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Chemistry

Higher level

Paper 1

Friday 14 May 2021 (morning)

1 hour

Instructions to candidates

- Do not open this examination paper until instructed to do so.
- Answer all the questions.
- For each question, choose the answer you consider to be the best and indicate your choice on the answer sheet provided.
- The periodic table is provided for reference on page 2 of this examination paper.
- The maximum mark for this examination paper is **[40 marks]**.

The Periodic Table

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	1 H 1.01																	2 He 4.00
2	3 Li 6.94	4 Be 9.01														8 O 16.00	9 F 19.00	10 Ne 20.18
3	11 Na 22.99	12 Mg 24.31														16 S 32.07	17 Cl 35.45	18 Ar 39.95
4	19 K 39.10	20 Ca 40.08	21 Sc 44.96	22 Ti 47.87	23 V 50.94	24 Cr 52.00	25 Mn 54.94	26 Fe 55.85	27 Co 58.93	28 Ni 58.69	29 Cu 63.55	30 Zn 65.38	31 Ga 69.72	32 Ge 72.63	33 As 74.92	34 Se 78.96	35 Br 79.90	36 Kr 83.90
5	37 Rb 85.47	38 Sr 87.62	39 Y 88.91	40 Zr 91.22	41 Nb 92.91	42 Mo 95.96	43 Tc (98)	44 Ru 101.07	45 Rh 102.91	46 Pd 106.42	47 Ag 107.87	48 Cd 112.41	49 In 114.82	50 Sn 118.71	51 Sb 121.76	52 Te 127.60	53 I 126.90	54 Xe 131.29
6	55 Cs 132.91	56 Ba 137.33	57 † La 138.91	72 Hf 178.49	73 Ta 180.95	74 W 183.84	75 Re 186.21	76 Os 190.23	77 Ir 192.22	78 Pt 195.08	79 Au 196.97	80 Hg 200.59	81 Tl 204.38	82 Pb 207.2	83 Bi 208.98	84 Po (209)	85 At (210)	86 Rn (222)
7	87 Fr (223)	88 Ra (226)	89 † Ac (227)	104 Rf (267)	105 Db (268)	106 Sg (269)	107 Bh (270)	108 Hs (269)	109 Mt (278)	110 Ds (281)	111 Rg (281)	112 Cn (285)	113 Unt (286)	114 Uug (289)	115 Uup (288)	116 Uuh (293)	117 Uus (294)	118 Uuo (294)

Atomic number
Element
Relative atomic mass

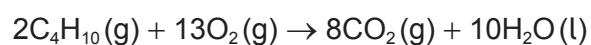
†

58 Ce 140.12	59 Pr 140.91	60 Nd 144.24	61 Pm (145)	62 Sm 150.36	63 Eu 151.96	64 Gd 157.25	65 Tb 158.93	66 Dy 162.50	67 Ho 164.93	68 Er 167.26	69 Tm 168.93	70 Yb 173.05	71 Lu 174.97
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‡

