End of topic questions

Topic review

1. Using your knowledge from the *Reactivity 3.1* topic, answer the guiding question as fully as possible:
   What happens when protons are transferred?

Exam-style questions

Multiple-choice questions

2. A solution of acid **X** has a pH of 1 while a solution of acid **Y** has a pH of 3. Which statement is correct?
   A [**X**] > [**Y**]
   B Acid **X** is stronger than acid **Y**
   C $[H^+]$ in the solution of **X** is three times higher than $[H^+]$ in the solution of **Y**
   D $[OH^-]$ in the solution of **X** is lower than $[OH^-]$ in the solution of **Y**

3. Which pair of species is a conjugate acid–base pair?
   A H^+ and OH^-
   B H_3O^+ and H_2O
   C HCl and NaOH
   B H_2CO_3 and CO_3^{2-}

AHL

4. Which indicators can be used for the titration of ammonia, $NH_3(aq)$, with sulfuric acid, $H_2SO_4(aq)$?
   I Bromocresol green ($pK_a = 4.7$)
   II Methyl red ($pK_a = 5.1$)
   III Phenol red ($pK_a = 7.9$)
   A I and II only
   B I and III only
   C II and III only
   D I, II and III

Extended-response questions

5. Identify the chemical formulas of parent acids and bases for the following salts:
   a. $Ca(NO_3)_2$
   b. $Fe_2(SO_4)_3$
   c. NH_4HCO_3

6. For each salt from question 5, formulate and balance **one** molecular equation that produces that salt from the parent acid and base.

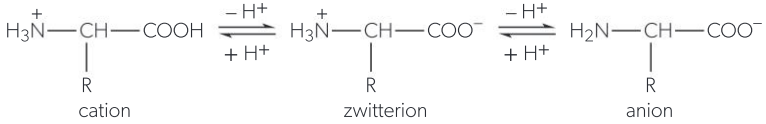
7. Two unlabelled bottles contain solutions of a strong monoprotic acid, HX(aq), and a weak monoprotic acid, HY(aq), of the same concentration.
   a. Suggest how these acids can be distinguished using solid calcium carbonate, $CaCO_3(s)$.
   b. Formulate molecular and net ionic equations for the reaction of each acid with calcium carbonate.

8. Deduce the formulas of conjugate acids and bases for each species listed in table 12. The first two rows are filled for you as examples.

Species	Conjugate acid	Conjugate base
H_2O	H_3O^+	OH^-
Cl^-	HCl	does not exist
HF		
NH_3		
$(CH_3)_3N$		
HCO_3^-		
CO_3^{2-}		

▲ Table 12 Conjugate acids and bases

9. 2-Amino acids exist as *zwitterions*, which have both a positive and a negative charge within the same species:



Identify **two** conjugate acid–base pairs involved in these equilibria and state the role of each species.

10. The K_w value at 10 °C is 3.47 times lower than that at 25 °C.
    a. Calculate the pH of pure water at 10 °C.
    b. Discuss whether pure water at 10 °C is acidic, basic or neutral.

AHL

11. Calculate the pH for the following solutions:
    a. 0.015 mol dm^{-3} HNO_3(aq)
    b. 0.010 mol dm^{-3} H_2SO_4(aq)
    c. 0.020 mol dm^{-3} KOH(aq)

12. A 0.100 dm^3 sample of 0.020 mol dm^{-3} KOH(aq) was mixed with 0.900 dm^3 of water. Calculate the pH of the final solution. Assume that solution volumes are additive.

13. Calculate:
    a. the pOH of a 0.015 mol dm^{-3} solution of sodium hydroxide, NaOH(aq)
    b. the concentration of hydroxide ions in a solution with pOH = 9.50.

14. A 0.020 mol dm^{-3} solution of benzoic acid, C_6H_5COOH(aq), has a pH of 2.95.
    a. Determine the pK_a of benzoic acid.
    b. Using the pK_a value from part **a**, calculate the pH of a 0.10 mol dm^{-3} solution of benzoic acid.

15. Calculate the pH values for the following solutions:
    a. 0.010 mol dm^{-3} methylamine, CH_3NH_2(aq)
    b. 2.0×10^{-3} mol dm^{-3} ethanoic acid, CH_3COOH(aq).

    Refer to table 8.

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16. The pK_a and pK_b values for the dihydrogenphosphate ion, $H_2PO_4^-$(aq), are 7.20 and 11.88, respectively.
    a. Formulate the equations that represent the acid–base equilibria characterized by K_a and K_b of the dihydrogenphosphate ion.
    b. Calculate the pK_a value for phosphoric acid, H_3PO_4(aq), and the pK_b value for the hydrogenphosphate ion, HPO_4^{2-}(aq).

