assumes acids and bases are always electrolytes because, to be an acid or base, the compound must dissociate in water to form hydrogen or hydroxide ions. In a neutral solution, the solute would either consist of other ions, or of molecules, so neutral solutions may be electrolytes or nonelectrolytes.
6. When scientists find a theory to be inadequate, they gather evidence and use it to restrict, revise, or replace the theory. The original Arrhenius theory did not explain bases that were not hydroxide compounds, and so had to be revised to include the concept of reaction with water to produce hydroxide ions.
7. The theoretical definition of a base changed from the Arrhenius concept (a compound that dissolves to form hydroxide ions) to the revised Arrhenius concept (a compound that dissolves to form hydroxide ions, or reacts with water to form hydroxide ions) to the Brønsted-Lowry concept (an entity in solution that gains proton(s) in a reaction).

8.

	Acidic, Basic, or Neutral	Electrolyte or Nonelectrolyte	IUPAC Name
(a)	neutral	nonelectrolyte	sucrose
(b)	acidic	electrolyte	hydrochloric acid
(c)	neutral	nonelectrolyte	methanol
(d)	basic	electrolyte	sodium hydroxide
(e)	neutral	electrolyte	sodium nitrate

9. (a) $Ag^+_{(aq)} + Cl^-_{(aq)} \rightarrow AgCl_{(s)}$
   (b) $Cu^{2+}_{(aq)} + 2\ OH^-_{(aq)} \rightarrow Cu(OH)_{2(s)}$
   (c) $Ca^{2+}_{(aq)} + CO^{2-}_{3(aq)} \rightarrow CaCO_{3(s)}$
   (d) $Pb^{2+}_{(aq)} + 2\ Cl^-_{(aq)} \rightarrow PbCl_{2(s)}$
   (e) $Ag^+_{(aq)} + Cl^-_{(aq)} \rightarrow AgCl_{(s)}$

10. A typical example in which a high concentration of a solute is beneficial would be the concentration of oxygen in air. An example in which it is harmful (even fatal!) would be a high concentration of ethanol in the bloodstream.

11. (a) $C_2H_3Cl_{(l)}$ high solubility
    (b) $CH_3CHO_{(l)}$ high solubility
    (c) $C_2H_5OH_{(l)}$ high solubility
    (d) $C_2H_{4(g)}$ low solubility
    (e) $HCH_3COO_{(l)}$ high solubility
    (f) $C_2H_{2(g)}$ low solubility
    (g) $C_2H_5NH_{3(l)}$ high solubility

12. (a) $C_3H_7OH_{(l)}$ is more soluble because the OH group causes hydrogen bonding.
    (b) $C_2H_4(OH)_{2(l)}$ is more soluble because the OH groups cause hydrogen bonding.
    (c) $CHCl_{3(l)}$ is more soluble because the molecule is polar.

13. $$\frac{20\ \text{mg}}{225\ \cancel{\text{mL}}} \times \frac{1000\ \cancel{\text{mL}}}{1\ \text{L}} = 89\ \text{mg/L}$$

The caffeine concentration in green tea is 89 mg/L.

$$\frac{100\ \text{mg}}{225\ \cancel{\text{mL}}} \times \frac{1000\ \cancel{\text{mL}}}{1\ \text{L}} = 444\ \text{mg/L}$$

The caffeine concentration in black tea is 444 mg/L.

14. $4 \times 2.16\ \text{g}/25.0\ \text{mL} = 8.64\ \text{g}/100\ \text{mL}$

The concentration of saturated $KCl_{(aq)}$ at 22°C is 8.64 g/100 mL.

15. 162 ppm = 162 mg/L = 0.162 g/L

$$\frac{0.162\ \text{g}}{1\ \cancel{\text{L}}} \times 2.5\ \cancel{\text{L}} = 0.41\ \text{g}$$

2.5 L of the Lake Ontario water contains 0.41 g of dissolved minerals.

16. $v_i = 40.0\ \text{mL} = 0.0400\ \text{L}$

$v_f = 5.00\ \text{L}$

$C_i = 2.50\ \text{mol/L}$

$C_f = ?$

$v_iC_i = v_fC_f$

$$C_f = \frac{v_iC_i}{v_f}$$

$$= \frac{0.0400\ \cancel{\text{L}} \times 2.50\ \text{mol/L}}{5.00\ \cancel{\text{L}}}$$

$C_f = 0.0200\ \text{mol/L}$

or $$C_f = 2.50\ \text{mol/L} \times \frac{0.0400\ \cancel{\text{L}}}{5.00\ \cancel{\text{L}}}$$

$C_f = 0.0200\ \text{mol/L}$

The final concentration of the sodium hydroxide solution will be 0.0200 mol/L, or 20.0 mmol/L.

