## Topic 1: Atomic Structure

1. **Give the amount of protons, electrons and neutrons in the following isotopes:**
a) $^{36}Cl$
b) $^{27}Al$
c) Explain whether the isotopes $^{36}Cl$ and $^{27}Al$ are expected to be the most abundant of the elements Cl and Al, respectively.

2. **What is the maximum number of electrons that can be present simultaneously in the following (types of) orbitals:**
a) 3d
b) 2s
c) 3p
d) 6f
e) $5p_x$

3. **Choose in the following statements the correct answer of the two {…/…} or three options {…/…/… } given.**
a) A bromine atom is {larger/smaller} than a fluorine atom.
b) The 3d orbitals can contain at most {six/ten/fourteen} electrons.
c) In all atoms with Z > 1 the 2p-orbitals are {lower/higher} in energy than the 2s orbital.
d) In the ground state, the element nitrogen has {one/two/three} unpaired electrons.
e) The three 2p orbitals together can contain at most {two/six/ten} electrons.
f) On average, an electron in one of the three 2p orbitals is {further away from/closer to} the nucleus compared to an electron in a 2s orbital.
g) The $Z_{eff}$ experienced by the valence electron(s) of the elements in a group of the periodic table decreases down the group, e.g. in group 1 for the series Na, K, Rb, Cs, Fr. This decrease of $Z_{eff}$ means that the outer-most (valence) electron(s) are {more/less/equally} strongly bonded to the nucleus.

**Multiple choice**

4. **The isotope $^{64}Cu$ contains**
A 35 protons, 29 neutrons and 35 electrons
B 29 protons, 35 neutrons and 35 electrons
C 29 protons, 35 neutrons and 29 electrons
D 35 protons, 35 neutrons and 29 electrons

5. **The total number of valence electrons of the element O equals**
A 2
B 4
C 6
D 8

6. **The number of unpaired valence electrons of the element carbon (C) in its ground state equals**
A zero
B one
C two
D three

7. **The amount of paired valence electrons of the element bromine (Br) in its ground state equals**
A 3
B 4
C 5
D 6

8. **Which one of the four following statements is correct?**
A The effective nuclear charge $Z_{eff}$ that a 3d electron experiences is lower than the $Z_{eff}$ that a 3p electron experiences
B An electron in a 3p orbital is better in shielding off the nucleus than an electron in a 3s orbital.
C A valence electron is on average closer to the nucleus than a non-valence electron.
D A 2s electron can never be present at the nucleus of an atom.

## Topic 2: The Periodic Table and Chemical Bonding

1. **In the Periodic Table of Elements information about the build-up of the element chlorine can be found.**
a) Explain what the '17' , the '35.453' and the '$3s^2 3p^5$' mean in terms of the atomic particles (electrons, protons, neutrons).
b) Which of the valence electron(s) of chlorine have on average the largest distance to the nucleus?
c) How many unpaired electrons does chlorine have in its ground state?

2. **Consider the following selection of elements: lithium, selenium, manganese, neodymium, xenon, boron, oxygen, yttrium, mercury. You can use the website ptable.com for this question.**
a) Which of these elements are classified as metals?
b) Which of these elements are classified as non-metals?
c) Which of these elements are not solids at room temperature?
d) Which of these elements has the highest atomic mass?
e) Which of these elements do you expext to be least likely to form chemical bonds?
f) Which two of these elements do you expect to show similar chemistry?

3. **The compound $H_2SO_4$ (sulfuric acid) contains**
A No ionic bonds
B No covalent bonds
C Both ionic and covalent bonds
D Only ionic bonds

4. **If it is assumed that in the inorganic pigment chrome yellow (lead (II) chromate, $PbCrO_4$) all four oxygens are in the oxide anion form, this would imply that the charge of the chromium (ion) equals**
A +2
B +4
C +6
D +8

5. **The number of valence electrons of the ion $Cu^{2+}$ equals**
A 1
B 2
C 8
D 9

6. **For each of the following bonds, determine whether it has ionic, polar, or non-polar character.**
a) O – N
b) Te – Ca
c) As – S
d) C – Cl
e) Pb – I
f) Mg – Br

7. **Consider a non-metal atom from period 3. Which one of the following statements is incorrect?**

A The effective nuclear charge $Z_{eff}$ depends on the number of electrons present in the atom.

B An electron in a 3p orbital is worse at shielding off the nucleus than an electron in a 3s orbital.

C A valence electron experiences a lower effective nuclear charge ($Z_{eff}$) compared to a non-valence electron.

D The effective nuclear charge ($Z_{eff}$) that an electron in a 1s-orbital experiences is lower than the $Z_{eff}$ experienced by an electron in a 2s-orbital.

## Topic 3: The Structure of Molecules

**For each of the following molecules/ions, draw its Lewis structure or equivalent resonance structures if they exist.**

1) $HClO$ (hypochlorous acid)
2) $CO_2$ (carbon dioxide)
3) $HCN$ (hydrocyanic acid, hydrogen cyanide)
4) $HNO_2$ (nitrous acid)
5) $CH_3CH_2OH$ (ethanol)
6) $CH_3CHO$ (ethanal, acetaldehyde)
7) $CH_3COOH$ (acetic acid, ethanoic acid)
8) $CH_3COCH_3$ (acetone, dimethylketone, propanone)
9) $CH_3CH_2OCH_2CH_3$ (diethylether, ethoxyethane)
10) $CH_3COOCH_3$ (methylacetate)
11) $CH_3CH_2NHCH_2CH_3$ (diethylamine)
12) $HCONH_2$ (formamide, methanamide)
13) $HNO_3$ (nitric acid)
14) $O_3$ (ozone)
15) $CO_3^{2-}$ (carbonate anion)
16) $SO_2$ (sulfur dioxide)
17) $H_3PO_4$ (phosphoric acid)
18) $HClO_2$ (chlorous acid)
19) $ClO_2^-$ (chlorite anion)
20) $NO_2$ (nitrogen dioxide)

## Lecture 4: The Shape of Molecules and Ionic Compounds

1. **Before, you drew Lewis structures for each of the following molecules/ions. Based on those structures**

a) **determine the electron-pair geometry (EPG) and molecular geometry (MG) around the central atom (for 5-12, give the EPG at all non-carbon atoms).**
b) **argue for each neutral molecule whether you expect it to be polar or non-polar.**

