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Chemistry

Higher level

Paper 1

Wednesday 10 November 2021 (afternoon)

1 hour

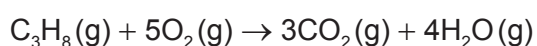
Instructions to candidates

- 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]**.

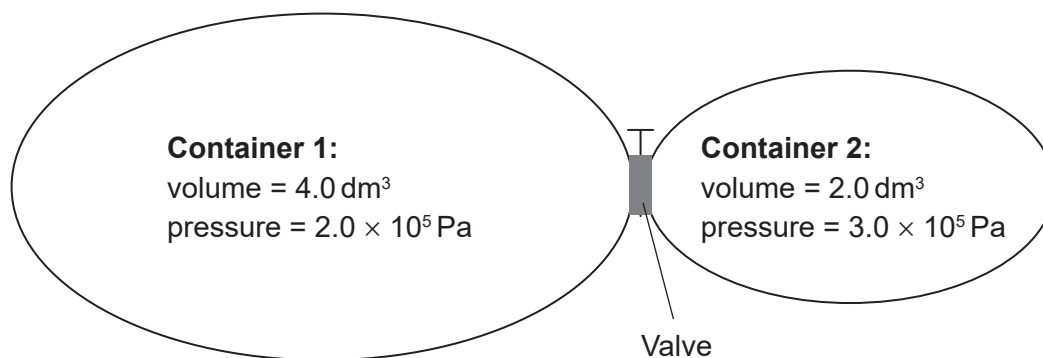
1. How much ethanol contains 1.20×10^{24} atoms of carbon?

Avogadro's constant, L or N_A : $6.02 \times 10^{23} \text{ mol}^{-1}$

- A. 0.333 mol
 B. 0.500 mol
 C. 1.00 mol
 D. 2.00 mol
2. 3.00 mol of C_3H_8 is mixed with 20.00 mol of O_2 . Which quantity is present at the end of the reaction?

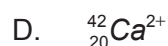
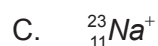
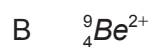
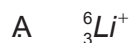


- A. 1.00 mol of C_3H_8
 B. 5.00 mol of O_2
 C. 12.00 mol of CO_2
 D. 16.00 mol of H_2O
3. The two containers shown are connected by a valve. What is the total pressure after the valve is opened and the two gas samples are allowed to mix at constant temperature?



- A. $1.5 \times 10^5 \text{ Pa}$
 B. $2.3 \times 10^5 \text{ Pa}$
 C. $2.5 \times 10^5 \text{ Pa}$
 D. $5.0 \times 10^5 \text{ Pa}$

4. Which species has two more neutrons than electrons?



5. Which statement explains why the **second** ionization energy of aluminium is higher than the **first** ionization energy of magnesium?

- A. Ionization energy increases along period 3.
- B. 3p electrons are at a higher energy level than 3s electrons.
- C. 3p electrons are further away from the nucleus than 2p electrons.
- D. Both have the same number of electrons and aluminium has one more proton.

6. Which ion has the largest radius?

- A. Na^+
- B. Mg^{2+}
- C. P^{3-}
- D. S^{2-}

7. Which combination describes the acid–base nature of aluminium and phosphorus oxides?

	Aluminium	Phosphorus
A.	Amphoteric oxide	Acidic oxide
B.	Basic oxide	Amphoteric oxide
C.	Acidic oxide	Amphoteric oxide
D.	Amphoteric oxide	Basic oxide

8. Which complex ion contains a central ion with an oxidation state of +3?

- A. $[\text{PtCl}_6]^{2-}$
- B. $[\text{Cu}(\text{H}_2\text{O})_4(\text{OH})_2]$
- C. $[\text{Ni}(\text{NH}_3)_4(\text{H}_2\text{O})_2]^{2+}$
- D. $[\text{Co}(\text{NH}_3)_4\text{Cl}_2]^+$

9. Which combination would create the strongest ionic bond?

	Ionic radius	Charges on ions
A.	large	high
B.	large	low
C.	small	high
D.	small	low

