8

Class	Adm No

Candidate Name: _____

H

millennia institute

2021 Preliminary Examination
Pre-University 3

H2 CHEMISTRY **9729/01**

Paper 1 Multiple Choice **21 Sep 2021**

1 hour

Additional materials: Multiple Choice Answer Sheet
Data Booklet

READ THESE INSTRUCTIONS FIRST

Do not turn over this question paper until you are told to do so

Write in soft pencil.

Do not use staples, paper clips, glue or correction fluid.

Write your name, class and admission number in the spaces provided at the top of this page and on the Multiple Choice Answer Sheet provided.

There are **thirty** questions on this paper. Answer **ALL** questions. For each question there are four possible answers **A**, **B**, **C** and **D**.

Choose the **one** you consider correct and record your choice in **soft pencil** on the Multiple Choice Answer Sheet provided.

Read the instructions on the Multiple Choice Answer Sheet very carefully.

Each correct answer will score one mark. A mark will not be deducted for a wrong answer.

Any rough working should be done in this question paper.

The use of an approved scientific calculator is expected, where appropriate.

FOR EXAMINER'S USE	
TOTAL (30 marks)	

This question paper consists of **11** printed pages and **1** blank page.

For each question there are four possible answers, **A**, **B**, **C**, and **D**. Choose the **one** you consider to be correct.

1 Which of the following contains the same number of stated particles as the number of atoms in 19.0 g of fluorine gas?

1 Number of molecules in 2.0 g of hydrogen gas
2 Number of ions in 58.5 g of sodium chloride solid
3 Number of atoms in 14.0 g of nitrogen gas
4 Number of atoms in 12.0 g of graphite

A 3 only **B** 1, 3 and 4 only **C** 2, 3 and 4 only **D** 1, 2, 3 and 4

2 20 cm^3 of an unknown hydrocarbon was completely combusted in excess oxygen gas. Upon cooling back to room temperature and pressure, the total volume of gases was 50 cm^3 less than the initial total volume. After passing the remaining gases through KOH(aq), the volume of gases further decreased by 80 cm^3.

What is the molecular formula of the unknown hydrocarbon?

A C_2H_4 **B** C_4H_4 **C** C_4H_6 **D** C_4H_8

3 Which of the following statements is **incorrect** about the following reaction?

$$3VO_2^- + 2H^+ \rightarrow VO_3^- + 2VO + H_2O$$

A It is a displacement reaction.
B The oxidation number of V in VO_3^- is +5.
C VO_2^- is acting as a reducing agent.
D VO_2^- is acting as an oxidising agent.

4 Use of the *Data Booklet* is relevant to this question.

A copper rod weighing 15 g was dipped into 50 cm^3 of 2.00 mol dm^{-3} $AgNO_3$ solution. Silver crystals were observed to grow on the copper rod after a while.

Which of the following statements are correct?

1 The $E^{\ominus}_{cell}$ of the reaction is +1.14V.
2 The solution turns blue.
3 6.35 g of copper would have reacted upon completion of reaction.

A 1 only **B** 2 only **C** 2 and 3 only **D** 1, 2 and 3

5 Which of the following statements is **not** true about lithium?

A It has a naturally occurring isotope which contains 3 neutrons.
B It has a naturally occurring isotope which contains 4 neutrons.
C It has the full electronic configuration $2s^1$.
D It forms an ion with a +1 oxidation number.

6 Which of the following properties can be explained by hydrogen bonding?

1 The higher density of ice compared to liquid water.
2 The ability of water glider insects to float on water.
3 Ethanoic acid having an apparent molecular mass of 120.0 in non-polar solvents.

A 1 and 2 only **B** 1 and 3 only **C** 2 and 3 only **D** 1, 2 and 3

7 Two elements **D** and **E** have the following properties.

	D	E
Melting point / °C	3600	–38
Appearance	Dull	Shiny
Electrical conductivity when solid	Yes	Yes

What are the likely identities of **D** and **E**?

	D	E
A	SiO_2	H_2
B	MgO	Si
C	Si	Na
D	C	Hg

8 Which of the following statements best explains the following observation?

Melting point of NaBr / °C	747
Melting point of $MgBr_2$ / °C	711

A The size of the anion electron cloud is large and easily distorted.

B NaBr has a larger magnitude of lattice energy than $MgBr_2$.

C There are more bromide ions in $MgBr_2$ than in NaBr.

D Magnesium has a higher charge and smaller size than sodium.

9 Which of the following statements about the standard enthalpy change of neutralisation is true?

A It has a constant magnitude of 57.3 kJ mol^{-1}.

B It has a smaller magnitude for the reaction between a weak acid and strong base.

C It is defined as the energy released when 1 mole of an acid reacts with 1 mole of a base.

D It is an endothermic reaction.

10 Which of the following statements best describes why the enthalpy change of solution for lithium chloride, LiCl(s), is more exothermic than that for sodium fluoride, NaF(s)?

A The $\Delta H^{\ominus}_{hydration}$ of $Li^+(g)$ is more exothermic than that of $Na^+(g)$.

B The $\Delta H^{\ominus}_{hydration}$ of $F^-(g)$ is more exothermic than that of $Cl^-(g)$.

C The lattice energy of LiCl(s) is more exothermic than that of NaF(s).

D The 1st electron affinity of sodium is more exothermic than that of lithium.

11 What is the identity of the gas which has a density of 89.8 g m^{-3} at 7862 Pa and 22 °C? Assume the gas behaviour to be ideal.