1) HClO (hypochlorous acid)
2) $CO_2$ (carbon dioxide)
3) HCN (hydrocyanic acid, hydrogen cyanide)
4) $HNO_2$ (nitrous acid)
5) $CH_3CH_2OH$ (ethanol)
6) $CH_3CHO$ (ethanal, acetaldehyde)
7) $CH_3COOH$ (acetic acid, ethanoic acid)
8) $CH_3COCH_3$ (acetone, dimethylketone, propanone)
9) $CH_3CH_2OCH_2CH_3$ (diethylether, ethoxyethane)
10) $CH_3COOCH_3$ (methylacetate)
11) $CH_3CH_2NHCH_2CH_3$ (diethylamine)
12) $HCONH_2$ (formamide, methanamide)
13) $HNO_3$ (nitric acid)
14) $O_3$ (ozone)
15) $CO_3^{2-}$ (carbonate anion)
16) $SO_2$ (sulfur dioxide)
17) $H_3PO_4$ (phosphoric acid)
18) $HClO_2$ (chlorous acid)
19) $ClO_2^-$ (chlorite anion)
20) $NO_2$ (nitrogen dioxide)

2. **The formula of an ionic material that contains only the elements calcium and chlorine is most likely**
A CaCl
B $Ca_2Cl$
C $CaCl_2$
D $CaCl_3$

3. **If it is assumed that the inorganic pigment red lead ($Pb_3O_4$) contains only oxygens in the oxide anion form, this would imply**
A equal amounts of $Pb^{2+}$ and $Pb^{4+}$
B more $Pb^{2+}$ than $Pb^{4+}$
C only $Pb^{2+}$
D only $Pb^{4+}$

4. **If it is assumed that in the mineral magnetite $Fe_3O_4$ all four oxygens are in the oxide anion form, this would imply that $Fe_3O_4$ contains the following types of iron cation(s):**
A $Fe^{+}$ and $Fe^{2+}$
B $Fe^{2+}$ and $Fe^{3+}$
C only $Fe^{2+}$
D only $Fe^{3+}$

5. **The compound $CaCO_3$ (chalk) contains**
A No ionic bonds
B No covalent bonds
C Both ionic and covalent bonds
D Only ionic bonds

6. **The formula of an ionic material that contains only the elements magnesium and phosphorus would most likely be**
A MgP
B $Mg_2P_3$
C $Mg_3P_2$
D $Mg_4P_3$

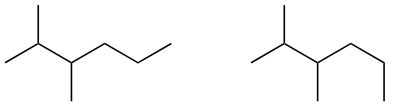
## Topic 5: Organic Molecules and Functional Groups

1. **Draw three structural isomers of $C_3H_6O$.**

2. **Draw five structural isomers of $C_4H_{11}N$.**

3. **For each of the following sets of molecules, indicate whether they are distinct molecules.**

a)



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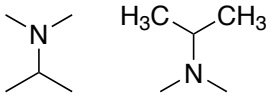
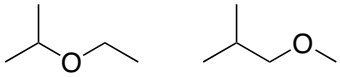



c)

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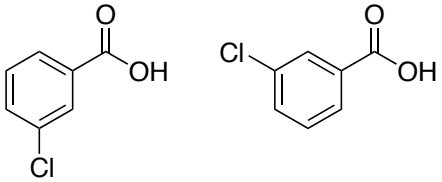


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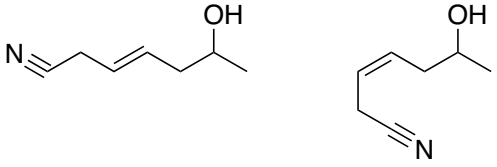


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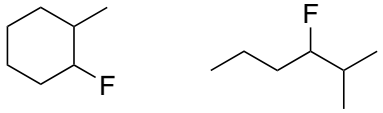
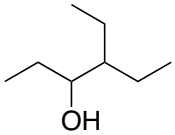



4. **For each of the following molecules, name the functional group(s) that it contains. Naming alkyl (methyl, ethyl, propyl, etc.) side-groups is optional.**

a)

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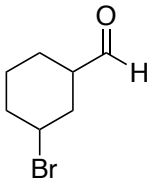

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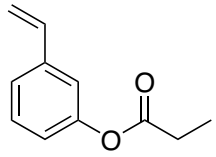

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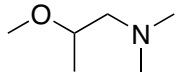

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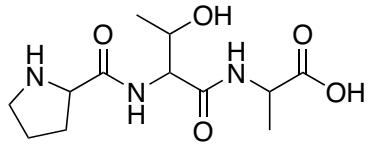

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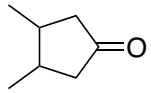
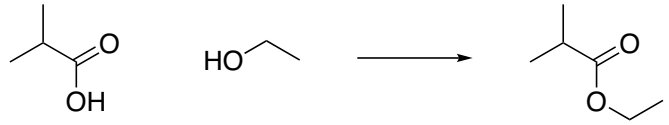
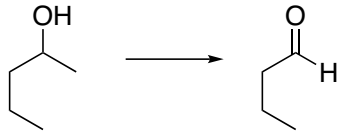


5. **State whether the following reactions can take place, and if so, what name it has.**

a)

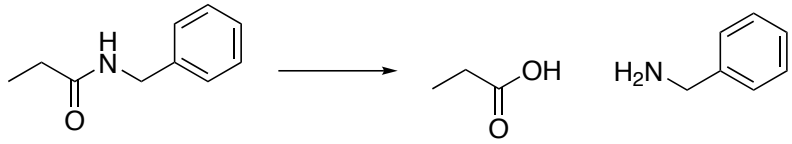


b)



c)

d)