10. Which compound contains both ionic and covalent bonds?

- A. CH_3COONa
- B. CH_3COOH
- C. K_2O
- D. CaCl_2

11. The following compounds have similar relative molecular masses. What is the order of increasing boiling point?

- A. $\text{CH}_3\text{CH}_2\text{CH}_2\text{OH} < \text{CH}_3\text{CH}_2\text{CHO} < \text{CH}_3\text{COOH}$
- B. $\text{CH}_3\text{CH}_2\text{CHO} < \text{CH}_3\text{CH}_2\text{CH}_2\text{OH} < \text{CH}_3\text{COOH}$
- C. $\text{CH}_3\text{CH}_2\text{CHO} < \text{CH}_3\text{COOH} < \text{CH}_3\text{CH}_2\text{CH}_2\text{OH}$
- D. $\text{CH}_3\text{COOH} < \text{CH}_3\text{CH}_2\text{CHO} < \text{CH}_3\text{CH}_2\text{CH}_2\text{OH}$

12. Which molecules contain two pi (π) bonds?

- I. HCN
- II. H_2CO_3
- III. $\text{H}_2\text{C}_2\text{O}_4$

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

13. What is the hybridization of nitrogen and chlorine in NCl_3 ?

	N	Cl
A.	sp^2	sp^2
B.	sp^2	sp^3
C.	sp^3	sp^2
D.	sp^3	sp^3

14. Which combustion reaction releases the **least** energy per mole of C_3H_8 ?

Approximate bond enthalpy / kJ mol^{-1}

$\text{O}=\text{O}$ 500

$\text{C}=\text{O}$ 800

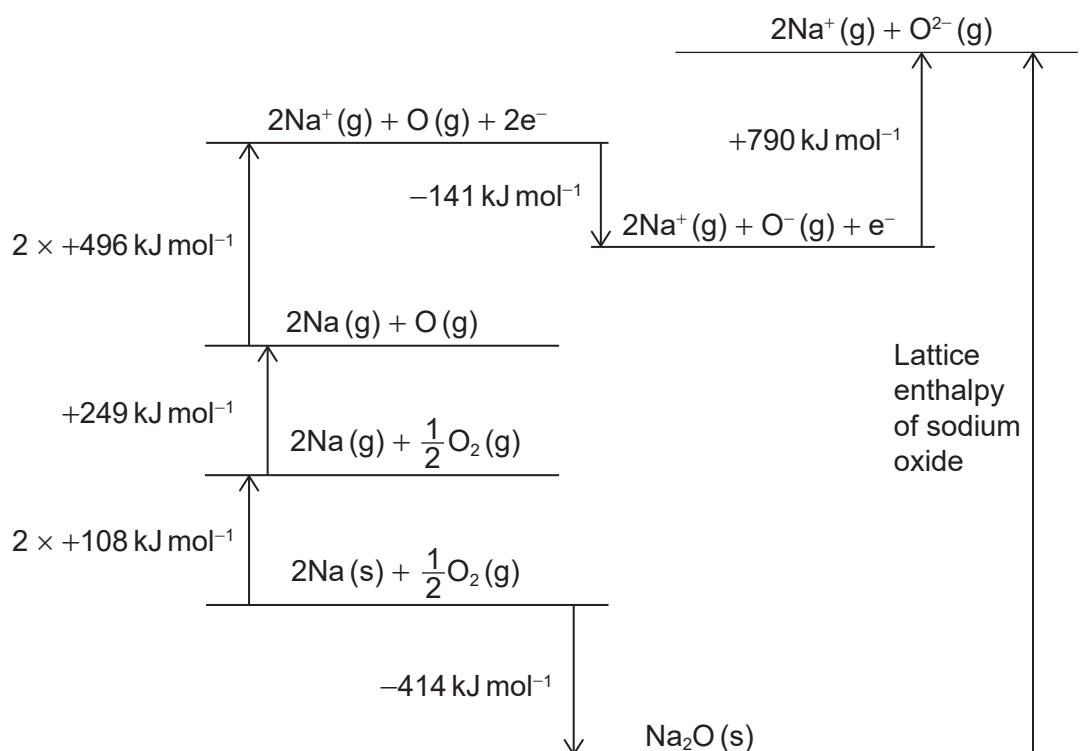
$\text{C}\equiv\text{O}$ 1000

- A. $\text{C}_3\text{H}_8(\text{g}) + 5\text{O}_2(\text{g}) \rightarrow 3\text{CO}_2(\text{g}) + 4\text{H}_2\text{O}(\text{g})$
- B. $\text{C}_3\text{H}_8(\text{g}) + \frac{9}{2}\text{O}_2(\text{g}) \rightarrow 2\text{CO}_2(\text{g}) + \text{CO}(\text{g}) + 4\text{H}_2\text{O}(\text{g})$
- C. $\text{C}_3\text{H}_8(\text{g}) + 4\text{O}_2(\text{g}) \rightarrow \text{CO}_2(\text{g}) + 2\text{CO}(\text{g}) + 4\text{H}_2\text{O}(\text{g})$
