Unit 2

APPLICATION OF CORE PRINCIPLES OF CHEMISTRY

Practice Unit Test 2

Section A

1 The answer is A. Beryllium has only two valence electrons. These are used in bonding, so there are no lone pairs. The two bonding pairs repel to maximum separation — a linear arrangement.

2 The answer is C. Phosphorus has five valence electrons. Three of these are used in bonding, leaving one lone pair. The three bonding pairs and the one lone pair of electrons repel and the atoms take up a pyramidal position with the lone pair above the pyramid.

e Boron has three valence electrons, so there are no lone pairs in BF_3, which is therefore planar. Chlorine has seven valence electrons, so there are three bond and two lone pairs in ClF_3 and thus it is not pyramidal. All six valence electrons of sulfur are used in SO_3, which is planar.

3 The answer is A. All four species contain polar bonds. Apart from HCN, they are symmetrical and their dipoles cancel. The hydrogen of HCN is δ^+ and the nitrogen is δ^-, so the molecule is polar (has a dipole moment).

4 The answer is D. The conditions for hydrogen bonding are a δ^+ hydrogen atom covalently bonded to a δ^- fluorine, oxygen or nitrogen atom. Only the amine, $CH_3CH_2NH_2$, fulfils these criteria.

e Propanone and methoxymethane both have a δ^- oxygen atom but neither has a hydrogen atom joined to the oxygen. Fluoroethane has a very δ^- fluorine atom but, again, no hydrogen atom joined to it.

5 The answer is C. For molecules with a similar number of electrons, the intermolecular forces in decreasing strength are:

hydrogen bonds > induced dipole > permanent dipole

Hydrogen bonding (A) is impossible because there is neither a suitable δ^- atom nor a δ^+ hydrogen atom. Covalent bonds (D) are even stronger but are within the molecule (intramolecular) — they are not intermolecular forces. Permanent dipole forces (B) are usually weaker than induced dipole forces and in this example the bonds in C_2H_5I are only very slightly polar.

6 The answer is B. Solubility of a molecular substance in water is determined mainly by the possibility of forming hydrogen bonds with the water. Of the four choices, only the two alcohols can do this. Methanol has a much shorter hydrophobic chain than pentanol and so is more soluble.

7 The answer is B. The oxidation number of chromium atoms in $K_2Cr_2O_7$ is +6 and in $Cr_2(SO_4)_3$ it is +3. Therefore, the oxidation number goes down by 3.

8 The answer is D. Equation A has two chlorine atoms on the right-hand side and only one on the left. Equation B does not balance for charge (left-hand side is +5; right-hand side is +6). Equation C has the electron on the wrong side (oxidation is loss of electrons, not gain).

9 The answer is B. The only group 1 nitrate that decomposes to produce nitrogen dioxide (brown fumes) is lithium nitrate. Group 2 nitrates decompose to give the metal oxide, oxygen and nitrogen dioxide. Sodium nitrate is the only one that does not give brown fumes of nitrogen dioxide, so is the correct response to this negative question.

e Sodium nitrate decomposes into sodium nitrite, $NaNO_2$, and oxygen.

10 The answer is C. Potassium produces a lilac flame.

11 The answer is B.

$$\text{amount (moles) of NaOH} = \frac{\text{mass}}{\text{molar mass}}$$

$$= \frac{1.2\,\text{g}}{40.0\,\text{g mol}^{-1}} = 0.030\,\text{mol}$$

$$\text{concentration} = \frac{\text{moles}}{\text{volume in dm}^3}$$

$$= \frac{0.030\,\text{mol}}{0.050\,\text{dm}^3} = 0.60\,\text{mol dm}^{-3}$$

12 The answer is D. When calculating the mean, you must choose consistent titres. In this example, $26.65\,\text{cm}^3$ and $26.45\,\text{cm}^3$ are consistent and their mean is $26.55\,\text{cm}^3$.

e $27.00\,\text{cm}^3$ is different by more than $0.20\,\text{cm}^3$ from the other titres, so it is not a consistent titre.