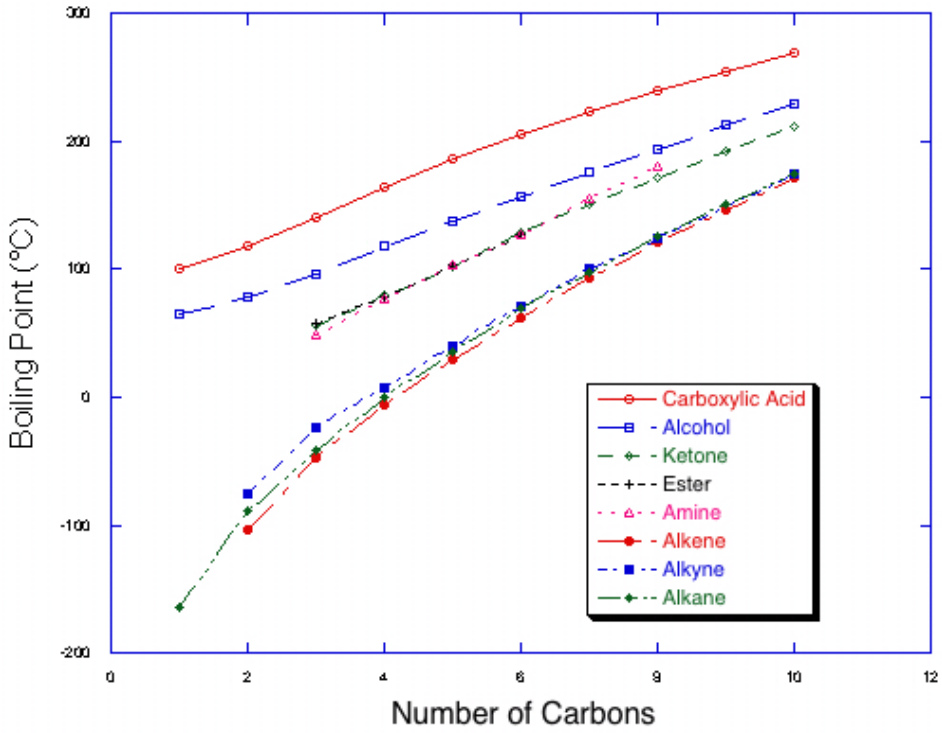


## Topic 6: Polarity and Intermolecular Interactions

1. **Previously, you drew Lewis structures for each of the following molecules/ions. Based on those structures, name the relevant intermolecular forces between a pair of each of the following neutral molecules. (LF = London dispersion forces, DP = dipole-dipole interactions, HB = hydrogen bonding)**

1) HClO (hypochlorous acid)
2) $CO_2$ (carbon dioxide)
3) HCN (hydrocyanic acid, hydrogen cyanide)
4) $HNO_2$ (nitrous acid)
5) $CH_3CH_2OH$ (ethanol)
6) $CH_3CHO$ (ethanal, acetaldehyde)
7) $CH_3COOH$ (acetic acid, ethanoic acid)
8) $CH_3COCH_3$ (acetone, dimethylketone, propanone)
9) $CH_3CH_2OCH_2CH_3$ (diethylether, ethoxyethane)
10) $CH_3COOCH_3$ (methylacetate)
11) $CH_3CH_2NHCH_2CH_3$ (diethylamine)
12) $HCONH_2$ (formamide, methanamide)
13) $HNO_3$ (nitric acid)
14) $O_3$ (ozone)
15) $CO_3^{2-}$ (carbonate anion)
16) $SO_2$ (sulfur dioxide)
17) $H_3PO_4$ (phosphoric acid)
18) $HClO_2$ (chlorous acid)
19) $ClO_2^-$ (chlorite anion)
20) $NO_2$ (nitrogen dioxide)

2. In pure liquids (without ions), one or more intermolecular attractive forces can be present, i.e. (i) dipole-dipole interactions (DP), (ii) London (or dispersion) forces (LF) and (iii) hydrogen bonding forces (HB). Differences in boiling points between liquids and mutual (in)solubility of liquids can often be explained in terms of these forces.
a) **List for each of the five molecules below all the types of intermolecular interactions that are expected to act between molecules in their liquid state.**
(i) $C_6H_6$ (benzene)
(ii) $CH_3CH_2OH$
(iii) HCOOH
(iv) $H_2S$
(v) $CCl_4$
b) In the figure below, some trends in boiling points are shown.
(i) **Explain for the difference in boiling point for the carboxylic acid $CH_3CH_2COOH$, the alcohol $CH_3CH_2CH_2OH$, the amine $CH_3CH_2CH_2NH_2$, and the alkane $CH_3CH_2CH_2CH_3$.**
(ii) **Explain why the boiling points of the compounds become closer when the number of carbon atoms increases.**




c) **Explain for each of five substances below what would be the better solvent, $CH_3COCH_3$ (acetone) or hexane ($C_6H_{14}$):**

(i) $CH_3CH_2OH$

(ii) $CHCl_3$

(iii) $CH_3CH_2COOH$

(iv) NaCl

(v) $C_6H_6$ (benzene)

## Topic 7: Chemical calculations

1. **Balance the following reaction equations with stoichiometric coefficients.**
a) $PCl_5$ (s) + $H_2O$ (l) → $POCl_3$ (l) + HCl (aq)
b) $H_2$ (g) + $I_2$ (s) → HI (s)
c) Fe (s) + $O_2$ (g) → $Fe_2O_3$ (s)
d) Cu (s) + $HNO_3$ (aq) → $Cu(NO_3)_2$ (aq) + $H_2O$ (l) + NO (g)
e) $(NH_4)_2Cr_2O_7$ (s) → $Cr_2O_3$ (s) + $N_2$ (g) + $H_2O$ (g)
f) $P_4$ (s) + $Cl_2$ (g) → $PCl_3$ (l)
g) $PtCl_4$ (s) → Pt (s) + $Cl_2$ (g)

2. **Write balanced reaction equations for the following reactions.**
a) Solid calcium carbonate decomposes to solid calcium oxide and carbon dioxide gas.
b) Gaseous butane, $C_4H_{10}$, reacts with diatomic oxygen gas to yield gaseous carbon dioxide and water vapor.
c) Aqueous solutions of magnesium chloride and sodium hydroxide react to produce solid magnesium hydroxide and aqueous sodium chloride.
d) Water vapor reacts with sodium metal to produce solid sodium hydroxide and hydrogen gas.

3. **Calculate the molar mass of the following compounds up to 2 decimals.**
a) $CH_4$
b) $CHCl_3$
c) $C_{12}H_{10}O_6$
d) $CH_3CH_2CH_2CH_2CH_3$
e) $Ca(NO_3)_2$
f) $Na_2S_2O_3$
g) $CuSO_4 \cdot 5H_2O$

4. **Calculate the amount in moles for each of the following compounds, with the right number of significant digits.**
a) 24.0 g of $CH_4$
b) 50.00 g of $CHCl_3$
c) 5.0 g of $C_{12}H_{10}O_6$
d) 193.00 g of $CH_3CH_2CH_2CH_2CH_3$
e) 20.000 g of $Ca(NO_3)_2$
f) 35.0 g of $Na_2S_2O_3$
g) 600 g of $CuSO_4 \cdot 5H_2O$

5. **Calculate the mass of each of the following amounts of compounds.**
a) 0.50 mol $CH_4$
b) 1.5 mol $CHCl_3$
c) 7.00 mol $C_{12}H_{10}O_6$
d) 0.002 mol $CH_3CH_2CH_2CH_2CH_3$
e) 50 mol $Ca(NO_3)_2$
f) 12.0 mol $Na_2S_2O_3$
g) 23 mol $CuSO_4 \cdot 5H_2O$

## Topic 8: Salts and solubility

1. **A 200 mL sample and a 400 mL sample of a solution of salt have the same molarity**.
a) In what ways are the two samples identical?
b) In what ways are these two samples different?
c) Is 0.5 mmol/mL the same concentration as 0.5 mol/L?
d) What do we mean with 0.5 mM?