- D. $\text{C}_3\text{H}_8(\text{g}) + \frac{7}{2}\text{O}_2(\text{g}) \rightarrow 3\text{CO}(\text{g}) + 4\text{H}_2\text{O}(\text{g})$

15. Which equation represents the standard enthalpy of formation of lithium oxide?

- A. $4\text{Li(s)} + \text{O}_2\text{(g)} \rightarrow 2\text{Li}_2\text{O(s)}$
- B. $2\text{Li(s)} + \frac{1}{2}\text{O}_2\text{(g)} \rightarrow \text{Li}_2\text{O(s)}$
- C. $\text{Li(s)} + \frac{1}{4}\text{O}_2\text{(g)} \rightarrow \frac{1}{2}\text{Li}_2\text{O(s)}$
- D. $\text{Li(g)} + \frac{1}{4}\text{O}_2\text{(g)} \rightarrow \frac{1}{2}\text{Li}_2\text{O(g)}$

16. Consider the Born-Haber cycle for the formation of sodium oxide:

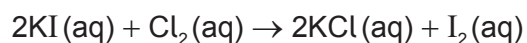


What is the lattice enthalpy, in kJ mol^{-1} , of sodium oxide?

- A. $414 + 2(108) + 249 + 2(496) - 141 + 790$
- B. $414 + 2(108) + 249 + 2(496) + 141 + 790$
- C. $-414 + 2(108) + 249 + 2(496) - 141 + 790$
- D. $-414 - 2(108) - 249 - 2(496) + 141 - 790$

17. In which of the following situations is the forward reaction spontaneous?
- A. The equilibrium constant is greater than one under standard conditions.
 - B. The cell potential is negative.
 - C. The Gibbs free energy change of the reverse reaction is negative.
 - D. The entropy change of the universe for the forward reaction is negative.

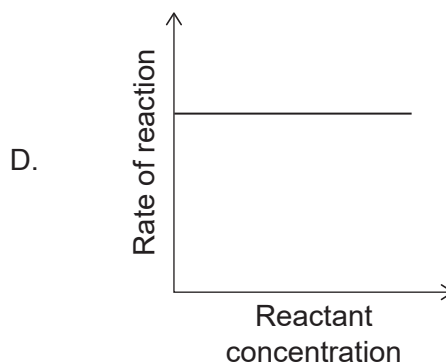
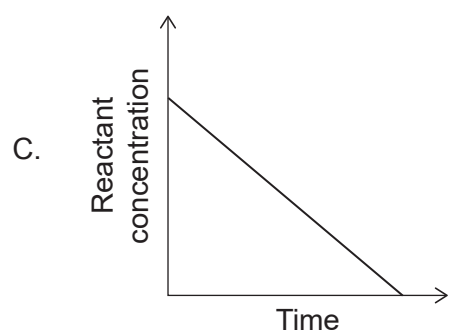
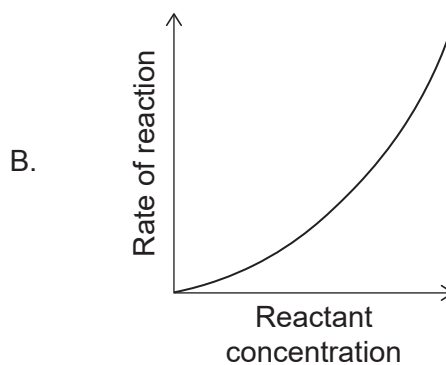
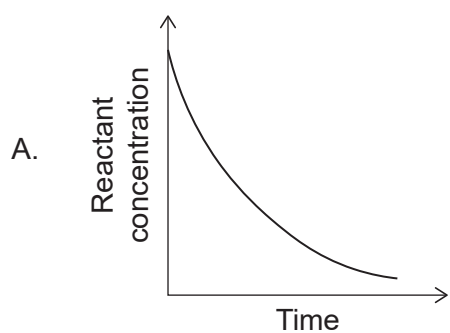
18. Which instrument would best monitor the rate of this reaction?