13 The answer is A.

$$\text{amount (moles) of hydrochloric acid} = \text{concentration} \times \text{volume in dm}^3$$

$$= 0.0500\,\text{mol dm}^{-3} \times 0.02375\,\text{dm}^3 = 0.001188\,\text{mol}$$

ratio of $Ba(OH)_2$:HCl = 1:2

so moles of $Ba(OH)_2 = \frac{1}{2} \times 0.001188 = 5.94 \times 10^{-4}\,\text{mol}$

$$\text{concentration} = \frac{\text{moles}}{\text{volume in dm}^3}$$

$$= \frac{5.94 \times 10^{-4}\,\text{mol}}{0.02500\,\text{dm}^3} = 0.02375\,\text{mol dm}^{-3}$$

e The answer 0.02375 is obtained by no rounding up intermediate values during the calculation. This is the correct procedure. Rounding gives 0.02376.

14 The answer is C. Iron(III) ions oxidise iodide ions to iodine.

e Although equation A balances, chlorine is such a powerful oxidising agent that it oxidises iron to iron(III) chloride, $FeCl_3$. The reaction in choice B works the other way round because chlorine is a better oxidising agent than bromine. Option D is wrong for a number of reasons, including that, in this incorrect equation, chlorine is reducing the Fe^{3+} ions.

15 The answer is D. The strength of the hydrogen–halogen bond is the critical factor. The larger the halogen atom, the weaker the bond and the stronger is the acid. Hydrogen iodide, which has the weakest bond, is the strongest acid.

e In questions about trends in a group of the periodic table, the answer is always the element at either the top or the bottom of the group. If you do not know the answer, choose either the top or the bottom option — you have a 50% chance of getting it right.

16 The answer is A. Statement A is false. Hydrogen chloride and gaseous ammonia react to form a white smoke, not steamy fumes. Gaseous hydrogen chloride itself appears as steamy fumes.

e The other three statements are all true. Chlorine disproportionates with hot aqueous NaOH to form NaCl (–1 oxidation state) and $NaClO_3$ (+5 oxidation state).

The equation is: $3Cl_2 + 6NaOH \rightarrow 5NaCl + NaClO_3 + 3H_2O$.

Silver chloride is decomposed by light to metallic silver and chlorine. The blue complex with starch is used as the indicator in iodine titrations.

17 i The answer is B. An increase in pressure and an increase in temperature would both increase the rate.

ii The answer is A. An increase in pressure drives the equilibrium to the right (the side with fewer gas molecules). A decrease in temperature drives the equilibrium to the right because the reaction left to right is exothermic.

18 The answer is C. Compound X has no effect on acidified potassium dichromate(VI), so it cannot be a primary or secondary alcohol. This rules out options B and D. It does not decolorise bromine water so it does not contain a C=C group, which also eliminates compound B. All four compounds react with sodium. It does not fizz with sodium hydrogencarbonate, so it is not an acid and is, therefore, not option A. It must be the tertiary alcohol in option C.

19 The answer is A. The only difference between these molecules is the halogen. Fluorine is the most electronegative so is more δ^- than the other halogens in these compounds. This makes the C–F bond, and hence the molecule, more polar.

e Note the comment after Question 15 about periodic table trends.

20 The answer is D. The critical point is not the polarity of the carbon–halogen bond but its strength. Iodine has the largest radius of the four halogens, so it has the weakest carbon–halogen bond. Therefore, the hydrolysis of CH_3CH_2I is the easiest and fastest.

e Note the comment after Question 15 about periodic table trends.

21 The answer is D. Sulfuric acid is reduced by iodide, which is the strongest reducing agent of the four options. The iodide ions are oxidised to iodine, so there would be no hydrogen iodide to react with the alcohol.

e Note the comment after Question 15 about periodic table trends.

22 The answer is B. A nucleophile contains a lone pair of electrons that are used to form a covalent bond. Nucleophiles are negative ions, or molecules that contain a covalently bonded oxygen or nitrogen atom. Radicals are not nucleophiles, so option B is the correct answer to this negative question.

23 The answer is C. The CN^- ion is a nucleophile and is substituted for the chlorine in the molecule. Reaction A is free-radical substitution. Reaction B is electrophilic addition and D is oxidation.

24 The answer is D. This type of arrow (full-headed) represents the movement of a pair of electrons. In this mechanism, the pair of electrons goes towards an atom (e.g. carbon) forming a new covalent bond, not an ionic bond.