A He

B Ne

C N_2

D H_2

12 Which of the following is a conjugate acid-base pair?

A HCl, H^+ **B** H_2SO_4, SO_4^{2-} **C** CO_2, H_2CO_3 **D** NH_3, NH_4^+

13 The half-life for a certain first order reaction is 2 hours.
How much time is required to form 25% of the products?

A 0.8 hours

B 2 hours

C 3 hours

D 4 hours

14 A reaction between NO and H_2 has the following suggested mechanism.

I: $2NO \rightleftharpoons N_2O_2$ (fast)

II: $N_2O_2 + H_2 \rightleftharpoons N_2O + H_2O$ (slow)

III: $N_2O + H_2 \rightarrow H_2O + N_2$ (fast)

Which of the following correctly describes the rate equation?

A rate = $k\,[NO]^2$

B rate = $k\,[NO]^2[H_2]$

C rate = $k\,[NO]^2[N_2O_2][H_2]$

D rate = $k\,[N_2O_2][H_2]$

15 Which of the following factors, when increased, will affect the position of equilibrium for the following reaction?

$$CO(g) + H_2O(g) \rightleftharpoons CO_2(g) + H_2(g) \qquad \Delta H < 0$$

1 Concentration of CO(g)

2 Total pressure

3 Temperature

4 Volume of the container

A 1 only **B** 1 and 3 only **C** 1, 3 and 4 only **D** 2 and 4

16 Nitrogen dioxide, $NO_2(g)$, was placed into a closed vessel of fixed volume and allowed to reach dynamic equilibrium. The equilibrium has a K_c value of 4.0×10^{-2} at a certain temperature.

$$2NO_2(g) \rightleftharpoons N_2O_4(g)$$

What is the initial concentration of $NO_2(g)$ if its equilibrium concentration was 0.50 mol dm^{-3}?

A 0.48 mol dm^{-3}

B 0.51 mol dm^{-3}

C 0.52 mol dm^{-3}

D 0.70 mol dm^{-3}

17 Given the formula, $\Delta G = -RT \ln K_c$, which of the following reactions will have an equilibrium constant value that is greater than 1 at all temperatures?

A	$CH_4(g) + H_2O(g) \rightleftharpoons CO(g) + 3H_2(g)$	$\Delta H > 0$
B	$C_3H_8(g) + 5O_2(g) \rightleftharpoons 3CO_2(g) + 4H_2O(g)$	$\Delta H < 0$
C	$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$	$\Delta H < 0$
D	$NH_4Cl(s) \rightleftharpoons NH_4^+(aq) + Cl^-(aq)$	$\Delta H > 0$

18 Which of the following mixtures will form an alkaline buffer?

A 1 mole of CH_3COOH and 1 mole of $CH_3COO^-Na^+$

B 2 moles of CH_3COOH and 1 mole of NaOH

C 2 moles of $CH_3CH_2NH_2$ and 1 mole of NaOH

D 2 moles of $CH_3CH_2NH_2$ and 1 mole of HCl

19 The K_w of water is 5.13×10^{-13} mol^2 dm^{-6} at 100 °C.
What is the pH of water at 100 °C?

A 6.14

B 7.00

C 7.16

D 12.29

20 An aqueous solution of compound **G** ($pK_a = 4.70$) is titrated against an aqueous solution of compound **H** ($pK_a = 13.8$).

Which of the following is the most suitable indicator for the titration?

	Indicator	pH Range
A	α-Naphthyl red	3.7-5.0
B	Bromocresol purple	5.2-6.8
C	Bromophenol blue	6.2-7.6
D	Thymolphthalein	9.4-10.6

21 Solid sodium carbonate is gradually added in small amounts to a solution containing a mixture of 0.0100 mol dm^{-3} of Ag^+ ions and 0.0100 mol dm^{-3} of Cu^{2+} ions until in excess.
Which of the following observations are correct?
[K_{sp} (Ag_2CO_3) = 8.1×10^{-12}; K_{sp} ($CuCO_3$) = 2.5×10^{-10}]

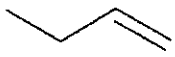
A Only a white precipitate of Ag_2CO_3 will be seen.
B Only a green precipitate of $CuCO_3$ will be seen.
C A green precipitate of $CuCO_3$ will be seen first, followed by white precipitate of Ag_2CO_3
D A white precipitate of Ag_2CO_3 will be seen first, followed by green precipitate of $CuCO_3$

22 Which of the following set of reagents is unable to react with ethene?

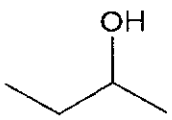
A Br_2 in methylbenzene solvent
B H_2 with palladium at high temperatures
C Hot alkaline $KMnO_4$
D $LiAlH_4$ in dry ether

23 Which of the following compounds **cannot** be formed from 2-bromobutane in one step?

A



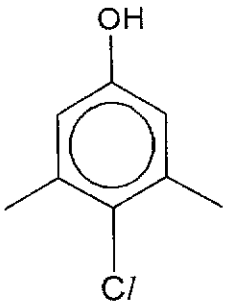
B



C

D

24 Chloroxylenol is one of the approved active ingredients in the disinfectants used for deep-cleaning places visited by Covid-19-positive persons.



chloroxylenol

Which of the following reagents will produce a positive test with the chloroxylenol?

1 Hot $AgNO_3(aq)$
2 Neutral $FeCl_3(aq)$
3 Hot acidified $KMnO_4(aq)$

A 3 only **B** 1 and 2 only **C** 2 and 3 only **D** 1, 2 and 3 only

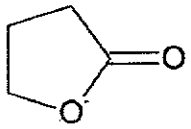
25 How many possible non-cyclic constitutional isomers and stereoisomers are there with the molecular formula C_3H_5Br?

A 2
B 3
C 4
D 5

26 Which of the following sequence of steps allows for butanone to be formed from but-1-ene?

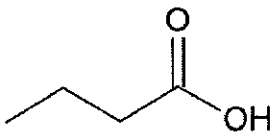
	step 1	**step 2**
A	addition	oxidation
B	hydrolysis	oxidation
C	mild oxidation	oxidation
D	oxidation	reduction

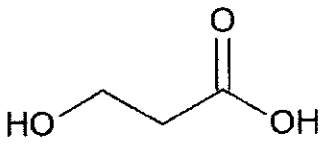
27 γ-Butyrolactone (gamma-butyrolactone) was used as a drug to increase sleep related growth hormone secretion, and was sold as a nutritional supplement until it was banned due to its severe negative side effects on the human body.

