

2021 Y6 Preliminary Examination
H2 Chemistry 9729 Paper 1
Suggested Solutions

Answer Key

1	2	3	4	5
C	D	B	D	B

6	7	8	9	10
C	C	A	D	C

11	12	13	14	15
B	B	C	A	C

16	17	18	19	20
A	D	D	B	C

21	22	23	24	25
A	B	A	D	C

26	27	28	29	30
A	D	B	A	C

1	C	No. of electrons in $^{187}_{75}\text{Re}^{3+} = 75 - 3 = 72$ No. of neutrons in $^{187}_{75}\text{Re}^{3+} = 187 - 75 = 112$ Calculate the number of electrons and neutrons in each ion and compare to that of $^{187}_{75}\text{Re}^{3+}$. This ion should have 72 electrons and 112 neutrons.
x	A	No. of electrons in $^{182}\text{W}^{2+}$ ($Z = 74$) $= 74 - 2$ $= 72$ No. of neutrons in $^{182}\text{W}^{3+}$ $= 182 - 74$ $= 108 (\neq 112)$
x	B	No. of electrons in $^{186}\text{W}^{+}$ ($Z = 74$) $= 74 - 1$ $= 73 (\neq 72)$ No. of neutrons in $^{186}\text{W}^{+}$ $= 186 - 74$ $= 112$
✓	C	No. of electrons in $^{188}\text{Os}^{4+}$ ($Z = 76$) $= 76 - 4$ $= 72$ No. of neutrons in $^{188}\text{Os}^{4+}$ $= 188 - 76$ $= 112$
x	D	No. of electrons in $^{189}\text{Os}^{3+}$ ($Z = 76$) $= 76 - 3$ $= 73 (\neq 72)$ No. of neutrons in $^{189}\text{Os}^{3+}$ $= 189 - 76$ $= 113 (\neq 112)$

2	D	The largest increase in successive ionisation energies (IE) occur between 9th and 10th IE. This implies that the 10th electron is removed from an inner shell. Since $Z \leq 20$, only s and p subshells exist. Hence, each shell can only accommodate up to a maximum of 8 electrons. This would imply that the 2nd to 9th electron also lies in another inner shell. There will be only one electron in the valence shell. This element therefore belongs to Group 1 (either Na or K).
x	A	The element belongs to Group 1 since it has only one electron in the valence shell.
x	B	There is insufficient data to conclude that the element lies in the third period. Since $Z \leq 20$, this Group 1 element can be in the fourth period.
x	C	As a Group 1 element, the 6 th and 7 th electrons are removed from the same p-subshell.
✓	D	There is a large electronegativity difference between the Group 1 element and oxygen (Group 16). Hence, the compound formed will be ionic in nature.

3	B	
x	A	$\text{Cl}-\text{Be}-\text{Cl}$ $\text{O}=\ddot{\text{S}}=\text{O}$ BeCl_2 is linear while SO_2 is bent.
✓	B	$\text{O}=\text{C}=\text{O}$ $[\text{I}:\ddot{\text{I}}:\ddot{\text{I}}]^-$ Both CO_2 and I_3^- are linear.
x	C	$\left[\begin{array}{c} \text{O} \\ \diagup \quad \diagdown \\ \text{N} \\ \diagdown \quad \diagup \\ \text{O} \end{array} \right]^-$ $\text{H}-\ddot{\text{P}}(\text{H})-\text{H}$ NO_3^- is trigonal planar while PH_3 is trigonal pyramidal.
x	D	$\left[\begin{array}{c} \text{O} \\ \diagup \quad \diagdown \\ \text{P} \\ \diagdown \quad \diagup \\ \text{O} \end{array} \right]^{3-}$ $\text{F}-\ddot{\text{S}}(\text{F})-\text{F}$ PO_4^{3-} is tetrahedral while SF_4 is see-saw.

4	D	
✗	A	In giant molecular structures, the lattice of <u>atoms</u> are held together by strong covalent bonds.
✗	B	Ionic bonding is <u>non-directional</u> . Each cation is electrostatically attracted to any anion, not necessarily to the anion to which electrons were transferred.
✗	C	In giant metallic structures, <u>only valence electrons</u> are delocalised within the metal lattice.
✓	D	Simple molecular structures are held together by weak intermolecular forces of attraction such as instantaneous dipole-induced dipole (id-id) interactions, permanent dipole-permanent dipole interactions and hydrogen bonding.