90 Th 232.04	91 Pa 231.04	92 U 238.03	93 Np (237)	94 Pu (244)	95 Am (243)	96 Cm (247)	97 Bk (247)	98 Cf (251)	99 Es (252)	100 Fm (257)	101 Md (258)	102 No (259)	103 Lr (262)
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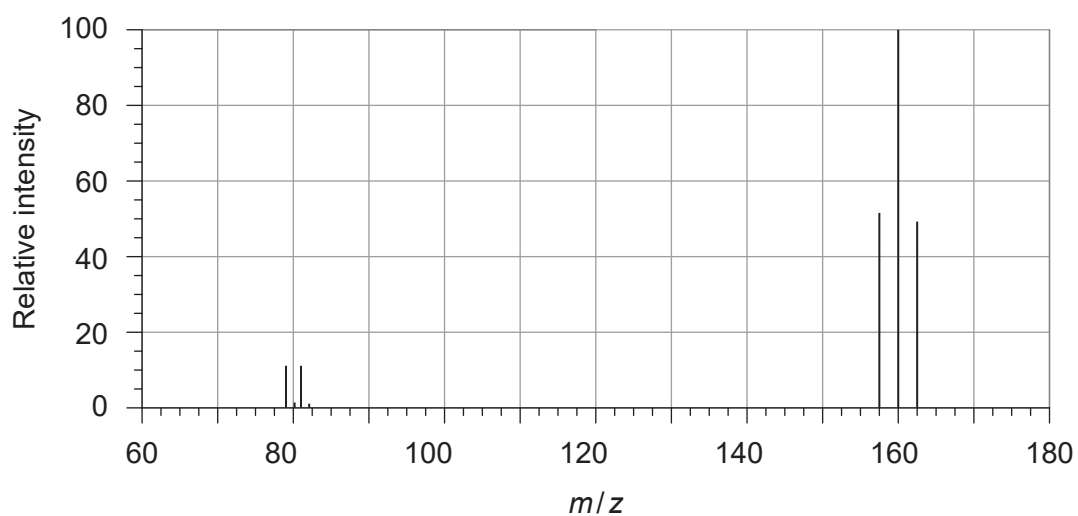
1. Which contains the most atoms of oxygen?
- A. 64 g of O_2
- B. 1.2×10^{24} molecules of O_2
- C. 64 g of $C_3H_5O_3$
- D. 1.2×10^{24} molecules of $C_3H_5O_3$
2. A sample of a compound contains approximately 24.0 g C, 3.0 g H, and 1.6 g O. What is the empirical formula of the compound?
- A. $C_{20}H_{30}O$
- B. $C_{84}H_{10}O_6$
- C. C_2H_3O
- D. $C_{24}H_{30}O_2$
3. What volume of oxygen, in dm^3 at STP, is needed when 5.8 g of butane undergoes complete combustion?



- A. $2 \times \frac{5.8}{12.01 \times 4 + 1.01 \times 10} \times 13 \times 22.7$
- B. $\frac{5.8}{12.01 \times 4 + 1.01 \times 10} \times \frac{13}{2} \times 22.7$
- C. $\frac{5.8}{12.01 \times 4 + 1.01 \times 10} \times \frac{2}{13} \times 22.7$
- D. $\frac{5.8}{12.01 \times 4 + 1.01 \times 10} \times \frac{13}{2} \times \frac{22.7}{1000}$

Turn over

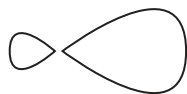
4. What is the relative molecular mass of bromine, according to the following mass spectrum?



- A. $\frac{158 \times 52 + 160 \times 100 + 162 \times 48}{52 + 100 + 48}$
- B. $\frac{158 \times 52 + 160 \times 100 + 162 \times 48}{158 + 160 + 162}$
- C. $\frac{79 \times 11 + 81 \times 11 + 158 \times 52 + 160 \times 100 + 162 \times 48}{11 + 11 + 52 + 100 + 48}$
- D. $\frac{79 \times 11 + 81 \times 11}{11 + 11}$

5. Which represents a *p* orbital?

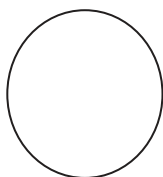
A.



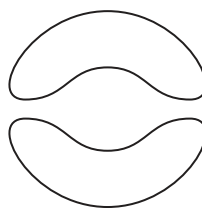
C.