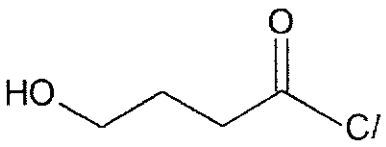


γ-Butyrolactone

Which of the following compounds can be used to form γ-butyrolactone in one step?

1 

2 

3 

A 1 only **B** 2 only **C** 3 only **D** 2 and 3 only

28 Which of the following factors help to explain the reducing strength of group 2 metals?

1 number of electron shells
2 charge
3 ionic radius

A 1 only **B** 1 and 3 only **C** 2 and 3 only **D** 1, 2 and 3

29 In Crystal Field Theory, ligands that bond to the central metal ion cause a splitting of d-orbitals. Assuming that the octahedral complexes below have a large energy gap between the split d-orbitals, which of the following central metal ions is likely to have the highest number of unpaired electrons in the ground state?

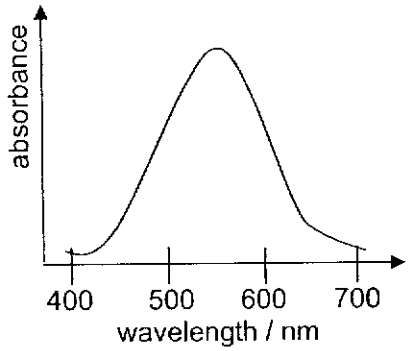
A $[Co(H_2O)_6]^{2+}$ **B** $[Cr(H_2O)_6]^{3+}$ **C** $[Cu(NH_3)_4]^{2+}$ **D** $[Fe(CN)_6]^{4-}$

30 Aqueous ions of transition metals are usually coloured.

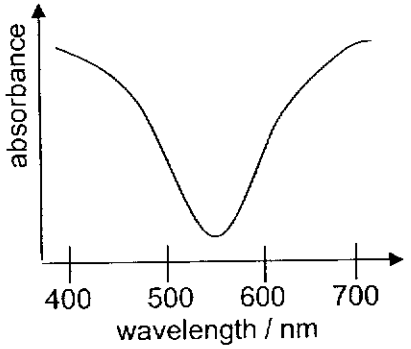
colour	violet	blue	green	yellow	orange	red
corresponding wavelength / nm	400	450	550	580	600	700

Which of the following absorption spectra will be produced by aqueous iron(II) ions?

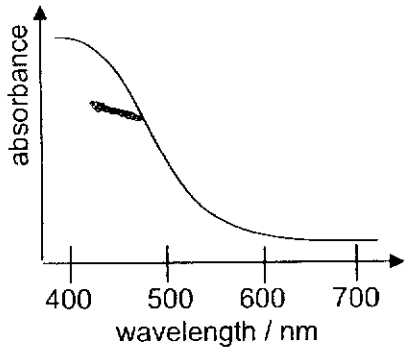
A



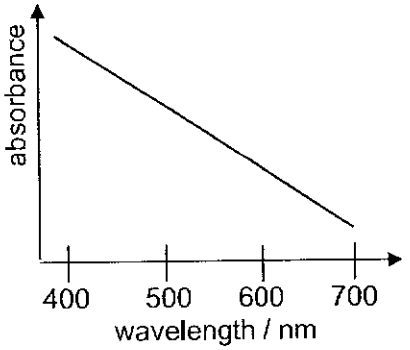
C



B



D



END OF PAPER 1

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H2 CHEMISTRY **9729/01**

Paper 1 Multiple Choice **xx[nd] Sep 2021**

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TOTAL (30 marks)	

This question paper consists of **12** printed pages and **2** blank pages.

For each question there are four possible answers, **A**, **B**, **C**, and **D**. Choose the **one** you consider to be correct.

1 Which of the following contains the same number of stated particles as the number of atoms in 19.0 g of fluorine gas?

1 Number of molecules in 2.0 g of hydrogen gas
2 Number of ions in 58.5 g of sodium chloride solid
3 Number of atoms in 14.0 g of nitrogen gas
4 Number of atoms in 12.0 g of graphite

A 3 only **B** 1, 3 and 4 only **C** 2, 3 and 4 only **D** 1, 2, 3 and 4

Number of atoms in 19.0 g of fluorine gas = 1 mole of F atoms
✓ 1) Number of molecules in 2.0 g of hydrogen gas = 1 mole of H_2 molecules
X 2) Number of ions in 58.5 g of sodium chloride = 2 moles of ions (both Na^+ and Cl^-)
✓ 3) Number of atoms in 14.0 g of nitrogen gas = 1 mole of N atoms
✓ 4) Number of atoms in 12.0 g of graphite solid = 1 mole of C atoms.

2 20 cm^3 of an unknown hydrocarbon was completely combusted in excess oxygen gas. Upon cooling back to room temperature and pressure, the total volume of gases was 50 cm^3 less than the initial total volume. After passing the remaining gases through KOH(aq), the volume of gases further decreased by 80 cm^3.

What is the molecular formula of the unknown hydrocarbon?

A C_2H_4 **B** C_4H_4 **C** C_4H_6 **D** C_4H_8

	C_xH_y +	$(x + y/4)\ O_2$ →	xCO_2 +	$(y/2)\ H_2O$	Total vol / cm^3
Initial vol / cm^3	20	**A**	0	-	A + 20
Change in vol / cm^3	-20	-20x – 20y/4	+20x	-	
Final vol / cm^3	0	**A** – 20x – 5y	20x	-	A – 5y

From qn, 80 cm^3 of CO_2 gas reacted with KOH(aq)

$20x = 80$

$x = 4$

From initial to final volume, volume dropped by 50 cm^3

$A + 20 - 50 = A - 5y$

$5y = 30$

$y = 6$

Answer: C_4H_6

3 Which of the following statements is incorrect about the following reaction?

$$3VO_2^- + 2H^+ \rightarrow VO_3^- + 2VO + H_2O$$

A It is a displacement reaction.