5	B			
Based on the mole ratio, CH ₃ OH is the limiting reagent.				
	2CH ₃ OH(g) + 3O ₂ (g) → 2CO ₂ (g) + 4H ₂ O(g)			
Initial V / dm ³	x	4x	0	0
Change in V / dm ³	-x	-1.5x	+x	+2x
End V / dm ³	0	2.5x	x	2x

✓	1	From the equation above, mole ratio between CH ₃ OH(g) and O ₂ (g) is 2 : 3.
✓	2	Partial pressure of CO ₂ , $p(\text{CO}_2)$, can be calculated using Dalton's Law of Partial Pressure: $p(\text{CO}_2) = \frac{n(\text{CO}_2)}{n_{\text{total}}} \times p_{\text{total}}$ $p(\text{CO}_2) = \frac{x}{2.5x + x + 2x} \times P$ $p(\text{CO}_2) = 0.18P$
✗	3	Assuming these gases behave ideally, the gas particles occupy a negligible volume as compared to the volume of the vessel containing these gases.

6	C	
✗	A	Electronegativity increases across the period. In Period 3, P precedes S and hence P has a lower electronegativity. Similarly, Arsenic precedes Se in Period 4, As is expected to have a lower electronegativity.
✗	B	In Period 3, the highest oxidation state of an element usually corresponds to maximum number of valence electrons. Using this idea, arsenic being a Group 15 element should have a highest oxidation state of +5 instead of +6.
✓	C	As is below P in Group 15. Since PCl ₅ reacts with water to produce HCl as one of its products, the solution is acidic. $\text{PCl}_5(\text{s}) + 4\text{H}_2\text{O}(\text{l}) \rightarrow \text{H}_3\text{PO}_4(\text{aq}) + 5\text{HCl}(\text{aq})$
✗	D	Oxides of As should behave chemically similar to that of P, which are acidic in nature. They react with water to form acids rather than bases. $\text{P}_4\text{O}_{10}(\text{s}) + 6\text{H}_2\text{O}(\text{l}) \rightarrow 4\text{H}_3\text{PO}_4(\text{aq})$

7	C	
		The Group 2 metal carbonates (MgCO ₃ , CaCO ₃ and BaCO ₃) are neutralised by dilute sulfuric acid to form a metal sulfate, water and carbon dioxide. MgSO ₄ dissolves in water to give a colourless solution while CaSO ₄ and BaSO ₄ are sparingly soluble, resulting in formation of white precipitate. From the table of observations given in the question, L can be deduced to be Mg. CaCO ₃ undergoes thermal decomposition at a lower temperature than BaCO ₃ since Ca ²⁺ having smaller ionic radius will have a stronger polarising power than Ba ²⁺ . The electron cloud of the CO ₃ ²⁻ ion in CaCO ₃ would be polarised to a greater extent. CaCO ₃ would be less thermally stable than BaCO ₃ and decomposes at a lower temperature. Since K decomposes at a higher temperature than J , K is Ba while J is Ca.

8	A	
✓	A	Down the group, Group 17 hydrides (H-X) would be more acidic since H-X bond energy decreases and results in decreased bond strength. It would be easier to break the H-X bond and form H ⁺ down the group.
✗	B	Oxidising power of the elements decreases down the group as reflected by the less positive E ^o values. The ability of the halogens to be reduced decreases and correspondingly, its ability to oxidise other species decreases.
✗	C	Hydrogen halides are colourless gases at room temperature. The colour intensity of the elements increases down the group.
✗	D	Down the group, the electron cloud size increases and becomes more polarisable. More energy is required to overcome the stronger instantaneous dipole-induced dipole interactions between non-polar halogen molecules. Boiling point increases and hence volatility decreases.

9	D
	Since enthalpy change of formation is required to be calculated, simply sum up all the required enthalpies (atomisation, ionisation energy, electron affinity and lattice energy), taking into account mole ratios where appropriate.