- A. Balance
 - B. Colorimeter
 - C. Volumetric flask
 - D. Gas syringe
19. Which combination has the greatest rate of reaction at room temperature?

	Zinc	CuSO ₄ (aq)
A.	1.00 g Zn powder	50.0 cm ³ of 0.200 mol dm ⁻³ CuSO ₄ (aq)
B.	1.00 g Zn powder	100.0 cm ³ of 0.100 mol dm ⁻³ CuSO ₄ (aq)
C.	1.00 g Zn strip	50.0 cm ³ of 0.200 mol dm ⁻³ CuSO ₄ (aq)
D.	1.00 g Zn strip	100.0 cm ³ of 0.100 mol dm ⁻³ CuSO ₄ (aq)

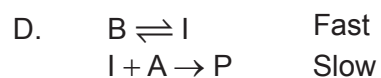
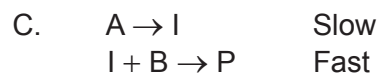
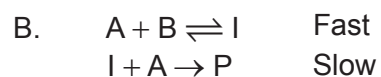
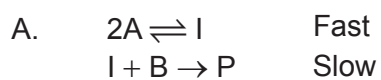
20. Which graph shows a first order reaction?



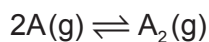
21. The rate equation for a reaction is:

$$\text{rate} = k[A][B]$$

Which mechanism is consistent with this rate equation?

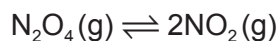


22. A reversible reaction has a reaction quotient, Q , of 4.5 and equilibrium constant, K_c , of 6.2.

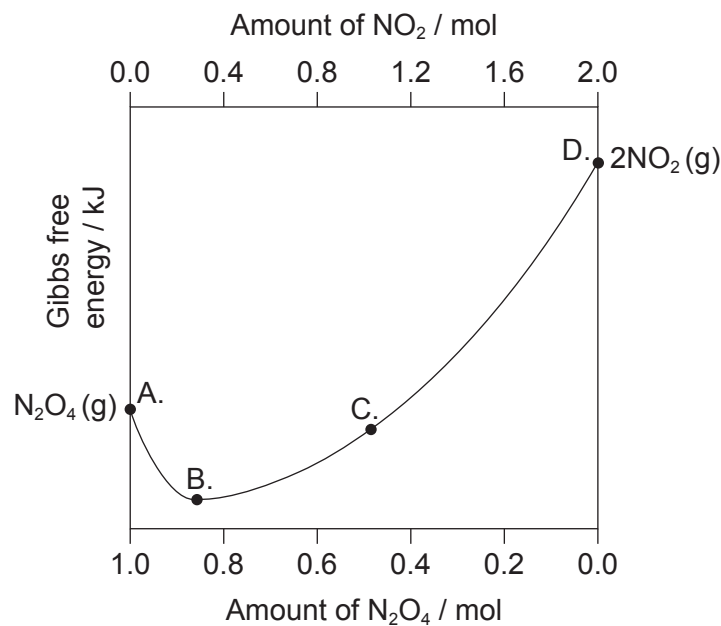


Which statement describes the reaction at this time?

- A. The system has reached equilibrium.
 - B. The rate of the forward reaction is greater than the rate of the reverse reaction.
 - C. The concentration of reactant is greater than the concentration of product.
 - D. At equilibrium, the concentration of reactant is greater than the concentration of product.
23. The graph shows Gibbs free energy of a mixture of $N_2O_4(g)$ and $NO_2(g)$ in different proportions.



Which point shows the system at equilibrium?