B The oxidation number of V in VO_3^- is +5.

C VO_2^- is acting as a reducing agent.

D VO_2^- is acting as an oxidising agent.

Oxidation number of V in the reactant VO_2^- = +3
B) TRUE. Let x be the oxidation number of V in VO_3^-.
x + 3(-2) = -1.
x = +5

Options C & D – TRUE.
Oxidation number of V is oxidised from +3 in VO_2^- to +5 in VO_3^- and simultaneously reduced to +2 in VO.
It is a disproportionation reaction where VO_2^- has acted as a reducing agent (itself oxidised) and also an oxidising agent (itself reduced)

Option A is incorrect as a displacement reaction is when a metal is oxidised when placed in a solution containing the cation of another metal which is reduced.

4 A copper rod weighing 15 g was dipped into 50 cm^3 of 2.00 mol dm^{-3} $AgNO_3$ solution. Silver crystals were observed to grow on the copper rod after a while.

Which of the following statements are correct?

1 The $E^{\ominus}_{cell}$ of the reaction is +1.14V.

2 The solution turns blue.

3 6.35 g of copper would have reacted upon completion of reaction.

A 1 only **B** 2 only **C** 2 and 3 only **D** 1, 2 and 3

✗ A) $E^{\ominus}_{cell}$ = (+0.80) – (+0.34) = +0.46 V
✓ B) Cu metal is oxidised to $Cu^{2+}(aq)$, which gives the solution a blue colour
✗ C) Amount of Ag^+ = 0.050 × 2.00 = 0.100 mol
Amount of Cu = 15 / 63.5 = 0.236 mol
2 mol of Ag^+ reacts with 1 mol of Cu. Ag^+ is the limiting reagent.
0.100 mol of Ag^+ reacts with ½ × 0.100 = 0.0500 mol of Cu
Mass of Cu reacted = 0.0500 × 63.5 = 3.175 g

5 Which of the following statements is **not** true about lithium?

A It has a naturally occurring isotope which contains 3 neutrons.

B It has a naturally occurring isotope which contains 4 neutrons.

C It has the full electronic configuration $2s^1$.

D It forms an ion with a +1 oxidation number.

✗ A & B) Both true as lithium as a relative atomic mass of 6.9 hence it is likely that there exists the ^6Li isotope with 3 neutrons and ^7Li isotope with 4 neutrons.
✓ C) FALSE. The full electronic configuration is $1s^2\ 2s^1$ and not just $2s^1$.
✗ D) Group 1 metals tends to lose an electron to form Li^+, which has +1 oxidation number.

6 Which of the following properties can be explained by hydrogen bonding?

1 The higher density of ice compared to liquid water.

2 The ability of water glider insects to float on water.

3 Ethanoic acid having an apparent molecular mass of 120.0 in non-polar solvents.

A 1 and 2 only **B** 1 and 3 only **C** 2 and 3 only **D** 1, 2 and 3

✗ 1) FALSE as ice has lower density due to the open tetrahedral arrangement of H_2O molecules in ice (due to hydrogen bonding, but not higher density)
✓ 2) TRUE as hydrogen bonding is considered strong intermolecular force which results in high surface tension of water
✓ 3) TRUE as the -COOH groups have H bonded to O and lone pair on electronegative O which forms hydrogen bonding.
As energy released from the formation of id-id of -COOH groups with non-polar solvents is insufficient to overcome the hydrogen bonding between -COOH groups, the ethanoic acid molecules dimerise through the formation of hydrogen bonding to give an apparent Mr which is double $2 \times 60.0 = 120.0$

7 Two elements **D** and **E** have the following properties.

	D	E
Melting point / °C	3600	–38
Appearance	Dull	Shiny
Electrical conductivity when solid	Yes	Yes

What are the likely identities of **D** and **E**?

	D	E
A	SiO_2	H_2
B	MgO	Si
C	Si	Na
D	C	Hg

D has very high melting point yet dull appearance – means it is likely to be giant covalent instead of metals which have a shiny appearance.
The only giant covalent structure we learnt that conducts electricity when solid is Carbon in the form of Graphite.

E has a low melting point indicating it could likely be a simple molecular structure. However, its shiny appearance and electrical conductivity contradicts that of a simple molecular structure. Instead we should be looking at metals which have a melting point lower than room temperature. Prior knowledge tells us one such metal is mercury which is a liquid metal.

8 Which of the following statements best explains the following observation?

Melting point of NaBr / °C	747
Melting point of $MgBr_2$ / °C	711

A The size of the anion electron cloud is large and easily distorted.

B NaBr has a larger magnitude of lattice energy than $MgBr_2$.

C There are more bromide ions in $MgBr_2$ than in NaBr.

D Magnesium has a higher charge and smaller size than sodium.

Both have giant ionic lattice structures. As the $MgBr_2$ theoretically has a larger magnitude lattice energy than NaBr, the melting point of $MgBr_2$ is predicted to be higher than NaBr yet in reality it is lower.

This is due to partial covalent character, which can be attributed to distortion of anion charge cloud by the cation. Since the anion is the same in both cases, the factor that changed is the charge density of the cation, which is $\alpha \frac{charge}{size\ (ionic\ radius)}$

9 Which of the following statements about the standard enthalpy change of neutralisation is true?

A It has a constant magnitude of 57.3 kJ mol^{-1}.

B It has a smaller magnitude for the reaction between a weak acid and strong base.