25 The answer is B.

$$\text{amount (moles) of 2-chlorobutane} = \frac{\text{mass}}{\text{molar mass}} = \frac{12.3\,\text{g}}{92.5\,\text{g mol}^{-1}} = 0.133\,\text{mol}$$

$$\text{theoretical yield of butan-2-ol} = 0.133\,\text{mol} = 0.133\,\text{mol} \times 74.0\,\text{g mol}^{-1} = 9.84\,\text{g}$$

$$\text{percentage yield} = \frac{7.54\,\text{g} \times 100}{9.84\,\text{g}} = 76.6\%$$

The percentage yield is never 'mass of product × 100/mass of reactant'. You have to work out the theoretical yield and then calculate the actual yield as a percentage of the theoretical yield.

26 The answer is A. The i.r. peak at 1720 cm^{-1} indicates a C=O group (option A or B). Alcohols (and acids) react with sodium, so it cannot be option C or D. It has a peak in its mass spectrum at *m/e* = 29, which means that it has either a CHO or a C_2H_5 group (options A or C). The only molecule that fits all the data is the one in A.

27 The answer is A. Biodiesel is often mixed with petrodiesel, but does not have to be. McDonald's uses pure biodiesel made from its own old frying oil to power its lorries. Statements B, C and D are true. Algae can produce oils that can be converted to biodiesel using methanol in a transesterification reaction.

28 The answer is D. Ultraviolet light causes ozone to decompose into O_2 and an oxygen radical. Nitric oxides and CFCs are destroyers of ozone. HCFCs, however, are oxidised in the lower atmosphere and do not reach the stratosphere. Therefore, they do not destroy the ozone layer.

Section B

29 a Although the nuclear charge increases, the number of shielding electrons increases by the same amount ✓. The atomic radii increase down the group, making it easier to remove an outer electron ✓.

Do not give 'the amount of shielding increases' as the only reason — the amount to shield (the nuclear charge) also increases.

b i $Ca + 2H_2O \rightarrow Ca(OH)_2 + H_2$ ✓

ii $CaO + H_2O \rightarrow Ca(OH)_2$ ✓

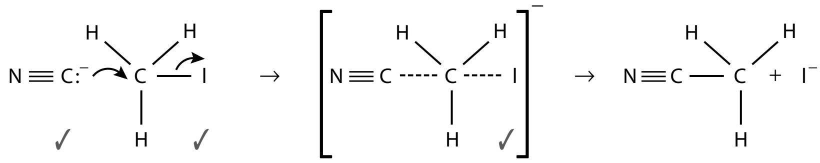
iii $2Ca(NO_3)_2 \rightarrow 2CaO + 4NO_2 + O_2$ ✓

or

$Ca(NO_3)_2 \rightarrow CaO + 2NO_2 + \frac{1}{2}O_2$ ✓

30 a A nucleophile is a species with a lone pair of electrons that it uses to form a covalent bond ✓. It is usually a negative ion or a molecule with a covalently bonded oxygen or nitrogen atom.

b



(An S_N1 mechanism would be accepted)

The marks are for:

- a curly arrow starting from the carbon of the CN^- ion and going towards the carbon in CH_3I
- a curly arrow from the C–I σ-bond to the iodine atom of CH_3I
- the transition state, which must be negatively charged and have partial bonds between the carbon of CN and the carbon of CH_3I and between the carbon of CH_3I and iodine

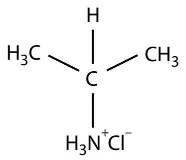
c The C–I bond in 2-iodopropane is weaker than the C–Br bond in 2-bromopropane ✓, so the activation energy is lower ✓ and the reaction is faster.

d An increase in temperature cause the molecules to have greater kinetic energy and, hence, to move faster. This results in an increase in the frequency ✓ of collisions and also means that more molecules have energy greater than or equal to the activation energy, E_a ✓. The effect of this is to increase the *proportion* of molecules that react on collision ✓ and, therefore, to increase the rate. The energy factor has a much greater effect than the increase in the frequency of collision ✓ .