17. (a) $v_{\text{water}} = 2.00\ \text{L}$

$m_{\text{Ca}} = 150\ \text{mg}$

$$c_{\text{Ca}} = \frac{150\ \text{mg}}{2.00\ \text{L}}$$

$c_{\text{Ca}} = 75.0\ \text{mg/L} = 75.0\ \text{ppm}$

The concentration of calcium in the water is 75.0 ppm.

(b) $c_{\text{Ca}} = 150\ \text{mg}/2.00\ \text{L} = 0.0750\ \text{g/L}$

$M_{\text{Ca}} = 40.08\ \text{g/mol}$

$C_{\text{NaCl}} = \frac{0.0750\ \cancel{\text{g}}}{1\ \text{L}} \times \frac{1\ \text{mol}}{40.08\ \cancel{\text{g}}}$

$C_{\text{NaCl}} = 0.00187\ \text{mol/L} = 1.87\ \text{mmol/L}$

The molar concentration of calcium in the water is 1.87 mmol/L.

18. $c_{HC_2H_3O_2} = 5\ \%V/V = 5\ \text{mL}/100\ \text{mL} = 5\ \text{mL}/0.100\ \text{L}$

$v_{HC_2H_3O_2} = 60\ \text{mL}$

$v_{\text{vinegar}} = 60\ \cancel{\text{mL}}\ \cancel{HC_2H_3O_2} \times \frac{0.100\ \text{L vinegar}}{5\ \cancel{\text{mL}}\ \cancel{HC_2H_3O_2}}$

$v_{\text{vinegar}} = 1.2\ \text{L}$

The volume of vinegar needed is 1.2 L.

Note: The answer has 2 significant digits because the only *measurement* given is 60 mL — the 5% is a commercial value (a legal minimum).

19. (a) $c_{CuSO_4\cdot 5H_2O} = 14.3\ \text{g}/100\ \text{mL} = 143\ \text{g/L}$

$M_{CuSO_4\cdot 5H_2O} = 249.71\ \text{g/mol}$

$C_{CuSO_4\cdot 5H_2O} = \frac{143\ \cancel{\text{g}}}{1\ \text{L}} \times \frac{1\ \text{mol}}{249.71\ \cancel{\text{g}}}$

$C_{CuSO_4\cdot 5H_2O} = 0.573\ \text{mol/L}$

The molar solubility of copper(II) sulfate pentahydrate is 0.573 mol/L.

(b) $m_{CuSO_4\cdot 5H_2O} = 4.54\ \cancel{\text{L}} \times \frac{143\ \text{g}}{1\ \cancel{\text{L}}}$

$m_{CuSO_4\cdot 5H_2O} = 649\ \text{g}$

The maximum mass of copper(II) sulfate pentahydrate that can be dissolved is 649 g.

20. (a) $Ag^+_{(aq)} + I^-_{(aq)} \rightarrow AgI_{(s)}$

(b) $Cu^{2+}_{(aq)} + 2\ OH^-_{(aq)} \rightarrow Cu(OH)_{2(s)}$

(c) $Pb^{2+}_{(aq)} + S^{2-}_{(aq)} \rightarrow PbS_{2(s)}$

(d) $Ca^{2+}_{(aq)} + CO^{2-}_{3(aq)} \rightarrow CaCO_{3(s)}$

(e) $Pb^{2+}_{(aq)} + 2\ I^-_{(aq)} \rightarrow PbI_{2(s)}$

21. (a) $v_i = ?$

$v_f = 500\ \text{mL}$

$C_i = 12.1\ \text{mol/L}$

$C_f = 1.00\ \text{mol/L}$

$v_iC_i = v_fC_f$

$v_i = \frac{v_fC_f}{C_i}$

$= \frac{500\ \text{mL} \times 1.00\ \cancel{\text{mol/L}}}{12.1\ \cancel{\text{mol/L}}}$

$v_i = 41.3\ \text{mL}$

or $v_i = 500\ \text{mL} \times \frac{1.00\ \cancel{\text{mol/L}}}{12.1\ \cancel{\text{mol/L}}}$

$v_i = 41.3\ \text{mL}$

The volume of concentrated hydrochloric acid required is 41.3 mL.