17. Formulate the equations for acid–base equilibria in aqueous solutions of the following salts:
    a. sodium methanoate, HCOONa
    b. potassium iodide, KI
    c. ammonium cyanide, NH_4CN
    d. trimethylammonium chloride, $(CH_3)_3NHCl$.

    For each solution, predict whether it will be neutral, acidic or basic.

The pK_a and pK_b values for weak acids and bases are given in table 8.

18. Calculate the pH values for buffer solutions containing the following compounds:
    a. 0.25 mol dm^{-3} HCOOH(aq) and 0.50 mol dm^{-3} HCOONa(aq);
    b. 0.50 mol dm^{-3} CH_3NH_2(aq) and 0.20 mol dm^{-3} CH_3NH_3Cl(aq).

19. Explain, using ionic equations, the buffer action of the solutions from the previous question.

20. Using table 10, identify the most suitable acid–base indicator for the titration of:
    a. methylamine, CH_3NH_2(aq), with hydrochloric acid, HCl(aq);
    b. hydrogen cyanide, HCN(aq), with potassium hydroxide, KOH(aq).

End of topic questions

Topic review

1. Using your knowledge from the *Reactivity 3.2* topic, answer the guiding question as fully as possible:
   What happens when electrons are transferred?

Exam-style questions

Multiple-choice questions

2. Which species contains nitrogen with an oxidation state of +5?
   A. N_2
   B. N_2O
   C. NO_2^-
   D. HNO_3

3. Which element is reduced in the following reaction?
   $2MnO_4^-(aq) + Br^-(aq) + H_2O(l) \rightarrow 2MnO_2(s) + BrO_3^-(aq) + 2OH^-(aq)$
   A. Mn
   B. O
   C. Br
   D. H

4. Which of the following is **not** a redox reaction?
   A. $2H_2O_2 \rightarrow 2H_2O + O_2$
   B. $CH_3COOH + LiOH \rightarrow CH_3COOLi + H_2O$
   C. $C_3H_6 + Br_2 \rightarrow C_3H_6Br_2$
   D. $Na + Cl_2 \rightarrow 2NaCl$

5. Which pair reacts most vigorously?
   A. Li and Br_2
   B. Li and F_2
   C. K and Br_2
   D. K and F_2

6. What are the products of the electrolysis of molten lead(II) bromide, $PbBr_2$?

	Cathode product	Anode product
A.	lead	bromine
B.	lead	bromide
C.	lead(II)	bromine
D.	lead(II)	bromide

7. The following reaction occurs in a voltaic cell.
   $2Ag^+(aq) + Cu(s) \rightarrow 2Ag(s) + Cu^{2+}(aq)$
   What reaction occurs at each electrode?

	Cathode	Anode
A.	$Ag^+(aq) \rightarrow Ag(s) + e^-$	$Cu(s) \rightarrow Cu^{2+}(aq) + 2e^-$
B.	$Ag^+(aq) + e^- \rightarrow Ag(s)$	$Cu(s) + 2e^- \rightarrow Cu^{2+}(aq)$
C.	$Ag^+(aq) + e^- \rightarrow Ag(s)$	$Cu(s) \rightarrow Cu^{2+}(aq) + 2e^-$
D.	$Cu(s) \rightarrow Cu^{2+}(aq) + 2e^-$	$Ag^+(aq) + e^- \rightarrow Ag(s)$

8. Which of the following classes of compound can be reduced?
   I alkene
   II carboxylic acid
   III aldehyde
   A. I and II only
   B. I and III only
   C. II and III only
   D. I, II and III

9. Which class of compound is formed when a secondary alcohol is oxidized?
   A. aldehyde
   B. ether
   C. ketone
   D. carboxylic acid

10. Hydrogen can be added to ethene to produce ethane.
    $C_2H_4(g) + H_2(g) \rightarrow C_2H_6(g)$
    Which of the following is correct for this reaction?