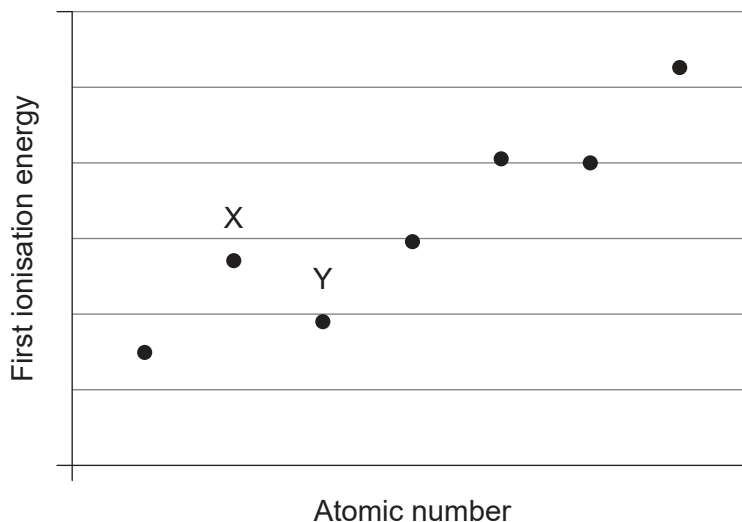
B.



D.



6. The diagram shows the first ionisation energies of consecutive elements in the same period of the periodic table.



Which factor explains why element X has a higher first ionisation energy than element Y?

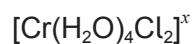
- A. Element Y loses an electron from a different sub-level.
- B. Element Y has a smaller atomic radius.
- C. Element X has a full octet.
- D. Element Y has a greater nuclear charge.

Turn over

7. Which species has the same electron configuration as argon?
- A. Br^-
 - B. Ca^{2+}
 - C. Al^{3+}
 - D. Si^{4+}

8. Which trend is correct, going down group 1?
- A. Melting point increases
 - B. Reactivity decreases
 - C. First ionisation energy increases
 - D. Electronegativity decreases

9. What is the overall charge, x , of the chromium (III) complex?



- A. 0
 - B. 1+
 - C. 2–
 - D. 3+
10. Which compound contains both ionic and covalent bonds?
- A. MgO
 - B. CH_2Cl_2
 - C. CH_3COOH
 - D. NaOH

11. Which substance is most likely to be ionic?

	Melting point	Solubility in hexane	Electrical conductivity of solid
A.	High	Low	High
B.	Low	Low	Low
C.	Low	High	Low
D.	High	Low	Low

12. Which contain delocalised electrons?

- I. $\text{C}_6\text{H}_5\text{OH}$
- II. CH_3COO^-
- III. CO_3^{2-}

- A. I and II only
- B. I and III only
- C. II and III only
- D. I, II and III

13. In which series are all carbon atoms sp^2 hybridized?

- A. C_2H_2 H_2CO HCOOH
- B. C_2H_4 H_2CO HCOOH
- C. C_2H_2 CO HCN
- D. C_2H_6 CH_3OH CH_3OCH_3

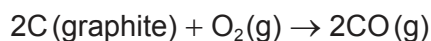
14. What is the enthalpy change, in J, when 5g of water is heated from 10°C to 18°C ?

Specific heat capacity of water: $4.18 \text{ kJ kg}^{-1} \text{ K}^{-1}$

- A. $5 \times 4.18 \times 8$
- B. $5 \times 10^{-3} \times 4.18 \times 8$
- C. $5 \times 4.18 \times (273 + 8)$
- D. $5 \times 10^{-3} \times 4.18 \times (273 + 8)$

Turn over

15. What is the enthalpy change of the reaction, in kJ?



Substance	$\Delta H_{\text{combustion}}^{\ominus} / \text{kJ mol}^{-1}$
C (graphite)	–394
CO (g)	–283

- A. –394 – 283
- B. 2(–394) + 2(–283)
- C. –394 + 283
- D. 2(–394) + 2(283)
16. The table shows the variation of standard Gibbs energy with temperature for a reversible reaction.