2. **If you dissolve the following salts up to a concentration of 1 mol/L, what is the molarity of the dissolved ions?**
a) Barium chloride ($BaCl_2$)
b) Sodium Sulfate ($Na_2SO_4$)
c) Lithium Phosphate ($Li_3PO_4$)
d) Magnesium Chloride ($MgCl_2$)
e) Potassium carbonate ($K_2CO_3$)
f) Ammonium phosphate ($(NH_4)_3PO_4$
g) Iron nitrate ($Fe(NO_3)_3$)

3. **Write down the balanced reaction equation for the precipitate that forms when solutions of the following pairs of salts are mixed. Use a qualitative solubility table to answer this question.**
a) barium chloride ($BaCl_2$) and sodium sulfate ($Na_2SO_4$)
b) magnesium chloride ($MgCl_2$) and potassium carbonate ($K_2CO_3$)
c) ammonium phosphate ($(NH_4)_3PO_4$ and iron nitrate ($Fe(NO_3)_3$)

4. **What is the concentration in mol/L (i.e. molarity) of the following solutions in water? Provide an answer with 4 decimal figures.**
a) 10 g of lithium chloride in 1 L
b) 3 g of magnesium sulfate in 250 mL
c) 25 g of copper sulfide in 100 mL
d) 5 g of zinc chloride in 2.5 L

5. **The following questions all concern dilution of solutions. For each, provide an answer with 2 decimal figures.**
a) How much should you dilute a 1.2 M solution to obtain a 0.1 M solution?
b) How much should you dilute a 0.25 M solution to obtain a 0.015 M solution?
c) What is the volume needed of a 1.00 M $Fe(NO_3)_3$ solution to create 200 mL of a solution with a concentration of 0.25 M?
d) If 0.1718 L of a 0.3556 M $C_3H_7OH$ solution is diluted to a concentration of 0.1222 M, what is the volume of the resulting solution?

## Topic 9: Acids and Bases

1. **Write down complete and balanced equations for the following acid-base reactions.**
a) HCl gas reacts with solid $Ca(OH)_2$.
b) A solution of $Sr(OH)_2$ is added to a solution of $HNO_3$.
c) Aqueous $H_2SO_4$ reacts with solid NaOH.
d) A $Ba(OH)_2$ solution reacts with HF gas.

2. **Show by writing a correct ionic dissociation equation that each of the following species can act as a Brønsted-Lowry <u>acid</u>.**
a) $H_3O^+$
b) HCl
c) $NH_3$
d) $CH_3COOH$
e) $NH_4^+$
f) $HSO_4^-$

3. **Show by writing a correct ionic dissociation equation that each of the following species can act as a Brønsted-Lowry <u>base</u>.**
a) $H_2O$
b) $OH^-$
c) $NH_3$
d) $CN^-$
e) $S^{2-}$
f) $H_2PO_4^-$

4. **Identify and label the Brønsted-Lowry acid, its conjugate base (CB), the Brønsted-Lowry base, and its conjugate acid (CA) in each of the following reaction equations.**
a) $HNO_3 + H_2O \rightarrow H_3O^+ + NO_3^-$
b) $CN^- + H_2O \rightarrow HCN + OH^-$
c) $H_2SO_4 + Cl^- \rightarrow HCl + HSO_4^-$
d) $HSO_4^- + OH^- \rightarrow SO_4^{2-} + H_2O$
e) $O^{2-} + H_2O \rightarrow 2\ OH^-$
f) $H_2S + NH_2^- \rightarrow HS^- + NH_3$

5. **Calculate the pH and the pOH of each of the following solutions at 25 °C, assuming that the substances ionize completely.**
a) 0.200 M HCl
b) 0.0143 M NaOH
c) 3.0 M $HNO_3$
d) 0.0031 M $Ca(OH)_2$

6. **Calculate the following concentrations.**
a) The concentration of hydronium ions in a solution HCl with a pH of 1.5
b) The concentration of hydroxide ions in a solution NaOH with a pH of 11.5
c) The concentration of hydronium ions in a solution HCl with a pOH of 13.
d) The concentration of hydroxide ions in a solution NaOH with a pOH of 12.

7. **Calculate the pH and the pOH for each of the following solutions at 25 °C, assuming the substances ionize completely.**

a) $2.59 \times 10^{-4}$ M $HClO_4$

b) $2.1 \times 10^{-1}$ M NaOH

c) $7.1 \times 10^{-5}$ M $Ba(OH)_2$

8. **Answer the following questions.**

a) What are the hydronium and hydroxide ion concentrations in a solution with a pH of 6.52?

b) If you have a relatively high concentration of acid in this solution (i.e., [acid] > 1 mM), what can you say about the strength of this acid?

c) Why is the concentration of $OH^-$ almost 10 times lower than $[H^+]$ in this solution?

9. **Calculate the following concentrations.**

a) The hydronium ion concentration in a sample of rainwater is found to be $1.7 \times 10^{-6}$ M. What is the concentration of hydroxide ions in the rainwater?

b) The hydroxide ion concentration in household ammonia is $3.2 \times 10^{-3}$ M. What is the concentration of hydronium ions in this solution?

## Topic 10: Redox reactions

1. **Identify in each half reaction whether there is an oxidant or reductant reacting.**
a) $Fe^{3+} + 3\ e^- \rightarrow Fe$
b) $Cr \rightarrow Cr^{3+} + 3\ e^-$
c) $MnO_4^{2-} \rightarrow MnO_4^- + e^-$
d) $Li^+ + e^- \rightarrow Li$

2. **Identify the oxidant and reductant in each reaction.**
a) $F_2 + Ca \rightarrow 2\ F^- + Ca^{2+}$
b) $Cl_2 + 2\ Li \rightarrow 2\ Cl^- + 2\ Li^+$
c) $3\ Br_2 + 2\ Fe \rightarrow 6\ Br^- + 2\ Fe^{3+}$
d) $MnO_4^- + 4\ H^+ + 3\ Ag \rightarrow MnO_2 + 3\ Ag^+ + 2\ H_2O$

3. **Determine the oxidation number of all elements in each compound.**
a) $Na$
b) $CCl_4$
c) $NO_3^-$
d) $SO_4^{2-}$
e) $SO_3$
f) $SO_2$

4. **What type of reaction is shown here?**
a) $CH_3COOH + H_2O \leftrightarrow CH_3COO^- + H_3O^+$
b) $2\ AgNO_3 + BaCl_2 \rightarrow 2\ AgCl + Ba(NO_3)_2$
c) $BaCl_2 + H_2SO_4 \rightarrow BaSO_4 + 2\ HCl$
d) $Cu + 2\ AgNO_3 \rightarrow 2\ Ag + Cu(NO_3)_2$
e) $3\ HCl + Fe(OH)_3 \rightarrow 3\ H_2O + FeCl_3$

# ANSWERS

## Topic 1: Atomic Structure

1
a) $^{36}Cl$ 19 neutrons, 17 protons, 17 electrons
b) $^{27}Al$ 14 neutrons, 13 protons, 13 electrons
c) $^{36}Cl$ is not expected to be the most abundant isotope of Cl because the (average) atomic mass of chlorine is 35.453, which is closer to 35 than to 36. $^{27}Al$ is expected to be the most abundant isotope of Al because 27 is the whole number that is closest to 26.982, the (average) atomic mass of aluminum.