	Degree of unsaturation	Species that undergoes reduction
A.	increases	ethene
B.	decreases	ethene
C.	increases	hydrogen
D.	decreases	hydrogen

AHL

11. Consider the standard reduction potentials:
    $Cd^{2+}(aq) + 2e^- \rightleftharpoons Cd(s)$ $\quad E^\ominus = -0.40\ V$
    $Cr^{3+}(aq) + 3e^- \rightleftharpoons Cr(s)$ $\quad E^\ominus = -0.74\ V$
    Which is the strongest oxidizing agent?
    A. Cd^{2+}
    B. Cr^{3+}
    C. Cd
    D. Cr

AHL

12. What are the major products of the electrolysis of concentrated sodium chloride solution, NaCl(aq)?

	Negative electrode	Positive electrode
A.	Na	O_2
B.	H_2	O_2
C.	Na	Cl_2
D.	H_2	Cl_2

Extended-response questions

13. The reaction between ethanedioate ions, $C_2O_4^{2-}$ and manganate(VII) ions, MnO_4^-, in acidic solution is a redox reaction. The incomplete equation for this reaction is shown below:

$C_2O_4^{2-} + MnO_4^- \rightarrow CO_2 + Mn^{2+}$

a. Deduce the oxidation state of carbon in the ethanedioate ion, $C_2O_4^{2-}$. [1]

b. The oxidation half-equation is:
$C_2O_4^{2-}(aq) \rightarrow 2CO_2(g) + 2e^-$
Deduce the reduction half-equation, including state symbols. [2]

c. Deduce the full redox reaction. [1]

14. Sodium chloride is found in table salt.

a. Describe how bonding occurs in sodium chloride. [2]

b. Explain why sodium chloride is not an electrical conductor when solid but can conduct electricity when molten. [1]

c. Molten sodium chloride can be electrolysed. Identify the half-equation for the reaction that takes place at the

i. cathode [1]

ii. anode. [1]

AHL

d. Deduce the half-equation for the oxidation reaction that takes place when dilute aqueous sodium chloride is electrolysed. [1]

e. A student prepares a concentrated sodium chloride solution and adds a few drops of phenolphthalein. The student then electrolyses the solution. Describe two observations made by the student during the electrolysis. [2]

15. a. $Li^+ + e^- \rightarrow Li(s)$ is a reaction occurring at one of the electrodes in a lithium-ion battery. State at which electrode (anode/cathode) this reaction occurs and whether this is the charging or discharging reaction. [2]

b. Identify the reaction at the opposite electrode. [1]

c. Explain why lithium-ion batteries must be sealed. [1]

16. a. Write an equation for the complete combustion of ethanol. [1]

b. i. Deduce the oxidation state of carbon in carbon dioxide. [1]

ii. Deduce the mean oxidation state of carbon in ethanol. [1]

iii. State and explain, with reference to oxidation states, whether carbon is oxidized or reduced when ethanol undergoes complete combustion. [1]

c. Ethanol can also be oxidized when reacted with acidified potassium dichromate(VI).

i. Draw the structural formulas and state the names of the two possible organic products of this reaction. [2]

ii. State the methods used to isolate each of the substances in your answer above. [1]

17. A student carries out the following reactions between three unknown metals (X, Y and Z) and several dilute solutions. The following results were obtained:

Reactants	Observations
$Y + Z(NO_3)_2(aq)$	Y is a shiny grey metal. $Z(NO_3)_2(aq)$ is a clear blue solution. When reacted together, a red-brown solid appeared on the surface of the metal. Over time, the solution's blue colour faded.
$X + Y(NO_3)_2(aq)$	No reaction
$Z + X(NO_3)_2(aq)$	No reaction
$Z + HCl(aq)$	No reaction

a. List metals X, Y and Z, in order of increasing reactivity. [1]

b. Suggest, with reference to **two** observations, which metal, X, Y or Z, could be copper. [2]

c. A standard nickel–copper voltaic cell is set up.

i. Draw the cell diagram for this voltaic cell and label the following:
- ions in each solution
- cathode
- anode
- direction of travel of electrons in the external circuit
- direction of travel of cations in the salt bridge. [2]

ii. Deduce the equation, including state symbols, for the spontaneous redox reaction that occurs in this cell. [2]

d. Calculate the standard cell potential, in V, for the redox reaction. Refer to section 19 of the data booklet. [1]

AHL

End of topic questions

Topic review

1. Using your knowledge from the *Reactivity 3.3* topic, answer the guiding question as fully as possible:
   What happens when a species possesses an unpaired electron?