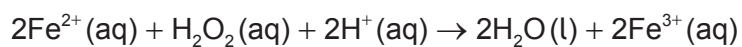
24. Which ions are present in an aqueous solution of Na_2CO_3 ?

- I. HCO_3^-
 - II. OH^-
 - III. CO_3^{2-}
- A. I and II only
 - B. I and III only
 - C. II and III only
 - D. I, II and III

25. What is the pH of 0.01 mol dm^{-3} KOH(aq)?
- A. 1.0
 B. 2.0
 C. 12.0
 D. 13.0
26. What is a possible value of pH at the equivalence point in the titration of a strong acid with a weak base?
- A. 5
 B. 7
 C. 9
 D. 11
27. What is correct for pure hot water?

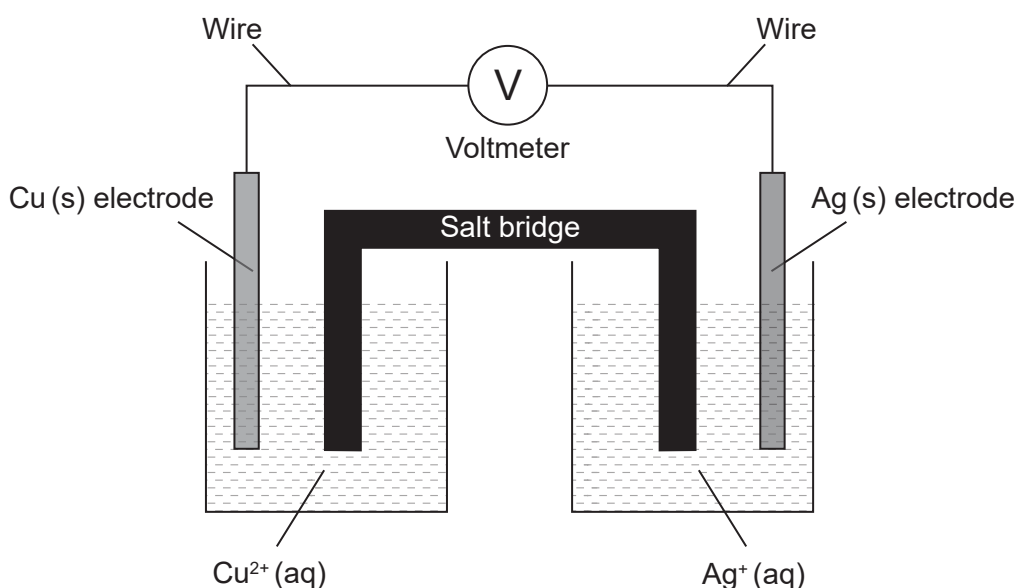
	pH	$[\text{H}^+]$ and $[\text{OH}^-]$
A.	exactly 7	$[\text{H}^+] = [\text{OH}^-]$
B.	below 7	$[\text{H}^+] = [\text{OH}^-]$
C.	below 7	$[\text{H}^+] > [\text{OH}^-]$
D.	above 7	$[\text{H}^+] = [\text{OH}^-]$

28. What is the change in the oxidation state of oxygen?



- A. +1
 B. 0
 C. -1
 D. -2

29. Consider this voltaic cell, where Cu is a more reactive metal than Ag:



Which combination describes the movement of charge in this cell?

	Flow of electrons in wire	Flow of negative ions in salt bridge
A.	Ag(s) to Cu(s)	Toward Ag ⁺ (aq)
B.	Cu(s) to Ag(s)	Toward Ag ⁺ (aq)
C.	Ag(s) to Cu(s)	Toward Cu ²⁺ (aq)
D.	Cu(s) to Ag(s)	Toward Cu ²⁺ (aq)

30. Consider the following standard electrode potentials:

Half-equation	E^\ominus / V
$\text{Zn}^{2+}(\text{aq}) + 2\text{e}^- \rightleftharpoons \text{Zn}(\text{s})$	-0.76
$\text{Pb}^{2+}(\text{aq}) + 2\text{e}^- \rightleftharpoons \text{Pb}(\text{s})$	-0.13
$\frac{1}{2}\text{Br}_2(\text{l}) + \text{e}^- \rightleftharpoons \text{Br}^-(\text{aq})$	+1.09

Which species will react with each other spontaneously under standard conditions?