(b) $v_i = 250$ mL

$v_f = ?$

$C_i = 14.8$ mol/L

$C_f = 2.00$ mol/L

$v_iC_i = v_fC_f$

$$v_f = \frac{v_iC_i}{C_f}$$

$$= \frac{250 \text{ mL} \times 14.8 \cancel{\text{mol/L}}}{2.00 \cancel{\text{mol/L}}}$$

$v_f = 1.85 \times 10^3$ mL $= 1.85$ L

or $$v_f = 250 \text{ mL} \times \frac{14.8 \cancel{\text{mol/L}}}{2.00 \cancel{\text{mol/L}}}$$

$v_f = 1.85 \times 10^3$ mL $= 1.85$ L

The maximum volume of phosphoric acid she can prepare is 1.85 L.

(c) $v_i = 25$ mL

$v_f = 750$ mL

$C = 0.73$ mol/L

$C_f = ?$

$v_iC_i = v_fC_f$

$$C_f = \frac{v_iC_i}{v_f}$$

$$= \frac{25 \cancel{\text{mL}} \times 0.73 \text{ mol/L}}{750 \cancel{\text{mL}}}$$

$C_f = 0.024$ mol/L $=$ 24 mmol/L

or $$C_f = 0.73 \text{ mol/L} \times \frac{25 \cancel{\text{mL}}}{750 \cancel{\text{mL}}}$$

$C_f = 0.024$ mol/L $=$ 24 mmol/L

The final concentration of diluted sulfurous acid is 24 mmol/L.

(d) $v_i = ?$

$v_f = 4.54$ L

$C_i = 14.8$ mol/L

$C_f = 2.50$ mol/L

$v_iC_i = v_fC_f$

$$v_i = \frac{v_fC_f}{C_i}$$

$$= \frac{4.54 \text{ L} \times 2.50 \cancel{\text{mol/L}}}{14.8 \cancel{\text{mol/L}}}$$

$v_i = 0.767$ L $= 767$ mL

or $$v_i = 4.54 \text{ L} \times \frac{2.50 \cancel{\text{mol/L}}}{14.8 \cancel{\text{mol/L}}}$$

$v_i = 0.767$ L $= 767$ mL

The initial volume of concentrated ammonia required is 767 mL.

22. The hydrogen ion concentration in any weak acid solution depends on the amount of solute in solution, the volume of the solution, and the degree of (percent) ionization of the weak acid solute.

23. **Table 2: pH and Hydrogen Ion Concentration of Some Common Beverages**

Beverage	pH	$[H^+_{(aq)}]$ (mol/L)
Antacid	10.46	3.5×10^{-11}
Apple juice	3.14	7.2×10^{-4}
Beer	4.506	3.12×10^{-5}
Cider	3.144	7.18×10^{-4}
Tap water	7.86	1.4×10^{-8}

24. (a) $Al_2(SO_4)_{3(aq)} \rightarrow 2\ Al^{3+}_{(aq)} + 3\ SO^{2-}_{4(aq)}$

(b) $Ca(OH)_{2(aq)} \rightarrow Ca^{2+}_{(aq)} + 2\ OH^{-}_{(aq)}$

(c) $NaOCl_{(aq)} \rightarrow Na^{+}_{(aq)} + OCl^{-}_{(aq)}$

25. $c_{\text{malathion}} = 145\text{ ppm} = 145\text{ mg/L} = 0.145\text{ g/L}$

$m_{\text{malathion}} = 1.00\text{ g}$

$v_{\text{malathion}} = 1.00\ \cancel{\text{g}} \times \frac{1\text{ L}}{0.145\ \cancel{\text{g}}}$

$v_{\text{malathion}} = 6.90\text{ L}$

The volume of room-temperature water needed to completely dissolve the malathion is 6.90 L.

26. $c_{Na_2CO_3} = 225\text{ ppm} = 225\text{ mg/L} = 0.225\text{ g/L}$

$v_{Na_2CO_3} = 200\text{ L}$

$m_{Na_2CO_3} = 200\ \cancel{\text{L}} \times \frac{0.225\text{ g}}{1\ \cancel{\text{L}}}$

$m_{Na_2CO_3} = 45.0\text{ g}$

The mass of sodium carbonate contained in the water is 45.0 g.

27. (a) $c_{\text{As}} = 25\text{ ppb} = 25\ \mu\text{g/L} = 0.025\text{ mg/L}$

$v_{\text{As}} = 365\ \cancel{\text{day}} \times \frac{1.5\text{ L}}{\cancel{\text{day}}} = 5.5 \times 10^2\text{ L}$

$m_{\text{As}} = 5.5 \times 10^2\ \cancel{\text{L}} \times \frac{0.025\text{ mg}}{1\ \cancel{\text{L}}}$

$m_{\text{As}} = 14\text{ mg}$

The mass of arsenic contained in the water is 14 mg.