2
a) 10
b) 2
c) 6
d) 14
e) 2

3
a) larger
b) ten
c) higher
d) three
e) six
f) further away from
g) less

4 C
5 C
6 C
7 D
8 A

## Topic 2: The Periodic Table and Chemical Bonding

1
a) The '17' denotes the number of protons and the number of electrons.
The '35.453' = the average number of protons + neutrons, taking into account all the naturally occurring isotopes of Cl and their relative abundance.
The '$3s^2 3p^5$ 'refers to the seven valence electrons of Cl, two (paired) in the 3s orbital and 5 in the three 3p orbitals.
b) The 5 electrons in the three 3p orbitals
c) One

2
a) Li, Mn, Nd, Y, Hg
b) Se, Xe, O
c) Xe, O, Hg
d) Hg
e) Xe (because it has a closed-shell electron configuration)
f) O and Se, because they are both in group 16.

3
A

4
C

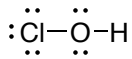
5
D

6
a) non-polar
b) polar
c) polar
d) polar
e) non-polar
f) ionic

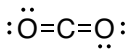
7 D

## Topic 3: The Structure of Molecules

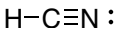
1) HClO (hypochlorous acid)



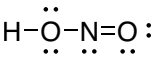
2) $CO_2$ (carbon dioxide)



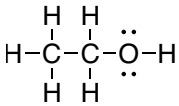
3) HCN (hydrocyanic acid, hydrogen cyanide)



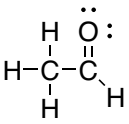
4) $HNO_2$ (nitrous acid)



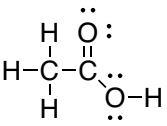
5) $CH_3CH_2OH$ (ethanol)



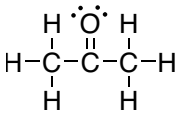
6) $CH_3CHO$ (ethanal, acetaldehyde)



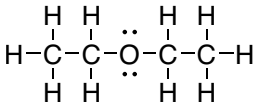
7) $CH_3COOH$ (acetic acid, ethanoic acid)



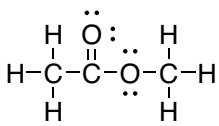
8) $CH_3COCH_3$ (acetone, dimethylketone, propanone)



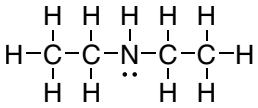
9) $CH_3CH_2OCH_2CH_3$ (diethylether, ethoxyethane)



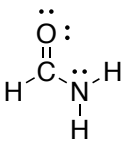
10) $CH_3COOCH_3$ (methylacetate)



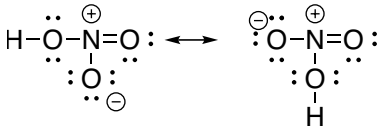
11) $CH_3CH_2NHCH_2CH_3$ (diethylamine)



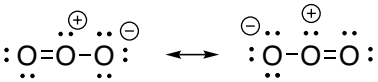
12) $HCONH_2$ (formamide, methanamide)



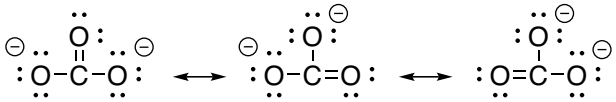
13) $HNO_3$ (nitric acid)



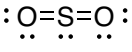
14) $O_3$ (ozone)



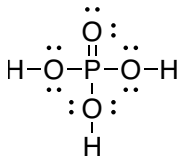
15) $CO_3^{2-}$ (carbonate anion)



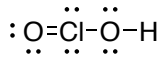
16) $SO_2$ (sulfur dioxide)



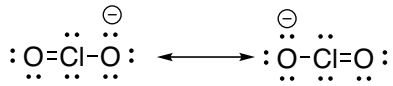
17) $H_3PO_4$ (phosphoric acid)



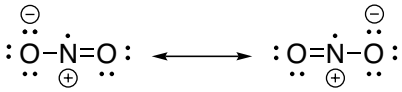
18) $HClO_2$ (chlorous acid)



19) $ClO_2^-$ (chlorite anion)



20) $NO_2$ (nitrogen dioxide)



Note: this molecule is a radical!

# Topic 4: The Shape of Molecules and Ionic Compounds

1.

**1) HClO (hypochlorous acid)**
a) EPG at O: tetrahedral. MG at O: bent.
b) Polar, because $\Delta\chi$ (O–H) = 1.2.

**2) $CO_2$ (carbon dioxide)**
a) EPG at C: linear. MG at C: linear.
b) Non-polar, because the two C–O dipoles cancel out.

**3) HCN (hydrocyanic acid, hydrogen cyanide)**
a) EPG at C: linear. MG at C: linear.
b) Polar, because $\Delta\chi$ (C–N) = 0.49, and it is not cancelled out by C–H.

**4) $HNO_2$ (nitrous acid)**
a) EPG at N: trigonal planar. MG at N: bent
b) Polar, because $\Delta\chi$ (O–H) = 1.24 (plus additional contribution from $\Delta\chi$ (N–O) = 0.4 towards O).

**5) $CH_3CH_2OH$ (ethanol)**
a) EPG at C and O: tetrahedral. MG at C: tetrahedral, MG at O: bent.
b) Polar, because $\Delta\chi$ (O–H) = 1.24 and $\Delta\chi$ (C–O) = 0.89 both point towards O and the section C–O–H is not linear.

**6) $CH_3CHO$ (ethanal, acetaldehyde)**
a) EPG at $CH_3$: tetrahedral, EPG at CHO: trigonal planar. MG at $CH_3$: tetrahedral, MG at CHO: trigonal planar.
b) Polar, because $\Delta\chi$ (C–O) = 0.89, which dominates the structure.