- A. $\text{Zn}^{2+}(\text{aq}) + \text{Pb}(\text{s})$
- B. $\text{Pb}^{2+}(\text{aq}) + \text{Br}_2(\text{l})$
- C. $\text{Zn}(\text{s}) + \text{Br}^-(\text{aq})$
- D. $\text{Pb}(\text{s}) + \text{Br}_2(\text{l})$

31. Which aqueous solutions produce oxygen gas during electrolysis?

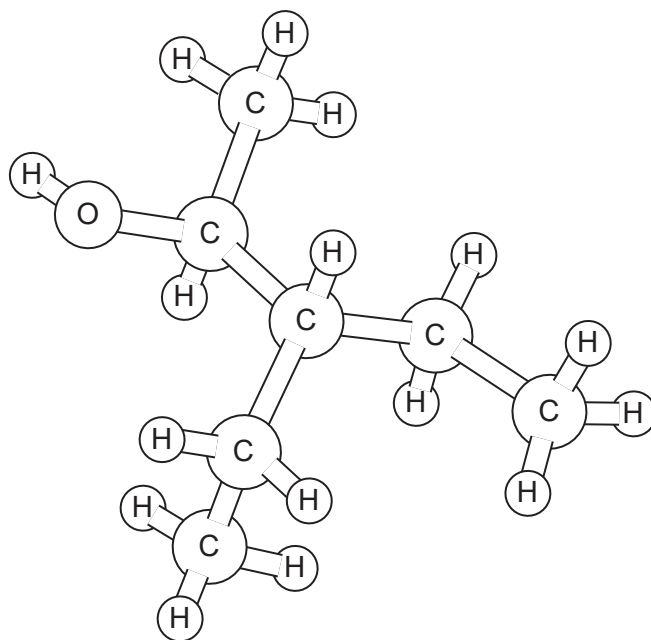
- I. Dilute $\text{CuCl}_2(\text{aq})$ with inert electrodes
- II. Dilute $\text{FeSO}_4(\text{aq})$ with inert electrodes
- III. Dilute $\text{CuCl}_2(\text{aq})$ with copper electrodes

The standard electrode potentials are provided in the table:

Half-equation	E^\ominus / V
$\text{Fe}^{2+}(\text{aq}) + 2\text{e}^- \rightleftharpoons \text{Fe}(\text{s})$	–0.45
$\text{Cu}^{2+}(\text{aq}) + 2\text{e}^- \rightleftharpoons \text{Cu}(\text{s})$	+0.34
$\frac{1}{2}\text{O}_2(\text{g}) + 2\text{H}^+(\text{aq}) + 2\text{e}^- \rightleftharpoons \text{H}_2\text{O}(\text{l})$	+1.23
$\frac{1}{2}\text{Cl}_2(\text{g}) + \text{e}^- \rightleftharpoons \text{Cl}^-(\text{aq})$	+1.36