10	C
x	1
	The enthalpy change of hydration of sodium ion is less exothermic than that of magnesium ion. Recall: $\Delta H_{hyd} \propto \left \frac{q}{r} \right$ Calculate the ratio of $\left \frac{q}{r} \right$ for Na^+ and Mg^{2+}: $\Rightarrow \left \frac{q}{r} \right$ for $\text{Na}^+ = \left \frac{1}{0.095} \right = 10.5$ $\Rightarrow \left \frac{q}{r} \right$ for $\text{Mg}^{2+} = \left \frac{2}{0.065} \right = 30.8$ $\therefore \Delta H_{hyd} \propto \left \frac{q}{r} \right$, Mg^{2+} has a more exothermic enthalpy change of hydration than Na^+.
✓	2
	Recall: Lattice energy, $\Delta H_{latt} \propto \frac{q_+ q_-}{r_+ + r_-}$. Since Mg^{2+} has twice the charge and a smaller ionic radius than that of Na^+ given the same anionic charge and radius, lattice energy for MgBr_2 will be more exothermic than that of NaBr.
✓	3
	A more exothermic enthalpy change of solution suggests higher solubility in water. Since NaBr has a less exothermic enthalpy change of solution (-18 kJ mol^{-1}) than that of MgBr_2 (-216 kJ mol^{-1}), NaBr is likely to be less soluble in water than MgBr_2 .

11	B
	Oxidation state of S changes from +4 in SO_2 to +6 in SO_3 . Since $\text{SO}_2 \equiv \text{V}_2\text{O}_5$, there are 2 mol of electrons transferred to 1 mol of V_2O_5 .

12	B
	The rate equation is derived from the slow step of the mechanism i.e. Rate = $k[\text{NO}_2]^2$
✓	1
	The reaction is zero order w.r.t. CO and the change in its partial pressure will not affect the rate.
✓	2
	Since step 1 is the slow step, it has a higher activation energy and hence a smaller rate constant.
x	3
	Units for k $= \frac{\text{units for rate}}{\text{units for } [\text{NO}_2]^2}$ $= \text{mol}^{-1} \text{ dm}^3 \text{ s}^{-1}$

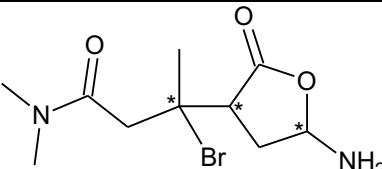
13	C
	Since reaction is first order with respect to H_2O_2, rate = $k[\text{H}_2\text{O}_2]$ and rate is directly proportional to $[\text{H}_2\text{O}_2]$. The graph of $[\text{H}_2\text{O}_2]$ against rate will be an upward sloping straight line passing through the origin.

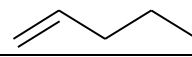
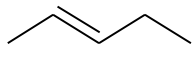
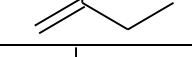
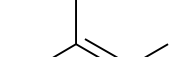
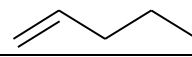
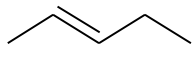
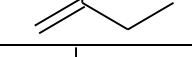
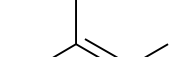
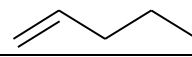
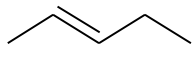
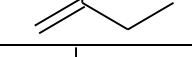
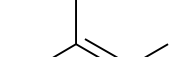
14	A			
		$\text{N}_2\text{O}_4(\text{g})$	$\rightleftharpoons$	$2\text{NO}_2(\text{g})$
	Initial moles / mol	1		0.2
	Change in moles / mol	-0.24		+0.48
	Eqm moles / mol	0.76		0.68
✓	1	See ICE table above.		
x	2	$K_c = \frac{[\text{NO}_2]^2}{[\text{N}_2\text{O}_4]}$ $= \left(\frac{0.68}{V}\right)^2 \div \left(\frac{0.76}{V}\right)$ $= \frac{0.608}{V}$ Since the volume of the reaction vessel is not known, it is not possible to calculate the value of K_c.		
x	3	Since V and T are constant, pressure is directly proportional to moles. As the total number of moles of gas increased from 1.2 mol to 1.44 mol, the total pressure in the vessel should also increase.		

15	C
x	A
	Adding a catalyst does not result in a shift in the equilibrium position as both the rate of the forward and backward reactions are increased by the same extent. The rate of both forward and backward reactions are increased because their rate constants are increased.
x	B
	Increasing temperature causes a rightward shift in the equilibrium position to favour the forward endothermic reaction to absorb heat. Increasing temperature also increases the rate constants of both the forward and backward reactions.
✓	C
	Increasing partial pressure of N_2 causes a rightward shift in the equilibrium position to reduce the amount of N_2. The rate of the forward reaction increases due to the increase in partial pressure of N_2. Rate constant remains unchanged.
x	D
	A smaller volume increases the total pressure of the system but this has no effect on equilibrium position as the moles of gaseous reactants and products are the same. Changing the total pressure of the system also has no effect on rate constant.