**7) $CH_3COOH$ (acetic acid, ethanoic acid)**
a) EPG at $CH_3$: tetrahedral, EPG at COOH: trigonal planar, EPG at OH: tetrahedral. MG at $CH_3$: tetrahedral, MG at COOH: trigonal planar, MG at OH: bent.
b) Polar, because $\Delta\chi$ (O–H) = 1.24 and $\Delta\chi$ (C–O) = 0.89, and the section C–O–H is not linear.

**8) $CH_3COCH_3$ (acetone, dimethylketone, propanone)**
a) EPG at $CH_3$: tetrahedral, EPG at CO: trigonal planar. MG at $CH_3$: tetrahedral, MG at CO: trigonal planar.
b) Polar, because $\Delta\chi$ (C–O) = 0.89.

**9) $CH_3CH_2OCH_2CH_3$ (diethylether, ethoxyethane)**
a) EPG at all C and O: tetrahedral. MG at all C: tetrahedral, MG at O: bent.
b) Polar, because $\Delta\chi$ (C–O) = 0.89, and the section C–O–C is not linear.
**10) $CH_3COOCH_3$ (methylacetate)**
a) EPG at $CH_3$: tetrahedral, EPG at COO: trigonal planar. MG at $CH_3$: tetrahedral, MG at COO: trigonal planar.

b) Polar, because $\Delta\chi$ (C–O) = 0.89, and the section O=C–O–C is not linear.

**11) $CH_3CH_2NHCH_2CH_3$ (diethylamine)**
a) EPG at all C and N: tetrahedral, MG at all C: tetrahedral, MG at N: trigonal pyramid.
b) Polar, because $\Delta\chi$ (C–N) = 0.49 and $\Delta\chi$ (N–H) = 0.84, and because the structure is not symmetric, the dipoles do not cancel out.

**12) $HCONH_2$ (formamide, methanamide)**
a) EPG at C: trigonal planar, EPG at N: tetrahedral. MG at C: trigonal planar, MG at N: trigonal pyramid.
b) Polar, $\Delta\chi$ (N–H) = 0.84 and $\Delta\chi$ (C–O) = 0.89, and they do not cancel out.

**13) $HNO_3$ (nitric acid)**
a) EPG at N: trigonal planar. MG at N: trigonal planar.
b) Polar, there is permanent charge separation with a positive charge on N and a negative charge spread over two O.

**14) $O_3$ (ozone)**
a) EPG at central O: trigonal planar. MG at central O: bent.
b) Polar, there is permanent charge separation with a positive charge on the central O and negative charge spread between the outer two O, and a non-linear O–O–O chain.

**15) $CO_3^{2-}$ (carbonate anion)**
a) EPG at C: trigonal planar. MG at C: trigonal planar.

**16) $SO_2$ (sulfur dioxide)**
a) EPG at S: trigonal planar. MG at S: bent.
b) Polar, $\Delta\chi$ (S–O) = 0.86, and the molecule is not linear.

**17) $H_3PO_4$ (phosphoric acid)**
a) EPG at P: tetrahedral. MG at P: tetrahedral.
b) Polar. $\Delta\chi$ (O–H) = 1.24 and $\Delta\chi$ (O–P) = 1.25, and the molecule is not symmetric.

**18) $HClO_2$ (chlorous acid)**
a) EPG at Cl: tetrahedral. MG at Cl: bent.
b) Polar, $\Delta\chi$ (O–H) = 1.24.

**19) $ClO_2^-$ (chlorite anion)**
a) EPG at Cl: tetrahedral. MG at Cl: bent

**20) $NO_2$ (nitrogen dioxide)**
a) EPG at N: trigonal planar. MG at N: bent.
b) Polar, there is permanent charge separation, with a positive charge on N and a negative charge spread over the two O.

2. C

3. B

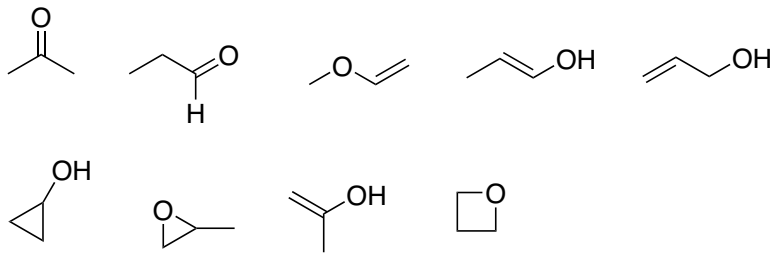
4. B

5. C

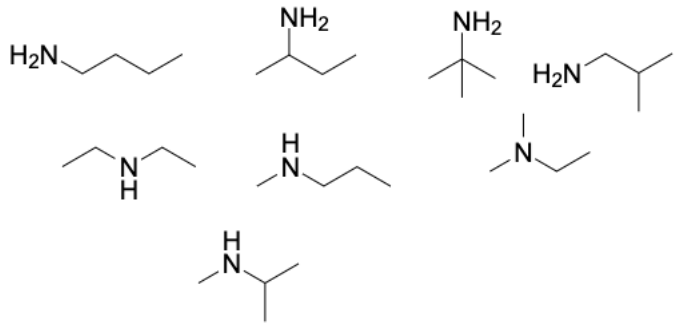
6. C

## Topic 5: Organic Molecules and Functional Groups

1.




2.




3.
a) same
b) same
c) different
d) same
e) different
f) different

4.
a) Alcohol (secondary), ethyl group.
b) Aldehyde, halogen (in this case bromide, not discussed in lecture).
c) Benzene ring, alkene group (sometimes called 'vinyl' if it is located at the end of a chain), ester group.
d) Ether, amine (tertiary), methyl group.
e) Amine (secondary), amide (2x), alcohol (secondary), carboxylic acid, methyl group.
f) Methyl group (2x), ketone.

5.
a) Yes, it is called condensation (or in this case, esterification).
b) No, oxidation of a secondary alcohol forms a ketone, not an aldehyde.
c) No, reduction of a carboxylic acid would form an aldehyde, not a ketone.
d) Yes, it is called hydrolysis (hydrolysis of amides was not on the lecture slides, but it is similar to hydrolysis of esters).