$$\Delta G^{\ominus} = \Delta H^{\ominus} - T\Delta S^{\ominus}$$

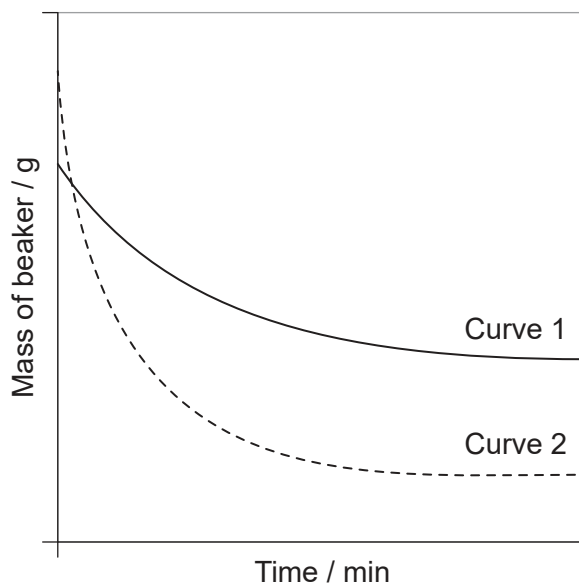
$$\Delta G^{\ominus} = -RT \ln K$$

Temperature / K	$\Delta G^{\ominus} / \text{kJ mol}^{-1}$
298	5.4
350	–3.9
400	–12.9

What can be concluded about the reaction?

- A. Equilibrium shifts left as temperature increases.
- B. The forward reaction is more spontaneous below 300K.
- C. Entropy is higher in the products than in the reactants.
- D. K_c decreases as temperature increases.
17. Which substance has the highest lattice enthalpy?
- A. KCl
- B. CaCl_2
- C. KF
- D. CaF_2

18. Curve 1 shows the mass change when marble chips are added to excess hydrochloric acid in an open beaker.

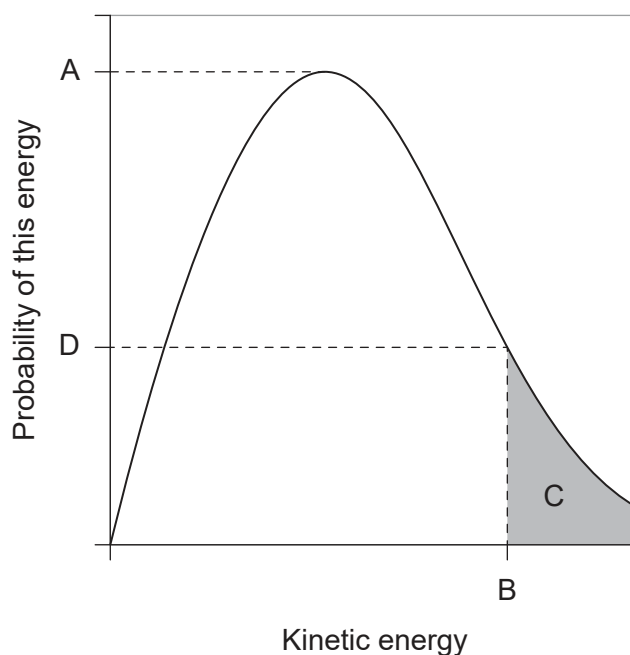


Which changes would produce curve 2?

- A. Powdering the marble chips and heating
- B. Powdering the marble chips and doubling their mass
- C. Doubling the volume of acid and heating
- D. Doubling the acid concentration and powdering the marble chips

