Trinidad and Tobago Chemistry Olympiad

Round 1 - Level B

INSTRUCTIONS TO CANDIDATES:

(1). **Do not turn this page until you are told to do so**

(2). This paper consists of **nineteen (19)** numbered pages

(3). There are **sixty (60)** multiple choice questions. The duration of this exam in **1 hour and 30 minutes**.

(4). Answer **all** questions. There is no negative marking.

(5). In addition to this question paper, you should also have an answer sheet.

(6). Each question has **four (4)** options - (A), (B), (C), (D). **Only one** is the correct answer.

(7). On your answer sheet, completely shade your choice.

(8). The use of non-programmable calculators is allowed.

(9). A Periodic Table will not be provided.

1. Carbon-14 is the radioisotope of carbon with the longest half-life. It may be formed by the following reaction:

$$^{14}N + {}^{1}n \longrightarrow {}^{14}C + X$$

What is the identity of X?

(A). e^-
(B). ^{1}H
(C). ^{13}C
(D). ^{12}C

Solution:

- Write in the atomic numbers for the different species:

$$^{14}_{7}N + {}^{1}_{0}n \longrightarrow {}^{14}_{6}C + X$$

- Consider the mass and atomic numbers as separate equations:

Mass Numbers:

14 + 1 = 14 + A

A = 1

Atomic Numbers:

7 + 0 = 6 + Z

Z = 1 = Hydrogen

- Therefore:

$$^{1}_{1}X$$

B is the correct answer.

2. Argon consists of three stable isotopes:

Isotope	*Mass*	*Abundance*
Ar-36	*35.968*	*0.334%*
Ar-38	*37.963*	*0.062%*
Ar-40	*39.963*	*99.604%*

What is the atomic mass of Argon?

(A). 38.000

(B). 37.965

(C). 37.963

(D). 39.948

Solution:

- Atomic mass = weighted contribution of the different isotopic masses

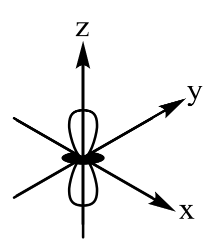
= (0.334% x 35.968) + (0.062% x 37.963) + (99.604% x 39.963)

= 39.948

- A: Average of mass numbers
- B; Average of isotopic masses, without consideration of relative abundance
- C: Middle isotope

D is the correct answer.

3. What is the name of the orbital shown below?



(A). s

(B). p_z

(C). p_z2

(D). d_z2

Solution:

- Examine (i) the shape of the orbital and (ii) the axis/axes it lies on

- A: Spherical orbital
- B: Dumbell shaped lobes lying along the z-axis
- C: Invalid orbital
- D: Dumbell shaped lobes lying alone the z-axis, with a "ring" around the centre

D is the correct answer.

Questions 4 and 5 refer to the following data:
You are utilizing red light at wavelength of 700 nm.
$c = 3.0 \times 10^{8}$ ms^{-1}; $h = 6.63 \times 10^{-34}$ J s

4. What is the frequency of this light?

(A). 2.84×10^{-19} Hz
(B). 2.84×10^{-28} Hz
(C). 4.29×10^{14} Hz
(D). 6.63×10^{-34} Hz

Solution:

- f (frequency) = c (speed of light) / λ (wavelength)
- It is imperative that the units match. One cannot divide a quantity with "m" by one with "nm".
- 1 nm = 1×10^{-9} m
- 700 nm = 700×10^{-9} m
- $f = (3.0 \times 10^{8}) / (700 \times 10^{-9}) = 4.29 \times 10^{14}$
- Units Check: $f = ms^{-1} / m = s^{-1}$ = Hz

C is the correct answer.

5. What is the energy of this light?

(A). 2.84×10^{-19} J
(B). 2.84×10^{-28} J
(C). 4.29×10^{14} J
(D). 3.0×10^{8} J

Solution:

- E (energy) = h (Planck's constant) x f (frequency)
  $= (6.63 \times 10^{-34}) \times (4.29 \times 10^{14})$
  $= 2.84 \times 10^{-19}$
- Units Check: $E = Js \times s^{-1} = J$

A is the correct answer.

6. Consider the 1st Electron Affinity of the following atoms:

$$X + e^- \longrightarrow X^-$$

Atom	*j*	*k*	*l*	*m*
Energy released (kJ mol^{-1})	*60*	*- 50*	*328*	*- 120*

Which of these atoms would you expect to most readily form an ionic compound with Na?

(A). j
(B). k
(C). l
(D). m

Solution:

- Na ionizes with the release of an electron
- From the table, the greater the energy released, the more favourable is the process that is depicted i.e. capture of an electron
- A negative sign for energy released in this case means that energy needs to be put into the system to facilitate the transformation
- Order of favourability for electron capture:
m < k < j < l

C is the correct answer.

7. Consider an element with electronic configuration: $1s^2$ $2s^2$ $2p^5$. What is the most likely oxidation number of its ion?

(A). 0
(B). -1
(C). + 1
(D). - 5

Solution:

- Atoms ionize in a manner which leads to 8 valence electrons
- This element has 7 valence electrons (2 x 2s and 5 x 2p), acquiring one more will complete the octet

- A: 7 valence electrons
- B: 8 valence electrons
- C: 6 valence electrons
- D: 12 valence electrons

B is the correct answer.

8. Consider the ionization energies of element J:

Ionization energy (kJ mol^{-1})	*1st*	*2nd*	*3rd*	*4th*
	578	*1817*	*2745*	*11580*

What is the likely formula of its oxide?