## Topic 6: Polarity and Intermolecular Interactions

1.
1) LF, DP, HB
2) LF
3) LF, DP
4) LF, DP, HB
5) LF, DP, HB
6) LF, DP
7) LF, DP, HB
8) LF, DP
9) LF, DP
10) LF, DP
11) LF, DP, HB
12) LF, DP, HB
13) LF, DP, HB
14) LF, DP

16) LF, DP
17) LF, DP, HB
18) LF, DP, HB

20) LF, DP

2.
a) (i) LF, (ii) LH, DP, HB, (iii) LF, DP, HB, (iv) LF, DP, (v) LF
b) (i) All molecules have (about) the same number of non-H atoms, so they will have approximately equal LF. The alkane has only LF, so the lowest boiling point. The amine and alcohol both have HB, but since O is more electronegative than N, the O–H dipole is stronger. So the alcohol will have stronger DP and HB, so a higher boiling point. The carboxylic acid also has LF, DP and HB, but it can form particularly strong dimer interactions, so it will have the highest boiling point.
(ii) With an increase in the number of carbon (and hydrogen) atoms, all other things staying equal the LF becomes increasingly more dominant in governing the overall interactions between molecules. Therefore, the boiling points move closer together.
c) Acetone is polar (LF and DP), hexane is apolar (only LF). In view of the rule 'like-dissolves-like', compounds are best dissolved in solvents that have similar intermolecular interactions.
(i) $CH_3CH_2OH$ has LF, DP and HB => acetone
(ii) $CHCl_3$ has LF and DP => acetone
(iii) $CH_3CH_2COOH$ has LF, DP and HB => acetone
(iv) NaCl ionic => acetone
(v) $C_6H_6$ only LF => hexane

## Topic 7: Chemical calculations

1.
a) $PCl_5$ (s) + $H_2O$ (l) → $POCl_3$ (l) + 2 HCl (aq)
b) $H_2$ (g) + $I_2$ (s) → 2 HI (s)
c) 4 Fe (s) + 3 $O_2$ (g) → 2 $Fe_2O_3$ (s)
d) 3 Cu (s) + 8 $HNO_3$ (aq) → 3 $Cu(NO_3)_2$ (aq) + 4 $H_2O$ (l) + 2 NO (g)
e) $(NH_4)_2Cr_2O_7$ (s) → $Cr_2O_3$ (s) + $N_2$ (g) + 4 $H_2O$ (g)
f) $P_4$ (s) + 6 $Cl_2$ (g) → 4 $PCl_3$ (l)
g) $PtCl_4$ (s) → Pt (s) + 2 $Cl_2$ (g)

2.
a) $CaCO_3$ (s) → CaO (s) + $CO_2$ (g)
b) 2 $C_4H_{10}$ (g) + 13 $O_2$ (g) → 8 $CO_2$ (g) + 10 $H_2O$ (g)
c) $MgCl_2$ (aq) + 2 NaOH (aq) → $Mg(OH)_2$ (s) + 2 NaCl (aq)
d) 2 Na (s) + 2 $H_2O$ (g) → 2 NaOH (s) + $H_2$ (g)

3.
a) 16.04 g/mol
b) 119.38 g/mol
c) 250.20 g/mol
d) 72.15 g/mol
e) 164.09 g/mol
f) 158.11 g/mol
g) 249.69 g/mol

4.
a) 1.50 mol
b) 0.4188 mol
c) 20 mmol
d) 2.675 mol
e) 0.12188 mol
f) 0.221 mol
g) 2.40 mol

5.
a) 8.02 g
b) 180 g
c) 1750 g
d) 0.14 g
e) 8204 g
f) 1900 g
g) 5742 g

## Topic 8: Salts and Solubility

1.
a) They are identical in the way that they have the same concentration of salt.
b) They are different in volume, and therefore in the total amount (mass) of salt in the sample. So for 400 mL, you would need twice as much of the salt to get the same concentration as for 200 mL.
c) Yes, the first 'm' represents 'milli' or $10^{-3}$. Rather than writing mmol/mL, you can leave out the m before mol and L, and write mol/L.
d) 0.5 mmol/L, which means 0.0005 or $0.5 \times 10^{-3}$ mol/L.

2.
a) 1 mol barium ions and 2 mol chloride ions
b) 2 mol sodium ions and 1 mol sulfate ions
c) 3 mol lithium ions and 1 mol phosphate ions
d) 1 mol magnesium ions and 2 mol chloride ions
e) 2 mol potassium ions and 1 mol carbonate ions
f) 3 mol ammonium ions and 1 mol phosphate ions
g) 1 mol iron ions and 3 mol nitrate ions

3.
a) Barium chloride and sodium sulfate will dissociate as follows:
$BaCl_2(s) \rightarrow Ba^{2+}(aq) + 2\ Cl^-(aq)$
$Na_2SO_4(s) \rightarrow 2\ Na^+(aq) + SO_4^{2-}(aq)$
With these ions in solution, the following precipitation reaction can occur:
$Ba^{2+}(aq) + SO_4^{2-}(aq) \rightarrow BaSO_4(s)$
while the sodium and chloride ions remain in solution.
b) Magnesium chloride and potassium carbonate will dissociate as follows:
$MgCl_2(s) \rightarrow Mg^{2+}(aq) + 2\ Cl^-(aq)$
$K_2CO_3(s) \rightarrow 2\ K^+(aq) + CO_3^{2-}(aq)$
With these ions in solution, the following precipitation reaction can occur:
$Mg^{2+}(aq) + CO_3^{2-}(aq) \rightarrow MgCO_3(s)$
while the potassium and chloride ions remain in solution.
c) Ammonium phosphate and iron(III) nitrate will dissociate as follows:
$(NH_4)_3PO_4(s) \rightarrow 3\ NH_4^+(aq) + PO_4^{3-}(aq)$
$Fe(NO_3)_3(s) \rightarrow Fe^{3+}(aq) + 3\ NO_3^-(aq)$
With these ions in solution, the following precipitation reaction can occur:
$PO_4^{3-}(aq) + Fe^{3+}(aq) \rightarrow FePO_4(s)$
while the ammonium and nitrate ions remain in solution.

4.
a) 10 g/L / 42.394 g/mol = 0.2359 mol/L
b) 3 g / 120.366 g/mol = 0.0249 mol. In 250 mL means 0.0249 mol / 0.25 L = 0.0997 mol/L
c) Copper sulfide does not dissolve in water!
d) 5 g / 136.286 g/mol = 0.0367 mol. In 2.5 L means 0.0367 mol / 2.5 L = 0.0147 mol/L

5.
a) 1.2 M / 0.1 M = 12. You should dilute 12 times.

b) 0.25 M / 0.015 M = 16.67. You should dilute 16.67 times.
c) 1.00 M / 0.25 M = 4. You should dilute 4 times. So you need 200 mL / 4 = 50 mL. 50 mL of a 1.00 M solution, diluted to a final volume of 200 mL, yields a 0.25 M solution.
d) 0.3556 M / 0.1222 M = 2.909 times dilution. 2.909 x 0.1718 = 0.50 L.