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

32. What is the name of this substance using IUPAC rules?

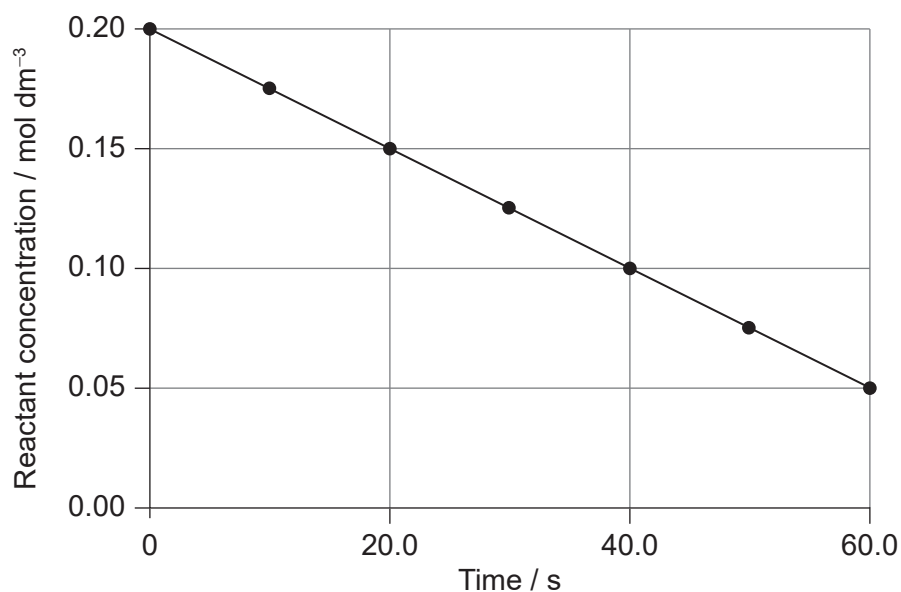


- A. 2-ethyl-1-methylbutan-1-ol
 - B. 1-methyl-2-ethylbutan-1-ol
 - C. 3-ethylpentan-2-ol
 - D. 3-ethylpentan-4-ol
33. Which pair of compounds are structural isomers?
- A. Propane and propene
 - B. Propanal and propanone
 - C. Propan-1-ol and propanal
 - D. Propyl propanoate and propanoic acid
34. What is the general formula of alkynes?
- A. C_nH_{2n+2}
 - B. C_nH_{2n}
 - C. C_nH_{2n-2}
 - D. C_nH_n

35. Which statement is correct about configurational isomers?
- A. Configurational isomers can only be interconverted by breaking and reforming bonds.
 - B. Configurational isomers have different molecular formulas but the same structural formulas.
 - C. Configurational isomers are not distinct compounds.
 - D. Configurational isomers always have identical physical properties.
36. Which product is formed when $\text{CH}_3\text{COCH}_2\text{CH}_3$ is reduced with sodium borohydride?
- A. $\text{CH}_3\text{CH}_2\text{CH}_2\text{CHO}$
 - B. $\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{OH}$
 - C. $\text{CH}_3\text{CH}(\text{OH})\text{CH}_2\text{CH}_3$
 - D. $\text{CH}_3\text{CH}_2\text{CH}_2\text{COOH}$
37. Which attacking species is matched with its mechanism of reaction?

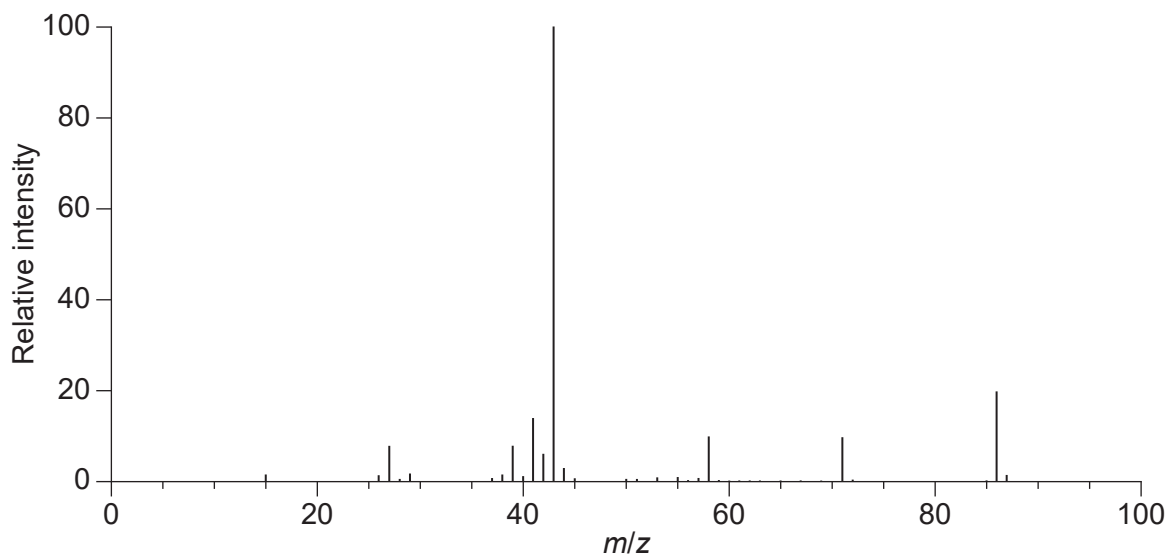
	Attacking species	Type of mechanism
A.	OH^-	Electrophilic substitution
B.	Cl^+	Nucleophilic addition
C.	NH_4^+	Nucleophilic addition
D.	NO_2^+	Electrophilic substitution