16	A
Before addition of HCl (i.e. initial pH of CH_3NH_2) A 0.1 mol dm^{-3} strong base has a pH of 13. Since CH_3NH_2 is a weak base, it will have a lower extent of dissociation. There will be a lower concentration of OH^- and hence, will have a lower pH than 13.	
Exact pH for 0.1 mol dm^{-3} CH_3NH_2, $\text{p}K_b = 3.3$ $[\text{OH}^-] = \sqrt{10^{-3.3} \times 0.1} = 0.0070795 \text{ mol dm}^{-3}$ Initial pH of $\text{CH}_3\text{NH}_2 = 14 - (-\lg(0.0070795)) = 11.9$	
After addition of 13.00 cm^3 of HCl The point where the buffer has maximum buffering capacity is when 12.50 cm^3 of HCl has been added. The pH at this point is where $\text{pH} = \text{p}K_a$ i.e. $\text{pH} = 14 - 3.3 = 10.7$ When slightly more acid (0.50 cm^3 more) is added, the pH will be slightly less than 10.7.	
$\text{pOH} = \text{p}K_b + \lg \frac{[\text{salt}]}{[\text{base}]}$ $\text{pOH} = 3.3 + \lg \left(\frac{13}{12} \right)$ $= 3.3 + 0.034762$ $= 3.3348$ pH of solution after adding 13.00 cm^3 of HCl $= 14 - 3.3348$ $= 10.66$	

17	D
$\text{Mg}(\text{OH})_2(\text{s}) \rightleftharpoons \text{Mg}^{2+}(\text{aq}) + 2\text{OH}^-(\text{aq})$ To determine the highest solubility In $\text{KNO}_3(\text{aq})$, there is no common ion present in the solution to suppress the dissolution of $\text{Mg}(\text{OH})_2$. As such, the solubility of $\text{Mg}(\text{OH})_2$ in $\text{KNO}_3(\text{aq})$ will be the same as that in water. In comparison, CH_3COOH is acidic. $\text{Mg}(\text{OH})_2$ will be more soluble in the acid than in water because the neutralisation reaction between H^+ from the acid and OH^- from $\text{Mg}(\text{OH})_2$ will cause the equilibrium above to shift right.	
To determine the lowest solubility In $\text{MgCl}_2(\text{aq})$, $K_{\text{sp}} = [\text{Mg}^{2+}][\text{OH}^-]^2$ $= (0.1 + x)(2x)^2 = 1.8 \times 10^{-11}$ Since $x \ll 0.1$, $0.1 + x \approx 0.1$ Hence, $(0.1)(2x)^2 = 1.8 \times 10^{-11}$ Solving for x, $x = 6.71 \times 10^{-6} \text{ mol dm}^{-3}$ Hence, solubility of $\text{Mg}(\text{OH})_2$ in 0.1 mol dm^{-3} $\text{MgCl}_2(\text{aq})$ is $6.71 \times 10^{-6} \text{ mol dm}^{-3}$ In $\text{NaOH}(\text{aq})$, $K_{\text{sp}} = [\text{Mg}^{2+}][\text{OH}^-]^2$ $= (x)(0.1 + 2x)^2 = 1.8 \times 10^{-11}$ Since $x \ll 0.1$, $0.1 + 2x \approx 0.1$ Hence, $(x)(0.1)^2 = 1.8 \times 10^{-11}$ Solving for x, $x = 1.8 \times 10^{-9}$ Hence, solubility of $\text{Mg}(\text{OH})_2$ in 0.1 mol dm^{-3} $\text{NaOH}(\text{aq})$ is $1.8 \times 10^{-9} \text{ mol dm}^{-3}$	

18	D
	
x	1 The molecule can act as a nucleophile because it has a reactive lone pair on the primary amine group ($-\text{NH}_2$). It can also act as an electrophile because there are carbons attached to electronegative atoms. These carbons are electron-deficient and hence, would attract nucleophiles.
✓	2 Hydrolysis can happen to both the ester and amide group. Condensation reaction with acyl chlorides can occur due to the presence of the primary amine.
✓	3 From the diagram above, there exists 3 chiral centres. Total no. of possible stereoisomers = $2^3 = 8$