## Topic 9: Acids and Bases

1.
a) $2\ HCl\ (g) + Ca(OH)_2\ (s) \rightarrow CaCl_2\ (aq) + 2\ H_2O$
b) $Sr(OH)_2\ (aq) + 2\ HNO_3\ (aq) \rightarrow Sr(NO_3)_2\ (aq) + 2\ H_2O$
c) $H_2SO_4\ (aq) + 2\ NaOH_{(s)} \rightarrow Na_2SO_4\ (aq) + 2\ H_2O$
d) $Ba(OH)_2\ (aq) + 2\ HF\ (g) \rightarrow BaF_2\ (aq) + 2\ H_2O$
Note: for soluble salts, writing the salt dissociated into constituent ions is also correct.

2.
a) $H_3O^+\ (aq) \rightarrow H^+(aq) + H_2O\ (l)$
b) $HCl\ (aq) \rightarrow H^+\ (aq) + Cl^-\ (aq)$
c) $NH_3\ (aq) \rightarrow H^+\ (aq) + NH_2^-\ (aq)$
d) $CH_3COOH\ (aq) \rightarrow H^+\ (aq) + CH_3COO^-\ (aq)$
e) $NH_4^+\ (aq) \rightarrow H^+\ (aq) + NH_3\ (aq)$
f) $HSO_4^-\ (aq) \rightarrow H^+\ (aq) + SO_4^{2-}\ (aq)$

3.
a) $H_2O\ (l) + H^+\ (aq) \rightarrow H_3O^+\ (aq)$
b) $OH^-\ (aq) + H^+\ (aq) \rightarrow H_2O\ (l)$
c) $NH_3\ (aq) + H^+\ (aq) \rightarrow NH_4^+\ (aq)$
d) $CN^-\ (aq) + H^+\ (aq) \rightarrow HCN\ (aq)$
e) $S^{2-}\ (aq) + H^+\ (aq) \rightarrow HS^-\ (aq)$
f) $H_2PO_4^-\ (aq) + H^+\ (aq) \rightarrow H_3PO_4\ (aq)$

4.
a) $HNO_3 + H_2O \rightarrow H_3O^+ + NO_3^-$
Acid Base CA CB
b) $CN^- + H_2O \rightarrow HCN + OH^-$
Base Acid CA CB
c) $H_2SO_4 + Cl^- \rightarrow HCl + HSO_4^-$
Acid Base CA CB
d) $HSO_4^- + OH^- \rightarrow SO_4^{2-} + H_2O$
Acid Base CB CA
e) $O^{2-} + H_2O \rightarrow 2\ OH^-$
Base Acid CA and CB!
f) $H_2S + NH_2^- \rightarrow HS^- + NH_3$
Acid Base CB CA

5.
a) $pH = -\log[0.2] = 0.7$ $pOH = 14 - 0.7 = 13.3$
b) $pOH = -\log[0.0143] = 1.84$ $pH = 14 - 1.84 = 12.16$
c) $pH = -\log[3.0] = -0.48$ $pOH = 14 - 0.48 = 14.48$
d) $pOH = -\log[2 \times 0.0031] = 2.21$ $pH = 14 - 2.21 = 11.79$

6.
a) $[H_3O^+] = 10^{-pH} = 10^{-1.5} = 0.0316$ M
b) pOH = 14 – 11.5 = 2.5, $[OH^-] = 10^{-pOH} = 10^{-2.5} = 0.00316$ M
c) pH = 14 – 13 = 1, $[H_3O^+] = 10^{-pH} = 10^{-1} = 0.1$ M
d) $[OH^-] = 10^{-pOH} = 10^{-12} = 1 \times 10^{-12}$ M

7.
a) $pH = -\log[2.59 \times 10^{-4}] = 3.59$ $pOH = 14 - 3.59 = 10.41$
b) $pOH = -\log[0.21] = 0.67$ $pH = 14 - 0.67 = 13.32$
c) $Ba(OH)_2$ contains two $OH^-$ ions, so the concentration of those ions is double the initial concentration of the salt.
$2 \times 7.1 \times 10^{-5} = 1.42 \times 10^{-4}$ M
$pH = -\log[1.42 \times 10^{-4}] = 3.85$ $pOH = 14 - 3.85 = 10.15$

8.
a) $[H_3O^+] = 10^{-pH} = 10^{-6.52} = 3.02 \times 10^{-7}$ M = 0.000000302 M
$[OH^-] = 10^{-pOH} = 10^{-(14 - 6.52)} = 10^{-7.48} = 3.31 \times 10^{-8}$ M = 0.0000000331 M
b) It is a weak acid.
c) The pH scale is a logarithmic scale; 1 pH unit means a factor of 10 difference in pH (here 7.48 – 6.52 = 0.96 difference).

9.
a) Hydronium = $H^+$ or $H_3O^+$, hydroxide = $OH^-$
$pH = -\log [H^+] = -\log [1.7 \times 10^{-6}] = 5.77$
$pOH = 14 - 5.77 = 8.23$
$[OH^-] = 10^{-pOH} = 10^{-8.23} = 5.88 \times 10^{-9}$ M
b) Hydronium = $H^+$ or $H_3O^+$, Hydroxide = $OH^-$
$pOH = -\log [OH^-] = -\log [3.2 \times 10^{-3}] = 2.49$
$pH = 14 - 2.49 = 11.51$
$[H^+] = 10^{-pH} = 10^{-11.51} = 3.13 \times 10^{-12}$ M

## Topic 10: Redox reactions

1.
a) $Fe^{3+}$ is an oxidant, receives electrons
b) Cr is a reductant, releases electrons
c) $MnO_4^{2-}$ is a reductant, releases an electron
d) $Li^+$ is an oxidant, receives electrons

2.
a) $F_2$ = oxidant; Ca = reductant
b) $Cl_2$ = oxidant; Li = reductant
c) $Br_2$ = oxidant; Fe = reductant
d) $MnO_4^-$ = oxidant, Ag = reductant

3.
a) Single element, so oxidation number is zero
b) Cl is –1, so C is +4
c) O is –2, 3 x –2 = –6, total ion charge is 1–, so N = +5
d) O is –2, 4 x –2 = –8, total ion charge is 2–, so S = +6
e) O is –2, 3 x –2 = –6, no molecule charge, so S = +6
f) O is –2, 2 x –2 = –4, no molecule charge, so S = +4

4.
a) Acid-base reaction
b) Precipitation reaction
c) Precipitation reaction
d) Redox reaction
e) Neutralisation reaction (after acid-base reaction)