(b) $c_{\text{As}} = \frac{1.2\ \mu\text{g}}{25.0\ \cancel{\text{mL}}} \times \frac{1000\ \cancel{\text{mL}}}{1\text{ L}} = 48\ \mu\text{g/L} = 48\text{ ppb}$

The sample level is 48 ppb, considerably exceeding the Health Canada MAC limit, which is 25 ppb.

(c) $Fe^{3+}_{(aq)} + AsO^{3-}_{4\,(aq)} \rightarrow FeAsO_{4(s)}$

28. $NaOH_{(aq)} + HCl_{(aq)} \rightarrow H_2O_{(l)} + NaCl_{(aq)}$

9.3 mL　　250 mL

0.0085 mol/L　　*C*

$n_{\text{NaOH}} = 9.3\text{ m}\cancel{\text{L}} \times \frac{0.0085\text{ mol}}{1\ \cancel{\text{L}}} = 0.079\text{ mmol}$

$n_{\text{HCl}} = 0.079\text{ mmol} \times \frac{1}{1} = 0.079\text{ mmol}$

$C_{\text{HCl}} = \frac{0.079\ \cancel{\text{m}}\text{mol}}{250\ \cancel{\text{m}}\text{L}}$

$C_{\text{HCl}} = 0.00032\text{ mol/L} = 0.32\text{ mmol/L}$

or $C_{HCl} = 9.3 \cancel{mL} \cancel{NaOH} \times \frac{0.0085 \cancel{mol} \cancel{NaOH}}{1 L \cancel{NaOH}} \times \frac{1 mol HCl}{1 \cancel{mol} \cancel{NaOH}} \times \frac{1}{250 \cancel{mL}}$

$C_{HCl} = 0.00032 mol/L = 0.32 mmol/L$

The concentration of hydrochloric acid in the pond is 0.32 mmol/L.

29. (a) $C_7H_50^-_{2(aq)}$ is a Brønsted-Lowry base and $HSO^-_{4(aq)}$ is a Brønsted-Lowry acid in this reaction.

(b) The $C_7H_5O_2^-$ ion is probably more soluble in water than the $HC_7H_5O_2$ molecule because the negative charge makes it more polar.

30. A Brønsted-Lowry acid need not form an acidic solution. $HCO^-_{3(aq)}$ ions can lose protons in reactions to act as a Brønsted-Lowry acid, but a solution of $NaHCO_{3(aq)}$ is basic, because this anion can also act as a base, depending on what the other reactant happens to be.

Applying Inquiry Skills

31. **Experimental Design**

Each of the five solutions is tested with blue and red litmus paper, then tested for the degree of electrical conductivity.

32. **Experimental Design**

This is one of several possible designs: Copper(II) nitrate solution will be added to the unknown sample. If a precipitate forms, excess copper(II) nitrate solution will be added, and the precipitate will be filtered. Silver nitrate solution will be added to the filtrate (or to the original sample if no precipitate forms in the first step).

33. The unknown solution might contain strontium hydroxide, $Sr(OH)_{2(aq)}$, or barium hydroxide, $Ba(OH)_{2(aq)}$. These compounds are basic and soluble, but have cations that are of low solubility with sulfate.

34. (a) $v_i = ?$

$v_f = 250 mL$

$C_i = 15.4 mol/L$

$C_f = 0.50 mol/L$

$$v_iC_i = v_fC_f$$

$$v_i = \frac{v_fC_f}{C_i}$$

$$= \frac{250 mL \times 0.50 \cancel{mol/L}}{15.4 \cancel{mol/L}}$$

$$v_i = 8.1 mL$$

or $$v_i = 250 mL \times \frac{0.50 \cancel{mol/L}}{15.4 \cancel{mol/L}}$$

$$v_i = 8.1 mL$$

The initial volume of concentrated nitric acid required is 8.1 mL.

(b) **Procedure**

1. Calculate the volume of a 15.4 mol/L stock solution of $HNO_{3(aq)}$ required to prepare 250 mL of a pH 0.30 solution.
2. Add about 100 mL of pure water to a clean 250-mL volumetric flask.
3. Measure the required volume (8.1 mL) of standard solution using a 10-mL graduated pipet.
4. Transfer the required volume of the initial (standard) solution into the 250-mL volumetric flask.
5. Add pure water until the final volume is reached.
6. Stopper the flask and mix the solution thoroughly.