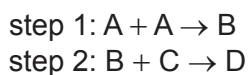
Turn over

19. On the following Maxwell-Boltzmann distribution, which letter represents activation energy?



- A. A
- B. B
- C. C
- D. D

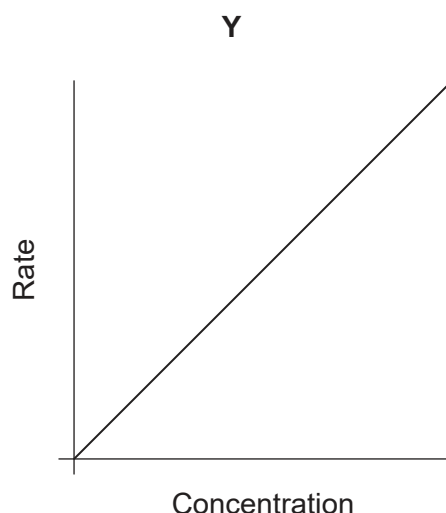
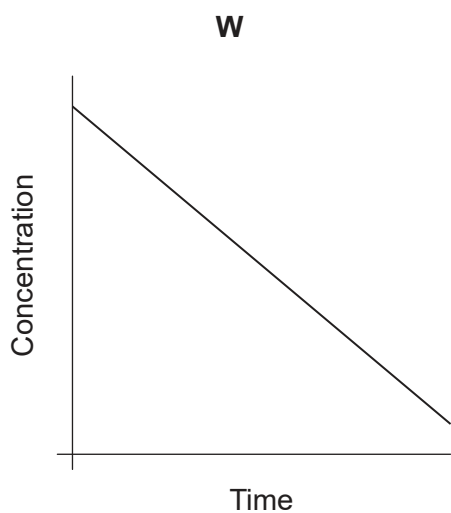
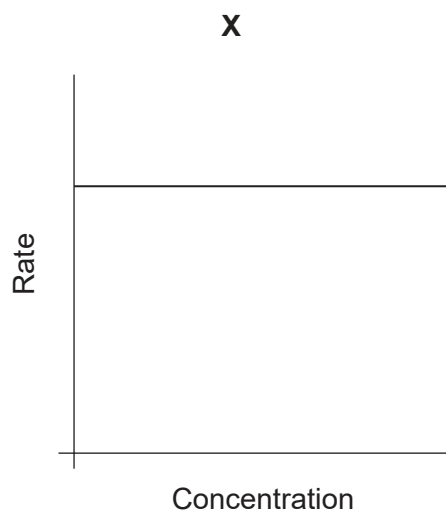
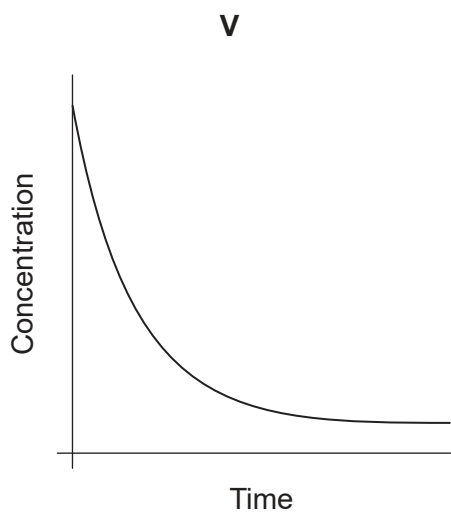
20. A reaction proceeds by the following mechanism:



Which rate equation is consistent with this mechanism?

- A. Rate = $k[B]^2[C]$
- B. Rate = $k[A]^2[B][C]$
- C. Rate = $k[A]^2$
- D. Rate = $k[A][C]$

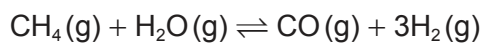
21. Which graphs show a first order reaction?



- A. V and X
- B. V and Y
- C. W and X
- D. W and Y

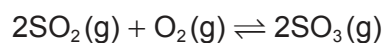
Turn over

22. Which changes produce the greatest increase in the percentage conversion of methane?



	Pressure	Proportion of H ₂ O(g)
A.	Doubled	Halved
B.	Doubled	Doubled
C.	Halved	Doubled
D.	Halved	Halved

23. 1.0 mol each of sulfur dioxide, oxygen, and sulfur trioxide are in equilibrium.



Which change in the molar ratio of reactants will cause the greatest increase in the amount of sulfur trioxide?

Assume volume and temperature of the reaction mixture remain constant.