ⓔ Do *not* say that:

- there are more collisions — it is their frequency (number per second) that alters
- there will be more successful collisions — 'more of the collisions are successful' or 'a greater proportion of the collisions are successful' will score the mark

31 a i



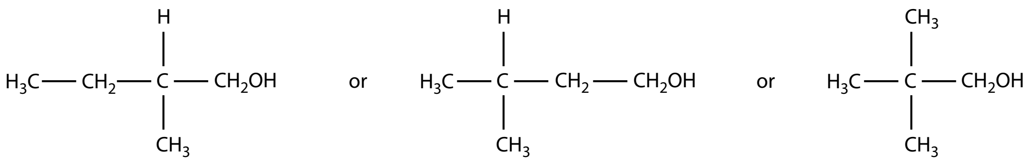
✓ or $(CH_3)_2CHNH_2$

ii $CH_3CH{=}CH_2$ ✓

b The reagents are (red) phosphorus and iodine ✓.

The condition is that the reagents must be damp ✓.

c



32 a i $I^- \rightarrow \frac{1}{2}I_2 + e^-$ *or* $2I^- \rightarrow I_2 + 2e^-$

ⓔ This is an oxidation (OIL) reaction, so the electron in this half-equation is on the right-hand side and the reactant, iodide ion, is on the left.

ii $IO_3^- + 6H^+ + 5e^- \rightarrow \frac{1}{2}I_2 + 3H_2O$

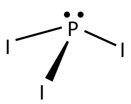
ⓔ This is a reduction (RIG) reaction, so the electron in this half-equation is on the left-hand side, as is the iodate(V) ion.

iii $IO_3^- + 6H^+ + 5I^- \rightarrow 3I_2 + 3H_2O$

ⓔ 'In acid solution' means that there have to be hydrogen ions on the left-hand side of the equation.

This final equation is obtained by multiplying the equation in (i) by 5 and adding the result to the equation in (ii). The number of electrons on each side is then the same and, therefore, they cancel.

b



✓

Phosphorus is in group 5 and has five valence electrons. Three of these are used in bonding with the iodine atoms, so there is one lone pair ✓. The three bond pairs and the lone pair repel each other to a position of maximum separation ✓, which is a pyramidal arrangement of atoms.

c The P–I bonds are polar, with the phosphorus atom δ^+ and the more electronegative iodine atoms δ^- ✓. The dipoles of the three bonds do not cancel ✓, so the molecule is polar.

ⓔ In this instance the dipoles do not cancel. However, if the dipoles do cancel, you must be careful to always use the word 'dipole' — *never* say 'the charges cancel'.

If you did not realise that the phosphorus atom in PI_3 has a lone pair of electrons and, hence, state (wrongly) that the molecule is planar, you could score the marks in part (c) by saying that the dipoles cancel and that the planar molecule is not polar. This is an example of consequential marking.

d A molecule of phosphorus triiodide, PI_3, contains 174 electrons (the sum of the atomic numbers of one atom of phosphorus and three atoms of iodine); a molecule of phosphorus trichloride, PCl_3, contains 66 electrons ✓. This means that the induced dipole (London/dispersion/van der Waals) forces between phosphorus trichloride molecules are weaker ✓ than those between phosphorus triiodide molecules, so less energy is required to separate them. Therefore, phosphorus trichloride has the lower melting temperature.

e The first mark could be obtained by saying that phosphorus triiodide has more electrons than phosphorus trichloride (or that phosphorus trichloride has fewer electrone than phosphorus triiodide). Do *not* say that the strength of the intermolecular forces is connected with either the size of the molecules, the mass of the molecules, or the strength of the permanent dipole forces. Any comparison of covalent bond strength will fail to score because covalent bonds are not broken on melting.