C It is defined as the energy released when 1 mole of an acid reacts with 1 mole of a base.

D It is an endothermic reaction.

Options A and B are contradictory –
✓ as B is true, as some energy would be used to complete the dissociation of the weak acid, the enthalpy change of neutralisation would be less exothermic for a weak acid compared to that of a strong acid.
✗ Hence, A is FALSE.
✗ C is FALSE as the definition states that it is the heat energy change when 1 mole of water is formed (from neutralisation), not when 1 mole of acid reacts with 1 mole of base (as the acid may not be monoprotic, neither may the base be a monoacidic base).
✗ D is FALSE as a neutralisation reaction involves forming a covalent O-H bond from H^+ ions and OH^- ions. Since there is primarily bond forming, heat energy is released and it is an exothermic process.

10 Which of the following statements best describes why the enthalpy change of solution for lithium chloride, LiCl(s), is more exothermic than that for sodium fluoride, NaF(s)?

A The $\Delta H^{\ominus}_{hydration}$ of $Li^+(g)$ is more exothermic than that of $Na^+(g)$.

B The $\Delta H^{\ominus}_{hydration}$ of $F^-(g)$ is more exothermic than that of $Cl^-(g)$.

C The lattice energy of LiCl(s) is more exothermic than that of NaF(s).

D The 1st electron affinity of sodium is more exothermic than that of lithium.

$\Delta H_{solution} = \Sigma \Delta H_{hydration}$ – Lattice Energy
Means LiCl either has its Li^+ or Cl^- ions with more exothermic $\Delta H_{hydration}$ or more endothermic L.E. to make the overall value of $\Delta H_{solution}$ more negative.
✓ A) Fulfils the condition laid out above.
✗ B) F^- indeed has a more exothermic $\Delta H_{hydration}$ but that makes the overall value of $\Delta H_{solution}$ more negative for NaF and not LiCl.
✗ C) LiCl should have a more endothermic L.E. to have a more exothermic $\Delta H_{solution}$, but this is not the case.
✗ D) 1st E.A. is not in play in the conditions above. Furthermore, Na does not gain electrons to form Na^- in NaF, and neither does Li for Li^- in LiCl, so electron affinity is not part of the reaction or calculations.

11 What is the identity of the gas which has a density of 89.8 g m^{-3} at 7862 Pa and 22 °C? Assume the gas behaviour to be ideal.

A He

B Ne

C N_2

D H_2

$Mr = \rho RT / p$

$= (89.8)(8.31)(22+273) / (7862)$

$= 28.0$

Identity = N_2

12 Which of the following is a conjugate acid-base pair?

A HCl, H^+ **B** H_2SO_4, SO_4^{2-} **C** CO_2, H_2CO_3 **D** NH_3, NH_4^+

Conjugate acid-base pairs differ by only 1 H^+.

✗ A) Differs by 1 Cl^-

✗ B) Differs by 2 H^+

✗ C) Differs by 1 H_2O

✓ D) Differs by 1 H^+

13 The half-life for a certain first order reaction is 2 hours.

How much time is required to form 25% of the products?

A 0.8 hours

B 2 hours

C 3 hours

D 4 hours

Half-life is the time required for the concentration of reactants to reach half its original concentration. For 25% products, the concentration of reactants will be at 75% which is not yet half. Hence, time taken will be less than the half-life. The only possible option is A.

$[reactant] = [reactant]_{initial} \times (\frac{1}{2})^n$, where n = number of half-lives

$(\frac{1}{2})^n = \frac{[reactant]}{[reactant]_{initial}} = 0.75$

$n \lg (\frac{1}{2}) = \lg 0.75$

$n = 0.415$

time = $0.415 \times 2 = 0.83 \approx 0.8$ hours

14 A reaction between NO and H_2 has the following suggested mechanism.

I: $2NO \rightleftharpoons N_2O_2$ (fast)

II: $N_2O_2 + H_2 \rightleftharpoons N_2O + H_2O$ (slow)

III: $N_2O + H_2 \rightarrow H_2O + N_2$ (fast)

Which of the following correctly describes the rate equation?

A rate = $k\,[NO]^2$

B rate = $k\,[NO]^2[H_2]$

C rate = $k\,[NO]^2[N_2O_2][H_2]$

D rate = $k\,[N_2O_2][H_2]$

The slow step is step two, so the rate equation for step 2 is

Rate = $k'\,[N_2O_2][H_2]$

However, N_2O_2 is an intermediate, not a reactant. Hence it will have to be re-expressed in terms of its reactants based on step I: where the $K_c = \frac{[N_2O_2]}{[NO]^2}$.

Rearranging, $[N_2O_2] = K_c\,[NO]^2$

Substituting,

Rate = $k'^*K_c\,[NO]^2\,[H_2] = k\,[NO]^2\,[H_2]$ $\quad (k = k'^*K_c)$

15 Which of the following factors, when increased, will affect the position of equilibrium for the following reaction?

$$CO(g) + H_2O(g) \rightleftharpoons CO_2(g) + H_2(g) \qquad \Delta H < 0$$

1 Concentration of CO(g)

2 Total pressure

3 Temperature

4 Volume of the container

A 1 only **B** 1 and 3 only **C** 1, 3 and 4 only **D** 2 and 4

Options 2 and 4 are related. If volume is increased, pressure decreases and vice versa. ✗ Lowering pressure / increasing volume will favour the side with more gaseous particles. However, since both sides of the equilibrium has the same number of gaseous particles (2 mole on each side), changing pressure or volume does not affect the position of equilibrium.

✓ Option 1 – Increasing the concentration of reactant CO(g) will cause the position of equilibrium to shift to the right, increasing the concentration of products and decreasing the concentration of reactants to oppose the change and re-establish equilibrium.