Exam-style questions

Multiple-choice questions

2. What is a propagation step in the radical substitution mechanism of ethane with chlorine?
   A $Cl_2 \rightarrow 2Cl\bullet$
   B $\bullet C_2H_5 + Cl_2 \rightarrow C_2H_5Cl + Cl\bullet$
   C $\bullet C_2H_5 + Cl\bullet \rightarrow C_2H_5Cl$
   D $C_2H_6 + Cl\bullet \rightarrow C_2H_5Cl + \bullet H$

3. Methane reacts with chlorine in sunlight.
   $CH_4(g) + Cl_2(g) \rightarrow CH_3Cl(g) + HCl(g)$
   Which type of reaction occurs?
   A radical substitution
   B electrophilic substitution
   C nucleophilic substitution
   D electrophilic addition

4. Which of these reactions proceeds by a radical mechanism in the presence of UV light?
   A $C_6H_6 + Cl_2 \rightarrow C_6H_5Cl + HCl$
   B $C_6H_6 + 3H_2 \rightarrow C_6H_{12}$
   C $CH_2CH_2 + HBr \rightarrow CH_3CH_2Br$
   D $CH_3CH_3 + Cl_2 \rightarrow CH_3CH_2Cl + HCl$

Extended-response questions

5. a. Define homolytic fission, including the required reaction conditions. [2]
   b. Write an equation to show the movement of electrons during homolytic fission of iodine. [1]

6. This question is about carbon and chlorine compounds.
   a. Ethane, C_2H_6, reacts with chlorine in sunlight. State the type of this reaction and the name of the mechanism by which it occurs. [1]
   b. Formulate equations for the two propagation steps and one termination step in the formation of chloroethane from ethane. [3]

7. Chloromethylbenzene, $C_6H_5CH_2Cl$, is a useful reagent in synthetic reactions in the manufacture of pesticides, medicines and fragrances.
   a. Draw the structural formula of methylbenzene, also known as toluene. [1]
   b. Methylbenzene can undergo chlorination in the presence of UV light to produce chloromethylbenzene. Explain the role of UV light in the initiation step. [1]
   c. Formulate the equation to describe the initiation step. [1]
   d. Write equations for the two propagation steps and one termination step. [3]
   e. Write an equation for the overall reaction, using structural formulas. [3]

End of topic questions

Topic review

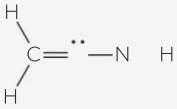
1. Using your knowledge from the *Reactivity 3.4* topic, answer the guiding question as fully as possible:
   What happens when reactants share their electron pairs with others?

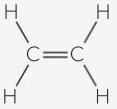
Exam-style questions

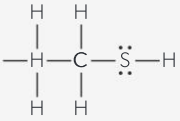
Multiple-choice questions

2. Identify and explain why one of the following species cannot act as a nucleophile.

A. 

B. 

C. 

D. 

3. Ethene, C_2H_4, reacts with steam in the presence of a strong acid.

   $C_2H_4 + H_2O \rightarrow C_2H_5OH$

   What is the name of this type of reaction?
   A. Nucleophilic substitution
   B. Neutralization
   C. Condensation
   D. Electrophilic addition

AHL

4. Which statement is correct?
   A. Electrophiles are Brønsted–Lowry acids.
   B. Nucleophiles are Brønsted–Lowry acids.
   C. Electrophiles are Lewis acids.
   D. Nucleophiles are Lewis acids.

AHL

5. Which is an example of a Lewis base?
   A. an electrophile
   B. BF_3
   C. CH_4
   D. a nucleophile

AHL

6. Which attacking species is matched with its mechanism of reaction?

A.	OH^-	electrophilic substitution
B.	Cl^+	nucleophilic addition
C.	NH_4^+	nucleophilic addition
D.	NO_2^+	electrophilic substitution

7. Which bromoalkane is most likely to hydrolyse via a S_N1 mechanism?
   A. $CH_3CHBrCH_2CH_3$
   B. $(CH_3)_2CHBr$
   C. $(CH_3)_3CBr$
   D. $CH_3CH_2CH_2CH_2Br$

Extended-response questions

8. Organic chemistry can be used to synthesize a variety of products.
   a. Draw the structure of the final product for reaction between but-2-ene and water. [1]

AHL

   b. Sketch the mechanism for the reaction of 2-methylbut-2-ene with hydrogen bromide using curly arrows. [3]
   c. Explain why the major organic product of the reaction in part (b) is 2-bromo-2-methylbutane and not 2-bromo-3-methylbutane. [2]

9. Chlorine, Cl_2, undergoes many reactions.
   a. State the type of reaction occurring when ethane reacts with chlorine to produce chloroethane. [1]
   b. Predict, giving a reason, whether ethane or chloroethane is more reactive. [1]

AHL

   c. Explain the mechanism of the reaction between chloroethane and aqueous sodium hydroxide, NaOH(aq), using curly arrows to represent the movement of electron pairs. [3]