35. **Analysis**

Solution 1 is the strong acid $HCl_{(aq)}$, because it conducts, turns blue litmus pink, and has very low pH.
Solution 2 is the neutral ionic compound $CuBr_{2(aq)}$, because it conducts, does not change litmus, and is blue — the colour of $Cu^{2+}_{(aq)}$ ions.
Solution 3 is the molecular compound acid $CH_3OH_{(aq)}$, because it does not change litmus, and does not conduct.

Solution 4 is the strong base $NaOH_{(aq)}$, because it conducts, turns pink litmus blue, and has very high pH.
Solution 5 is the neutral ionic compound $KCl_{(aq)}$, because it conducts, tests neutral with litmus, and is colourless.
Solution 6 is the weak base $NH_{3(aq)}$, because it turns pink litmus blue, and has high pH, but not as high as that of solution 4.
Solution 7 is the weak acid $HC_2H_3O_{2(aq)}$, because it conducts, turns blue litmus pink, and has low pH, but not as low as that of solution 1.

Evaluation

The design for this experiment is judged to be adequate. It allowed the question to be answered, using simple equipment to produce reliable results.

Making Connections

36. (a) $HC_2O_3H_{3(aq)}$ or $CH_2OHCOOH_{(aq)}$

(b) Glycolic acid is a weak acid, ionizing much less than 50% in water.

(c) A solution of glycolic acid would react more rapidly with rust than a vinegar solution of the same concentration, because it is stronger (more ionized) than the vinegar (acetic acid), and it is the hydrogen ions that are actually reacting.

(d) The same amount would react. The amount of both acids present to react will be the same; one will react just a little faster than the other.

(e)The decision here will probably involve two major factors: whether the vinegar removes rust and scale as well as the glycolic acid, and whether the vinegar is less expensive. The glycolic acid is probably more concentrated than any vinegar one can buy in food stores, and experimentation would be needed to see if that makes it a better cleaner (not just faster) than vinegar. Likely the vinegar would be much less expensive, since it is a very common foodstuff. Another significant factor might be the environmental impact of the glycolic acid.

37. (a) Aqueous hypochlorite ions must be reactive, and every time a bottle is opened some reagent is used up as gas escapes, so the label cannot promise how much will be in a bottle that has been opened.

(b) $c_{\text{NaOCl}} = 5.25\%\ \text{W/V} = 5.25\ \text{g}/100\ \text{mL (of solution)}$

$v_{\text{NaOCl}} = 3.6\ \text{L}$

$m_{\text{NaOCl}} = 3.6\ \cancel{\text{L}} \times \dfrac{5.25\ \text{g}}{0.100\ \cancel{\text{L}}}$

$m_{\text{NaOCl}} = 189\ \text{g}$

The minimum mass of sodium hypochlorite needed to make the solution in the large bottle of bleach is 189 g.

Note: All of the values used in this question are given as commercial label readings — hence are guaranteed minimums — and significant digits do not apply.

(c) $c_{\text{NaOCl}} = 1.84\%\ \text{W/V} = 1.84\ \text{g}/100\ \text{mL (of solution)}$

$v_{\text{NaOCl}} = 700\ \text{mL}$

$m_{\text{NaOCl}} = 700\ \cancel{\text{mL}} \times \dfrac{1.84\ \text{g}}{100\ \cancel{\text{mL}}}$

$m_{\text{NaOCl}} = 12.88\ \text{g}$

The minimum mass of sodium hypochlorite needed to make the solution in the small bottle of “bleach cleaner” is 12.88 g, so therefore, there will be 189/12.88 = 14.7 times as much sodium hypochlorite in the jug as there is in the spray bottle.

(d) Usually, cost/g price ratios are much lower for the larger containers of retail solutions.

(e) The symbol is a skeletal hand, and the triangle frame means “caution.”

(f) $2\ H^+_{(aq)} + OCl^-_{(aq)} + Cl^-_{(aq)} \rightarrow Cl_{2(g)} + H_2O_{(l)}$

This isn’t a simple Brønsted-Lowry acid–base reaction because it isn’t possible to easily determine what, if anything, is gaining and losing protons. Much more is changing than just the position of protons.

Exploring

38. (a) Students will find the regulations on size and contrast not very specific. Normally, a brand logo is found to be much more visible than a hazard logo on a retail product.

(b) As an example, the 50% lethal-level exposure to chlorine gas for rats is about 300 ppm in air for 1 hr. Breathing chlorine damages tissue in the lungs, interfering with the absorption of oxygen, and causing pulmonary edema and death by suffocation if the damage is severe enough. Chlorine was used in World War 1 to poison infantry in trenches, because it is both toxic and denser than air, which kept it from dispersing quickly.

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