✓ Option 3 – Increasing temperature will cause the system to favour the endothermic (backward) reaction to absorb excess heat to oppose the change, by shifting the position of equilibrium to the left to re-establish equilibrium.

16 Nitrogen dioxide, $NO_2(g)$, was placed into a closed vessel of fixed volume and allowed to reach dynamic equilibrium. The equilibrium has a K_c value of 4.0×10^{-2} at a certain temperature.

$$2NO_2(g) \rightleftharpoons N_2O_4(g)$$

What is the initial concentration of $NO_2(g)$ if its equilibrium concentration was 0.50 mol dm^{-3}?

A 0.48 mol dm^{-3}

B 0.51 mol dm^{-3}

C 0.52 mol dm^{-3}

D 0.70 mol dm^{-3}

$K_c = \frac{[N_2O_4]}{[NO_2]^2} = 0.04 = \frac{[N_2O_4]}{(0.50)^2}$

$[N_2O_4]_{eqm} = 0.04 \times (0.05)^2 = 0.01$ mol dm^{-3}

	$2NO_2(g)$	$\rightleftharpoons N_2O_4(g)$
Initial conc / mol dm^{-3}	x	0
Change in conc / mol dm^{-3}	-2(0.01)	+0.01
Eqm conc / mol dm^{-3}	x – 0.02 = 0.50	0.01

$x = 0.50 + 0.02 = 0.52$ mol dm^{-3}

17 Given the formula, $\Delta G = -RT \ln K_c$, which of the following reactions will have an equilibrium constant value that is greater than 1 at all temperatures?

A $CH_4(g) + H_2O(g) \rightleftharpoons CO(g) + 3H_2(g)$ $\Delta H > 0$

B $C_3H_8(g) + 5O_2(g) \rightleftharpoons 3CO_2(g) + 4H_2O(g)$ $\Delta H < 0$

C $N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$ $\Delta H < 0$

D $NH_4Cl(s) \rightleftharpoons NH_4^+(aq) + Cl^-(aq)$ $\Delta H > 0$

$\Delta G = -RT \ln K_c$ (for $K_c > 1$, $\ln K_c$ is positive, i.e. $\ln K_c > 0$, ΔG will be negative)
$\Delta G = \Delta H - T\Delta S$
for ΔG to be negative at all temperatures,
ΔH must be negative, i.e. exothermic reaction, and
ΔS must be positive, i.e. has more gaseous (or more mobile, such as more liquid or aqueous particles in) products than reactants stoichiometrically

✓ **B** has a positive ΔS value as it has 7 gaseous molecules on product side but only 6 on the reactant side.
✗ **A** and **D** are eliminated as they are endothermic reaction (positive ΔH values)
✗ **C** has a negative ΔS value as it has 2 gaseous molecules on product side but has 4 on the reactant side.

18 Which of the following mixtures will form an alkaline buffer?

A 1 mole of CH_3COOH and 1 mole of $CH_3COO^-Na^+$

B 2 moles of CH_3COOH and 1 mole of NaOH

C 2 moles of $CH_3CH_2NH_2$ and 1 mole of NaOH

D 2 moles of $CH_3CH_2NH_2$ and 1 mole of HCl

Alkaline buffer will be formed between a weak base and its conjugate acid.
✗ Options A and B are using a weak acid and its conjugate base hence will form an acidic buffer instead of alkaline buffer.
✗ Option C is the mixing of a weak base, $CH_3CH_2NH_2$, and a strong base, NaOH, and will not produce any buffer.
✓ Option D is the mixing of 2 moles of a weak base, out of which 1 mole will completely react with 1 mole of the strong acid HCl to give 1 mole of the conjugated acid, $R\text{-}NH_3^+$. Since 1 mole of the weak base is still remaining, as both weak base and conjugate acid is present, an alkaline buffer is formed.

19 The K_w of water is 5.13×10^{-13} mol^2 dm^{-6} at 100 °C.

What is the pH of water at 100 °C?

A 6.14

B 7.00

C 7.16

D 12.29

Since $[H^+] = [OH^-]$ for water,
$K_w = [H^+][OH^-] = [H^-]^2$
$[H^+]^2 = \sqrt{K_w} = \sqrt{(5.13 \times 10^{-13})} = 7.1624 \times 10^{-7}$
$pH = -\lg [H^+] = 6.14$

20 An aqueous solution of compound **G** (pK_a = 4.70) is titrated against an aqueous solution of compound **H** (pK_a = 13.8).

Which of the following is the most suitable indicator for the titration?

	Indicator	pH Range
A	α-Naphthyl red	3.7-5.0
B	Bromocresol purple	5.2-6.8
C	Bromophenol blue	6.2-7.6
D	Thymolphthalein	9.4-10.6

pK_a = 4.70 means **G** is a weak acid.

pK_a = 13.8 means **H** is a strong base (very near to 14).

At the equivalence point, pH will be in the basic region as conjugate **base** of **G** that is formed will undergo salt hydrolysis.

The working pH range of bromophenol blue is very near neutral pH (mid-point around 6.9). Although it spans a small region of alkaline pH, the most suitable indicator will still be thymolphthalein.

21 Solid sodium carbonate is gradually added in small amounts to a solution containing a mixture of 0.0100 mol dm^{-3} of Ag^+ ions and 0.0100 mol dm^{-3} of Cu^{2+} ions.

Which of the following observations are correct?

[K_{sp} (Ag_2CO_3) = 8.1 × 10^{-12}; K_{sp} ($CuCO_3$) = 2.5 × 10^{-10}]

A Only a white precipitate of Ag_2CO_3 will be seen.

B Only a green precipitate of $CuCO_3$ will be seen.