	Moles of SO ₂ (g) changed from 1.0 to...	Moles of O ₂ (g) changed from 1.0 to...
A.	0.8	1.2
B.	0.9	1.1
C.	1.1	0.9
D.	1.2	0.8

24. Which is amphiprotic?

- A. NH₄⁺
- B. PO₄³⁻
- C. H₂O
- D. H₃O⁺

25. Which solution has a pH of 9?
- A. $1.0 \times 10^{-9} \text{ mol dm}^{-3} \text{ HCl (aq)}$
- B. $1.0 \times 10^{-5} \text{ mol dm}^{-3} \text{ KOH (aq)}$
- C. $1.0 \times 10^{-9} \text{ mol dm}^{-3} \text{ KOH (aq)}$
- D. $1.0 \times 10^{-5} \text{ mol dm}^{-3} \text{ HCl (aq)}$
26. Which is a Lewis acid, but not a Brønsted-Lowry acid?
- A. BF_3
- B. H_3O^+
- C. NH_3
- D. Cl^-
27. Which combination will produce an alkaline buffer in water?
- A. 0.10 mol NH_3 and 0.05 mol H_2SO_4
- B. 0.50 mol NH_3 and 0.10 mol H_2SO_4
- C. 0.10 mol CH_3COOH and 0.05 mol NaOH
- D. 0.10 mol CH_3COOH and 0.50 mol NaOH
28. A student performed displacement reactions using metals W and X and solutions of salts of metals W, X, Y and Z. The results are summarized in the table.

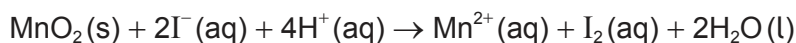
		Salt solution			
		W^{2+}	X^{2+}	Y^{2+}	Z^{2+}
Metal	W		No reaction	No reaction	No reaction
	X	Reaction		Reaction	No reaction

Which of the four metals is most reactive?

- A. W
- B. X
- C. Y
- D. Z

Turn over

29. What is correct for this redox reaction?



	Reduced	Reducing agent
A.	$\text{MnO}_2(\text{s})$	$\text{I}^-(\text{aq})$
B.	$\text{I}^-(\text{aq})$	$\text{H}^+(\text{aq})$
C.	$\text{I}^-(\text{aq})$	$\text{MnO}_2(\text{s})$
D.	$\text{H}^+(\text{aq})$	$\text{I}^-(\text{aq})$

30. Which gives the equation and cell potential of the spontaneous reaction?

	E^\ominus / V
$\text{Mn}^{2+}(\text{aq}) + 2\text{e}^- \rightleftharpoons \text{Mn}(\text{s})$	-1.18
$\text{Ag}^+(\text{aq}) + \text{e}^- \rightleftharpoons \text{Ag}(\text{s})$	+0.80

		E^\ominus / V
A.	$\text{Mn}^{2+}(\text{aq}) + 2\text{Ag}(\text{s}) \rightarrow \text{Mn}(\text{s}) + 2\text{Ag}^+(\text{aq})$	-1.98
B.	$\text{Mn}^{2+}(\text{aq}) + 2\text{Ag}(\text{s}) \rightarrow \text{Mn}(\text{s}) + 2\text{Ag}^+(\text{aq})$	+0.38
C.	$\text{Mn}(\text{s}) + 2\text{Ag}^+(\text{aq}) \rightarrow \text{Mn}^{2+}(\text{aq}) + 2\text{Ag}(\text{s})$	-0.38
D.	$\text{Mn}(\text{s}) + 2\text{Ag}^+(\text{aq}) \rightarrow \text{Mn}^{2+}(\text{aq}) + 2\text{Ag}(\text{s})$	+1.98

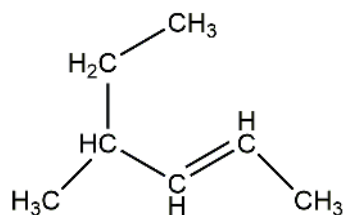
31. What are the products when concentrated aqueous copper (II) chloride is electrolysed using platinum electrodes?