Section C

33 a i $C_4H_9OH + 6O_2 \rightarrow 4CO_2 + 5H_2O$ ✓

e State symbols are not required as they were neither asked for nor is it a thermochemical question.

ii molar mass of butan-2-ol = 74.0 g mol^{-1} ✓

$$\text{volume of 1 mol} = \frac{\text{mass}}{\text{density}}$$

$$= \frac{74.0\,\text{g}}{0.80\,\text{g cm}^{-3}} = 92.5\,\text{cm}^3 ✓$$

1 mol releases 2650 kJ of heat energy

$$\text{so, energy density} = \frac{2650\,\text{kJ}}{92.5\,\text{cm}^3} = 28.6\,\text{kJ cm}^{-3} ✓$$

iii 1 mol of 2-butanol produces 4 × 44.0 = 176.0 g of carbon dioxide and 2650 kJ of energy

$$\text{carbon footprint per 1000 kJ} = \frac{176.0\,\text{g} \times 1000\,\text{kJ}}{2650\,\text{kJ}} = 66.4\,\text{g} ✓ \text{ of carbon dioxide}$$

This is almost the same as the carbon footprint of petrol.

iv The peak at *m/e* = 59 is 15 less than the value for the molecular ion peak and is caused by the loss of CH_3. The peak is due to either the $^+CH_2CH(OH)CH_3$ ion or the $CH_3CH_2CH(OH)^+$ ion ✓.

The peak at *m/e* = 45 is 29 less than the value of the molecular ion peak and is caused by the loss of C_2H_5. This peak is due to the $^+CH(OH)CH_3$ ion ✓.

Peak A is at about 3350 cm^{-1} and is due to the hydrogen-bonded O–H bond stretch ✓.

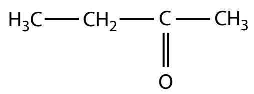
Peak B is at about 2900 cm^{-1} and is due to the alkane C–H bond stretch ✓.

e When identifying peaks in mass spectra remember to include the charge. When identifying peaks in infrared spectra remember to include the wavenumber.

v Butan-2-ol is a secondary alcohol whereas 2-methylpropan-2-ol is a tertiary alcohol. Butan-2-ol will reduce acidified potassium dichromate solution from orange to green ✓, whereas 2-methylpropan-2-ol will not and the solution will stay orange ✓.

e Remember to state the observations with *both* organic substances.

vi



e The formula $CH_3CH_2COCH_3$ does not show the double bond in the C=O group and so would not score the mark.

b i Hydrogen will evaporate and an explosive mixture of hydrogen and air ✓ will build up in the enclosed space of the garage.

ii The hydrogen has to be manufactured ✓.

This can be achieved by reacting methane with steam:

$CH_4 + 2H_2O \rightarrow CO_2 + 4H_2$

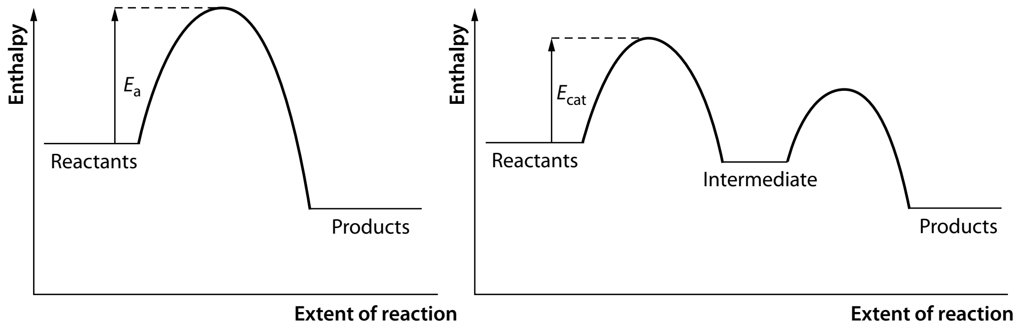
This produces carbon dioxide ✓ and requires the combustion of more methane to provide the heat energy for this endothermic reaction.

or

It can be manufactured by the electrolysis of water. Until most electricity is made from nuclear power or renewable resources, the generation of electricity involves burning fossil fuels and, therefore, produces carbon dioxide ✓ .

iii A homogeneous catalyst is in the same phase as the reactants (all in the gas phase or all dissolved in the same solvent). A heterogeneous catalyst is in a different phase from the reactants ✓.

c



e The marks are for:

- labelled axes with levels marked reactants and products ✓ (the energy level of the products must be below that of the reactants) at the same energy level in both diagrams ✓
- activation energies labelled, with E_a greater than E_{cat} ✓
- in the catalyst diagram, an intermediate drawn and labelled ✓

Note that it is acceptable for the two profiles to be drawn on the same set of axes.