C A green precipitate of $CuCO_3$ will be seen first, followed by white precipitate of Ag_2CO_3

D A white precipitate of Ag_2CO_3 will be seen first, followed by green precipitate of $CuCO_3$

For ppt, IP > K_{sp}

$[Ag^+]^2[CO_3^{2-}] > 8.1 \times 10^{-12}$
$(0.01)^2[CO_3^{2-}] > 8.1 \times 10^{-12}$
$[CO_3^{2-}] > 8.1 \times 10^{-8}$ mol dm^{-3}

$[Cu^{2+}][CO_3^{2-}] > 2.5 \times 10^{-10}$
$(0.01)[CO_3^{2-}] > 2.5 \times 10^{-10}$
$[CO_3^{2-}] > 2.5 \times 10^{-8}$ mol dm^{-3}

$CuCO_3$ requires a smaller $[CO_3^{2-}]$ to ppt, hence it precipitates first.

Note that since the formula unit of the 2 salts are different, K_{sp} is not a measure of solubility.

22 Which of the following set of reagents is unable to react with ethene?

A Br_2 in methylbenzene solvent

B H_2 with palladium at high temperatures

C Hot alkaline $KMnO_4$

D LiA/H_4 in dry ether

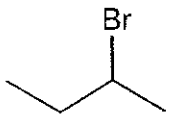
✗ A) Methylbenzene is a non-polar solvent similar to CCl_4 which does not react with Br2 in the absence of a catalyst. Hence electrophilic addition of ethene with Br_2 will take place under room temperature conditions.

✗ B) Palladium is similar to nickel as they are in the same group and is able catalyse the electrophilic addition of hydrogen to ethene due to the availability of energetically accessible d orbitals

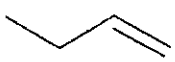
✗ C) Ethene already reacts with cold alkaline $KMnO_4$ to form diols. Heating it will not prevent any reaction but instead provides more energy for the reaction to occur, and may even lead to vigorous oxidation / oxidative cleavage of the C=C to form carbon dioxide and water instead of mild oxidation.

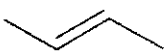
✓ D) Ethene does not have any known reactions with LiA/H_4.
The anhydrous environment refers to a dry environment like dry ether.

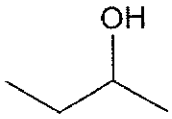
23 Which of the following compounds **cannot** be formed from 2-bromobutane in one step?

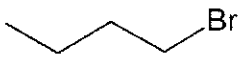


2-bromobutane

A 

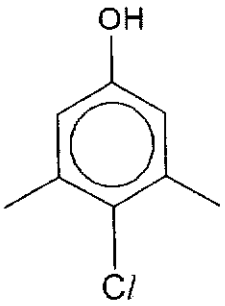
C 

B 

D 

A and **C** are formed via elimination with ethanolic NaOH, heat under reflux
B is formed via nucleophilic substitution with NaOH(aq), heat under reflux
D cannot be formed in one step, but can be formed in two steps.
1st elimination to form **A**, then electrophilic addition of HBr to form **D**.

24 Chloroxylenol is one of the approved active ingredients in the disinfectants used for deep-cleaning places visited by Covid-19-positive persons.



chloroxylenol

Which of the following reagents will produce a positive test with the chloroxylenol?

1 Hot $AgNO_3(aq)$

2 Neutral $FeCl_3(aq)$

3 Hot acidified $KMnO_4(aq)$

A 3 only **B** 1 and 2 only **C** 2 and 3 only **D** 1, 2 and 3 only

✗ Option 1 – C-Cl bond is strengthened due to partial p-orbital overlap with π-electron cloud of benzene ring so nucleophilic substitution does not take place, there will not be any halide ions for precipitation with Ag^+

✓ Option 2 – The presence of a phenol group will produce a positive test, a dark colouration

✓ Option 3 – Methyl side-chains on the benzene will be oxidised to benzoic acid groups, decolourising purple $KMnO_4$.

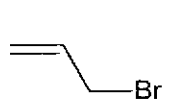
25 How many possible non-cyclic constitutional isomers and stereoisomers are there with the molecular formula C_3H_5Br?

A 2

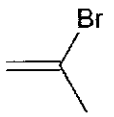
B 3

C 4

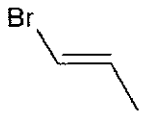
D 5



3-bromopropene



2-bromopropene



trans-1-bromopropene

cis-1-bromopropene

26 Which of the following sequence of steps allows for butanone to be formed from but-1-ene?

	step 1	step 2
A	addition	oxidation
B	hydrolysis	oxidation
C	mild oxidation	oxidation
D	oxidation	reduction

Step 1

But-1-ene can undergo electrophilic addition with steam: $H_2O(g)$, conc. H_3PO_4 catalyst at high temperatures and pressures to form butan-2-ol.

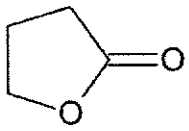
$$CH_3CH_2CH{=}CH_2 \rightarrow CH_3CH_2CH(OH)CH_3$$

Step 2

Butan-2-ol can subsequently undergo strong / vigorous oxidation with $KMnO_4$, $H_2SO_4(aq)$, heat under reflux to form butanone.

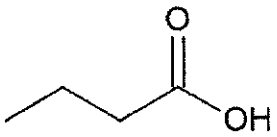
$$CH_3CH_2CH(OH)CH_3 \rightarrow CH_3CH_2COCH_3$$

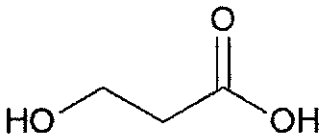
27 γ-Butyrolactone (gamma-butyrolactone) was used as a drug to increase sleep-related growth hormone secretion, and was sold as a nutritional supplement until it was banned due to its severe negative side effects on the human body.

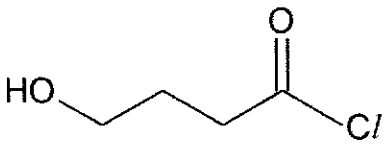


γ-Butyrolactone

Which of the following compounds can be used to form γ-butyrolactone in one step?