38. What is the slope of the graph?



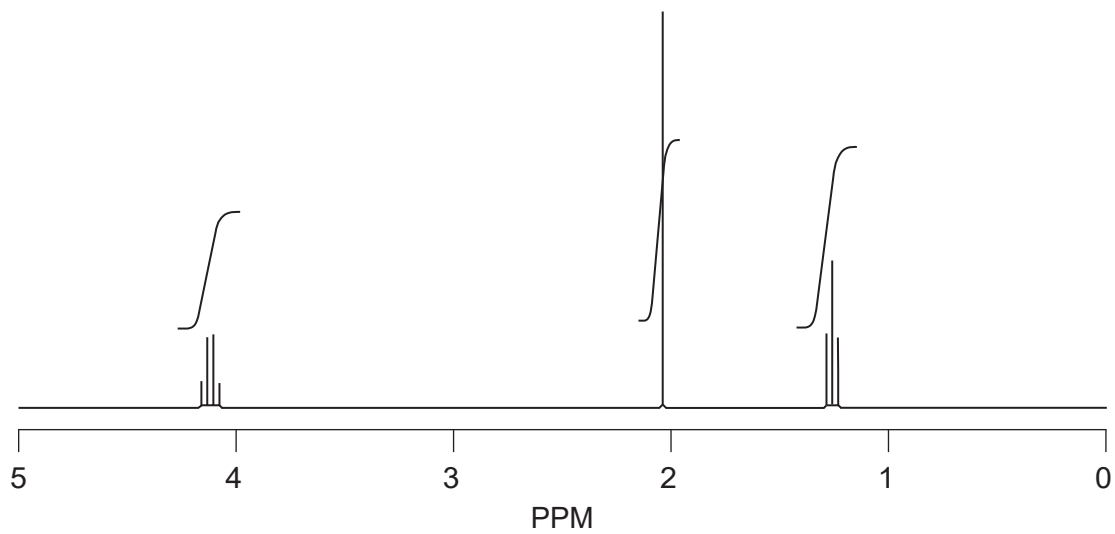
- A. $-0.0025 \text{ mol dm}^{-3} \text{ s}^{-1}$
- B. $-0.0025 \text{ mol dm}^{-3} \text{ s}$
- C. $-0.0033 \text{ mol dm}^{-3} \text{ s}^{-1}$
- D. $-0.0033 \text{ mol dm}^{-3} \text{ s}$

39. What can be deduced from the mass spectrum of $\text{CH}_3\text{COCH}_2\text{CH}_2\text{CH}_3$?



- A. The molar mass is 43 g mol^{-1} .
- B. The atoms have many isotopes.
- C. The most likely bond to break is C-C between carbons 2 and 3.
- D. The signal with the largest mass is due to the oxidation of the ketone in the spectrometer.

40. Which substance has the following ^1H NMR spectrum?



- A. Propane
 - B. Propanal
 - C. Butanoic acid
 - D. Ethyl ethanoate
-

References:

14. Chemistry: Atoms First 2e, <https://openstax.org/books/chemistry-atoms-first-2e/pages/9-4-strengths-of-ionic-and-covalent-bonds> © 1999–2021, Rice University. Except where otherwise noted, textbooks on this site are licensed under a Creative Commons Attribution 4.0 International License. (CC BY 4.0) <https://creativecommons.org/licenses/by/4.0/>.
39. NIST Mass Spectrometry Data Center Collection © 2021 copyright by the U.S. Secretary of Commerce on behalf of the United States of America. All rights reserved. 2-Pentanone Mass Spectrum, MS Number 291264. [graph] Available at: <https://webbook.nist.gov/cgi/cbook.cgi?ID=C107879&Units=SI&Mask=200#Mass-Spec2-pentanone> [Accessed 4 May 2020]. Source adapted.
40. SDBS, National Institute of Advanced Science and Technology.