19	B												
Since the required isomers are non-cyclic, the molecular formula C_5H_{10} indicates that there is one $\text{C}=\text{C}$ present. The isomers are:													
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Isomer	Able to exhibit cis-trans?												
	No												
	Yes												
	No												
	No												
	No												
Total number of isomers (including stereoisomers) = $1 + 2 + 1 + 1 + 1 = \underline{6}$													

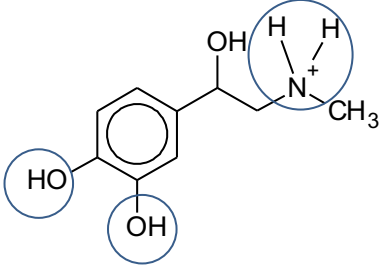
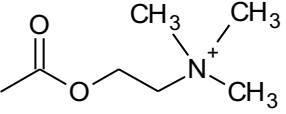
20	C	
✗	A	While this is true, alkenes are also non-polar. Hence, it is unable to explain the difference.
✗	B	The greater s character of the sp^2 carbons in alkenes, resulting in a shorter C–H bond and hence a greater bond strength. This explains why H attached to sp^2 C of C=C bond is not substituted in free radical substitution.
✓	C	This is true and best explains the difference because the C=C bond in alkenes polarizes the electron cloud of the halogen, producing partial charges on the halogen. This allows the halogen to act as an electrophile for electrophilic addition to happen. This cannot happen for alkanes due to the lack of π bonds.
✗	D	While this is true, the geometry of the carbon atoms does not account for the difference in reactivity.

21	A	
		Br is less electronegative than Cl, hence Br is the electrophilic site of $BrCl$. As the electrophilic addition across each C=C bond occurs, the Br atom is added to the C with fewer H atoms to form the more stable carbocation intermediate (Markovnikov's rule). The structure of the major product is shown below.
		It contains two chiral alkyl chlorides, each marked with an asterisk (*). The last alkyl chloride on the right is not chiral as the C atom is bonded to two identical methyl groups.

22	B (2 and 3 only)	
		Since a yellow ppt of AgI was formed, iodoethane is more susceptible to nucleophilic attack by ethanol, and undergoes nucleophilic substitution much more readily.
✗	1	Statement is true but does not explain the difference in observations. Chlorine being more electronegative results in a more polar C–X, which should result in a more electrophilic (δ^+) C and faster nucleophilic substitution. This contradicts the experimental observations.
✓	2	Iodine has a larger atomic radius, forming a longer and weaker C–X bond that breaks more readily.
✓	3	The overlap of chlorine p-orbital with the C=C π bond allows the delocalisation of electrons, leading to partial double bond character of the C–Cl bond. The stronger bond breaks less readily.
✗	4	The π electrons in the C=C bond repels approaching nucleophiles instead of attracting them. This repulsion contributes to the inertness of vinyl chloride.

23	A	
		X is an acyl chloride that undergoes hydrolysis in water to form a strong acid, HCl . $RCOCl + H_2O \rightarrow RCOOH + HCl$ The pH of the solution containing X is the lowest at about 1–2. Both Z and W are weak acids that undergo partial dissociation in water to form solutions with $pH < 7$. Z, a carboxylic acid, is a stronger acid than W, phenol. Hence the solution containing Z will have the second lowest pH. Y is an aldehyde that has no acid–base properties. The solution containing Y has the highest pH of 7. In order of increasing pH: $X < Z < W < Y$

24	D	
✗	A	Nucleophilic addition of HCN across a symmetrical ketone forms a cyanohydrin without a chiral centre.
✗	B	Elimination of HCl from an alkylhalide forms an alkene without a chiral centre.
✗	C	Electrophilic substitution on the benzene ring does not form a chiral centre. The original chiral centre is not affected by the reaction.
✓	D	The reaction is likely to occur via the unimolecular nucleophilic substitution (S_N1) mechanism as the carbocation intermediate formed can be resonance-stabilised. The NH_3 nucleophile can approach the trigonal planar carbocation from the top and bottom face with equal probability, forming a 1:1 mixture of two enantiomeric products.