1 

2 

3 

A 1 only **B** 2 only **C** 3 only **D** 2 and 3 only

An ester can be formed form a carboxylic acid or acid derivative (such as acyl chloride) reacting with an alcohol, i.e.

-COOH + -OH (with conc. H_2SO_4, heat under reflux)

Or

-COCl + -OH (room temperature)

In this question, γ-butyrolactone is a cyclic ester with 4 carbons in its longest chain.

✗ 1) this option is out as it only has a -COOH group and no -OH group to react with

✗ 2) this option is out as it only has 3 carbon atoms in the backbone.

✓ 3) this is the correct answer as the alcohol has a lone pair and acts as a nucleophile to attack the electrophilic (electron deficient) carbon on -COCl, leading to the removal of Cl^- as the leaving group (nucleophilic substitution), to form the ester.

28 Which of the following factors help to explain the reducing strength of group 2 metals?

1 number of electron shells

2 charge

3 ionic radius

A 1 only **B** 1 and 3 only **C** 2 and 3 only **D** 1, 2 and 3

✓ Option 1 – down the group, number of electron shells increase and the valence electron is further and experiences less attraction from the nucleus (lower electronegativity), less energy required to remove the electron and hence electron is more easily lost (itself more easily oxidised, hence higher reducing strength).

✗ Option 2 – Group 2 metals usually form cations of +2 charge, hence the charge is the same for all group 2 metals – not a differentiating factor.

✗ Option 3 – Ionic radius refers to the cations formed from group 2 metals with the +2 charge, but that does not help to explain the trend for reducing strength of group 2 metal in the elemental state (with no charge)

29 In Crystal Field Theory, ligands that bond to the central metal ion cause a splitting of d-orbitals. Assuming that the octahedral complexes below have a large energy gap between the split d-orbitals, which of the following central metal ions is likely to have the highest number of unpaired electrons in the ground state?

A $[Co(H_2O)_6]^{2+}$

B $[Cr(H_2O)_6]^{3+}$

C $[Cu(NH_3)_4]^{2+}$

D $[Fe(CN)_6]^{4-}$

✗ A) In $[Co(H_2O)_6]^{2+}$, Co has **seven** d electrons with 6 electrons occupying lower energy d_{xy}, d_{xz}, d_{yz} orbitals in an octahedral field (6 ligands), with the remaining **1 unpaired electron** occupying the higher energy d orbitals

✓ B) In $[Cr(H_2O)_6]^{3+}$, Cr has **three** d electrons with each electron occupying lower energy d_{xy}, d_{xz}, d_{yz} orbitals in an octahedral field (6 ligands) ➔ **3 unpaired electrons**

✗ C) In $[Cu(NH_3)_4]^{2+}$, Cu has **nine** d electrons distributed across five d orbitals resulting in 4 paired and **1 unpaired electron**.

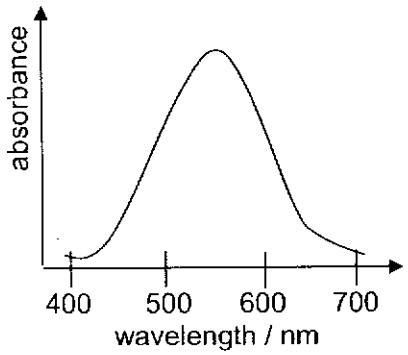
✗ D) In $[Fe(CN)_6]^{4-}$, Fe has **six** d electrons with all six filling the lower energy d_{xy}, d_{xz}, d_{yz} orbitals in an octahedral field (6 ligands) resulting in all paired electrons and **no unpaired electrons**

30 Aqueous ions of transition metals are usually coloured.

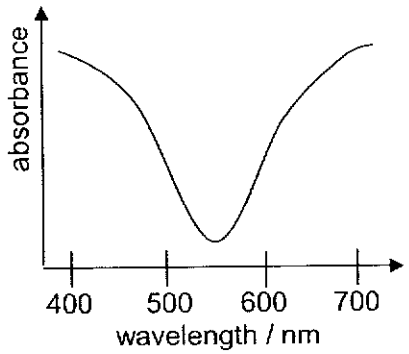
colour	corresponding wavelength / nm
violet	400
blue	450
green	550
yellow	580
orange	600
red	700

Which of the following absorption spectra will be produced by aqueous iron(II) ions?

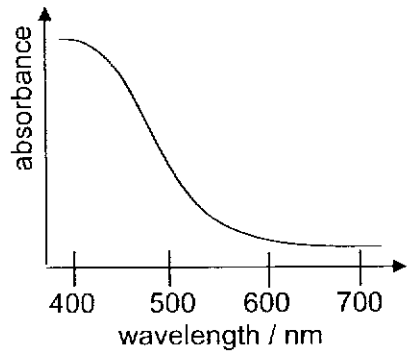
A



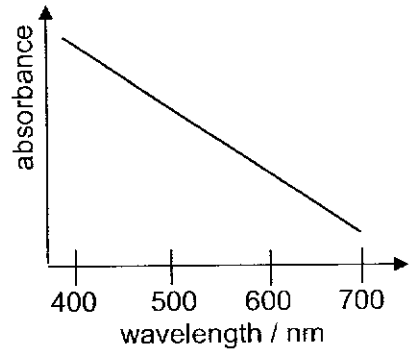
C



B



D



✓ C) aqueous iron(II) ions are green and will absorb the complementary colours red (and blue), hence high absorption in the red and blue regions.

None of the remaining options absorb the complementary colour: red

✗ A) This absorption spectrum will produce a complementary colour mix of red and blues, resulting in overall magenta.

✗ B) This absorption spectrum will produce a complementary colour mix of yellow, orange, red, resulting in overall orange.

✗ D) This absorption spectrum will produce a complementary colour mix of purple, blue, green, resulting in overall blue / cyan.

END OF PAPER 1