	Anode (positive electrode)	Cathode (negative electrode)
A.	$\text{O}_2(\text{g})$	$\text{Cu}(\text{s})$
B.	$\text{Cl}_2(\text{g})$	$\text{H}_2(\text{g})$
C.	$\text{Cl}_2(\text{g})$	$\text{Cu}(\text{s})$
D.	$\text{O}_2(\text{g})$	$\text{H}_2(\text{g})$

32. Which series is in order of increasing boiling point?

- A. $\text{CH}_2\text{CH}_2\text{CH}_3\text{OH}$ CH_3COCH_3 $\text{CH}_3\text{CH}_2\text{CH}_3$
 B. $\text{CH}_3\text{CH}_2\text{CH}_3$ CH_3COCH_3 $\text{CH}_2\text{CH}_2\text{CH}_3\text{OH}$
 C. CH_3COCH_3 $\text{CH}_2\text{CH}_2\text{CH}_3\text{OH}$ $\text{CH}_3\text{CH}_2\text{CH}_3$
 D. $\text{CH}_3\text{CH}_2\text{CH}_3$ $\text{CH}_2\text{CH}_2\text{CH}_3\text{OH}$ CH_3COCH_3

33. What is the name of this compound, applying IUPAC rules?

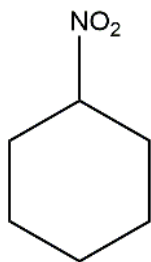


- A. 4-methylhex-2-ene
 B. 4-ethylpent-2-ene
 C. 2-ethylpent-3-ene
 D. 3-methylhex-4-ene
34. What is formed in a propagation step of the substitution reaction between bromine and ethane?
- A. $\text{CH}_3\text{CH}_2\cdot$
 B. $\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_3$
 C. $\text{H}\cdot$
 D. Br^-
35. Which is most likely to hydrolyse via a $\text{S}_{\text{N}}1$ mechanism?
- A. $\text{CH}_3\text{CHBrCH}_2\text{CH}_3$
 B. $(\text{CH}_3)_2\text{CHBr}$
 C. $(\text{CH}_3)_3\text{CBr}$
 D. $\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{Br}$

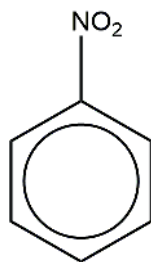
Turn over

36. What is the product of the reaction of benzene with a mixture of concentrated nitric and sulfuric acids?

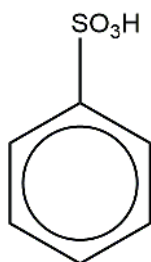
A.



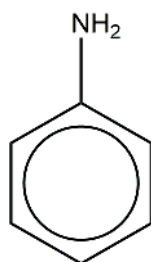
C.



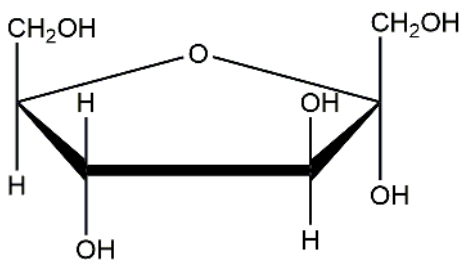
B.



D.