25	C
One mole of adrenaline reacts with three mol of NaOH(aq). The two phenol groups and the protonated amine groups are neutralised. The alcohol is too weak an acid to react with NaOH(aq).	
	
Acetylcholine does not contain any functional groups that react with NaOH(aq). Ester hydrolysis requires heating. The quarternary ammonium salt does not contain an acidic proton.	
	
Hence the difference in the number of moles of NaOH(aq) required is 3.	

26	A (1 only)	
✓	1	Only adrenaline contains phenol functional groups, hence give a violet colouration with neutral iron(III) chloride. No violet complex is formed with acetylcholine.
✗	2	Neither neurotransmitter contains a carbonyl functional group. Both will not form an orange ppt with 2,4—DNPH.
✗	3	The secondary alcohol on adrenaline can be oxidised, causing the orange acidified dichromate(VI) to be reduced to green Cr^{3+}. Acetylcholine also gives a positive result. The ester undergoes acid hydrolysis to form a carboxylic acid and a primary alcohol. The alcohol can be further oxidised.

27	D
Polypeptide sequences are written from the N to C terminus. Hence the enzyme cleaves the peptide bonds on the right of proline residues.	
Arg-Pro-Pro-Gly-Phe-Ser-Pro-Phe-Arg ↑ ↑ ↑	
The four fragments formed are: Arg-Pro Pro Gly-Phe-Ser-Pro Phe-Arg	

28	B
Since $E^\ominus(\text{O}_2/\text{OH}^-)$ is more positive than $E^\ominus(\text{Zn}(\text{OH})_4^{2-}/\text{Zn}^{2+})$, the air electrode is the cathode and the zinc electrode is the anode. Electrons flow from the anode (zinc electrode) to the cathode (air electrode) through the external circuit. $E^\ominus_{\text{cell}} = E^\ominus_{\text{cathode}} - E^\ominus_{\text{anode}}$ $= +0.34 - (-1.25) = +1.59\text{V}$ Since 2 mol of electrons are transferred per mol of zinc. Hence for 1 mol of zinc species, $\Delta G^\ominus = -nFE^\ominus_{\text{cell}}$ $= -2 \times 96500 \times 1.59$ $= -306\,870\text{ J mol}^{-1}$ $= -307\text{ kJ mol}^{-1}$	

29	A (1 and 3 only)	
	cathode(-) : $2\text{H}^+(\text{aq}) + 2\text{e}^- \rightarrow \text{H}_2(\text{g})$ anode(+) : $2\text{H}_2\text{O}(\text{l}) \rightarrow \text{O}_2(\text{g}) + 4\text{H}^+(\text{aq}) + 4\text{e}^-$ $4\text{Al}(\text{s}) + 3\text{O}_2(\text{g}) \rightarrow 2\text{Al}_2\text{O}_3(\text{s})$ Overall : $2\text{Al}(\text{s}) + 3\text{H}_2\text{O}(\text{l}) \rightarrow \text{Al}_2\text{O}_3(\text{s}) + 3\text{H}_2(\text{g})$	
✓	1	Based on the setup, the right electrode is the cathode. $\text{H}_2(\text{g})$ is evolved.
✗	2	An inert electrode is used for the cathode in the anodising of aluminium. The mass of the cathode does not change as the reaction proceeds. The mass of the anode will increase as the layer of aluminium oxide is thickened.
✓	3	The aluminium object to be coated is the anode, the left electrode in the diagram.
✗	4	At the anode, oxygen is evolved and the aluminium object is oxidised. There is no anode sludge formed in the process.

(Q30 is not assessed in 2021.)

30 is not accessed in 2021/7

30	C	
×	A	Melting point of transition metals do vary. The properties that are invariant are atomic radii and first ionisation energy.
×	B	An empty 4s orbital has a lower energy than an empty 3d orbital. Thus, the 4s orbital is filled before the 3d orbital. Once these orbitals are occupied, the 3d electrons help to shield the 4s electrons, hence the energy order is reversed. The filled 4s orbital is the outermost, highest-energy orbital. Hence, 4s electrons are removed before 3d when first row transition metals form cations.
✓	C	The maximum oxidation state of first row transition metals increases from +4 for titanium to +7 for manganese, before decreasing to +3 for copper.
×	D	As electrons are added to the penultimate shell, the increase in nuclear charge is almost cancelled by the increase in shielding effect.