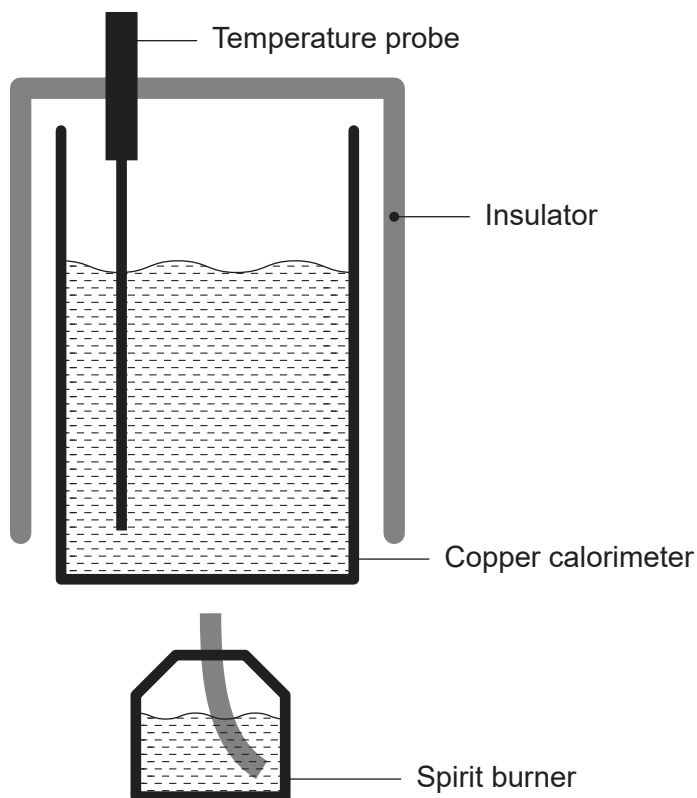


37. How many chiral centres are there in the following molecule?



- A. 2
- B. 3
- C. 4
- D. 6

38. The enthalpy of combustion of a fuel was determined using the calorimeter shown. The final result was lower than the literature value.



Which factors could have contributed to this error?

- I. Not all heat from the combustion was transferred to the calorimeter.
 - II. Incomplete combustion occurred.
 - III. The temperature probe touched the bottom of the calorimeter.
- A. I and II only
 - B. I and III only
 - C. II and III only
 - D. I, II and III

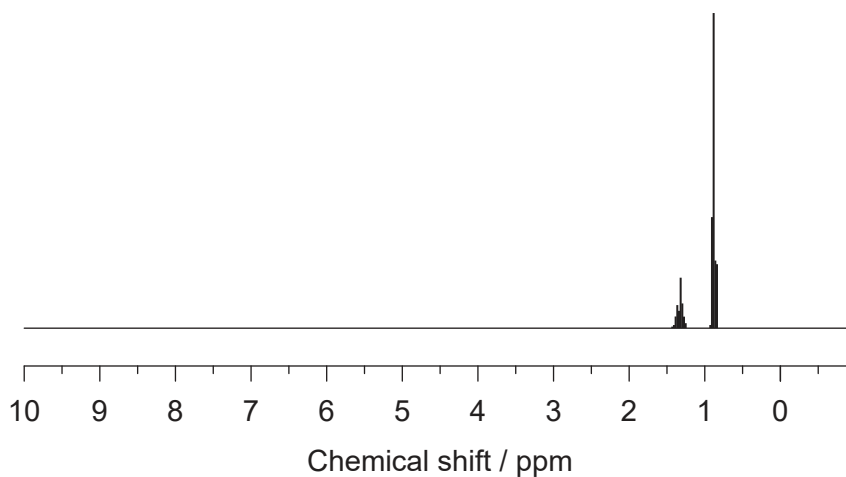
Turn over

39. Burette readings for a titration are shown.

Burette readings / $\text{cm}^3 \pm 0.05 \text{ cm}^3$	Trial 1	Trial 2	Trial 3
Final	11.35	24.60	11.70
Initial	0.20	13.50	0.50

What is the mean titre?

- A. $11.1 \text{ cm}^3 \pm 0.1 \text{ cm}^3$
 - B. $11.15 \text{ cm}^3 \pm 0.05 \text{ cm}^3$
 - C. $11.2 \text{ cm}^3 \pm 0.05 \text{ cm}^3$
 - D. $11.2 \text{ cm}^3 \pm 0.1 \text{ cm}^3$
40. Which compound produces the following ^1H NMR spectrum?



- A. Propane
- B. Propanone
- C. Propanal
- D. 2,2-dimethylpropane

References:

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40. SDBS, National Institute of Advanced Industrial Science and Technology (AIST).

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