(A). JO
(B). J_2O
(C). JO_2
(D). J_2O_3

Solution:

- The magnitude of ionization energies can be used to determine the number of valence electrons
- When there is a large increase in a particular ionization energy, this is indicative that an inner shell has been broken into
- From the table, a large increase occurs with the 4th ionization energy
- Element J therefore has three valence electrons, and will likely ionize to form J^{3+}
- Its compound with oxygen (O^{2-}) will be J_2O_3 (similar to Al_2O_3 for Al)

D is the correct answer.

9. Arrange the following intermolecular forces of attraction in terms of increasing strength:

(A). H-bonding < Van der Waals < Dipole-dipole < Electrostatic
(B). Van der Waals < H-bonding < Dipole-dipole < Electrostatic
(C). Van der Waals < Dipole-dipole < H-bonding < Electrostatic
(D). Van der Waals < H-bonding < Electrostatic < Dipole-dipole

Solution:

- Van der Waals dispersion forces: < 8 kJ mol^{-1}
- Dipole-dipole: 8 - 25 kJ mol^{-1}
- H-bonding: ≈ 40 kJ mol^{-1}
- Electrostatic: > 200 kJ mol^{-1}

Note that these values are averages, there are examples that can fall outside of the ranges listed.

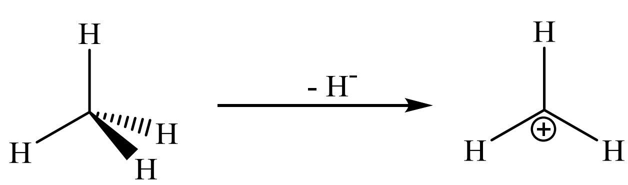
C is the correct answer.

10. What is the shape of the methyl cation, $^{+}CH_3$?

(A). Trigonal planar
(B). Tetrahedral
(C). Pyramidal
(D). Linear

Solution:

- A carbocation is sp^2 hybridized and will therefore have a trigonal planar shape



A is the correct answer.

11. Arrange the following atoms in terms of increasing electropositivity:

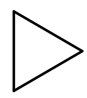
(A). F < P < C < K
(B). K < C < P < F
(C). F < C < P < K
(D). K < P < C < F

Solution:

- Electropositivity increases down a Group, and from left to right across a Period

C is the correct answer.

12. Consider the symmetrical molecule cyclopropane, in which the carbon-carbon bond angles are 60°:



What is the hybridization of each carbon?

(A). sp
(B). sp^2
(C). sp^3
(D). Varies

Solution:

- This is a saturated system, with only C-C single bonds. Therefore, this is sp^3 hybridization. Note that typical sp^3 hybridization results in bond angles of 109.5 °. The much smaller bond angles in cyclopropane results in substantial ring strain for this molecule, and makes systems based on it highly reactive.

C is the correct answer.

13. Balance the following redox reaction in acidic conditions:

$$MnO_4^- + C_2O_4^{2-} \longrightarrow Mn^{2+} + CO_2$$

(A). $MnO_4^- + C_2O_4^{2-} \longrightarrow Mn^{2+} + 2CO_2 + 2O_2$

(B). $2MnO_4^- + 5C_2O_4^{2-} + 16H^+ \longrightarrow 2Mn^{2+} + 10CO_2 + 8H_2O$

(C). $MnO_4^- + C_2O_4^{2-} \longrightarrow Mn^{2+} + CO_2$

(D). $MnO_4^- + C_2O_4^{2-} + 8H^+ \longrightarrow Mn^{2+} + 2CO_2 + 4H_2O$

Solution:

Balancing a redox reaction is not the simple accounting for atomic stoichiometry (as presented in options (A) and (D)). Additional steps are required in order to account for the oxidative and reductive processes occurring:

- (i) Separate into half equations
- (ii) Balance non O and H atoms
- (iii) Balance the O atoms by adding H_2O to the relevant side
- (iv) Balance the H atoms by adding H+ to the relevant side
- (v) Balance the charges on both sides by adding the necessary number of electrons
- (vi) Ensure that the number of electrons in each half equation is the same
- (vii) Add the two half equations together
- (viii) Remove excess species (cancel out common terms)

$$MnO_4^- + C_2O_4^{2-} \longrightarrow Mn^{2+} + CO_2$$

Mn Half Equation	C Half Equation
(i) $MnO_4^- \longrightarrow Mn^{2+}$	$C_2O_4^{2-} \longrightarrow CO_2$
(ii) $MnO_4^- \longrightarrow Mn^{2+}$	$C_2O_4^{2-} \longrightarrow 2CO_2$
(iii) $MnO_4^- \longrightarrow Mn^{2+} + 4H_2O$	$C_2O_4^{2-} \longrightarrow 2CO_2$
(iv) $MnO_4^- + 8H^+ \longrightarrow Mn^{2+} + 4H_2O$	$C_2O_4^{2-} \longrightarrow 2CO_2$
-1 + +8 → +2 + 0	-2 → 0
+7 → +2	-2
+5	
(v) $MnO_4^- + 8H^+ + 5e^- \longrightarrow Mn^{2+} + 4H_2O$	$C_2O_4^{2-} - 2e^- \longrightarrow 2CO_2$
This equation has 5 electrons x2	This equation has 2 electrons x5
(vi) $2MnO_4^- + 16H^+ + 10e^- \longrightarrow 2Mn^{2+} + 8H_2O$	$5C_2O_4^{2-} - 10e^- \longrightarrow 10CO_2$

(vii) $2MnO_4^- + 16H^+ + 10e^- + 5C_2O_4^{2-} - 10e^- \longrightarrow 2Mn^{2+} + 8H_2O + 10CO_2$

(viii) $2MnO_4^- + 16H^+ + 5C_2O_4^{2-} \longrightarrow 2Mn^{2+} + 8H_2O + 10CO_2$

B is the correct answer.

14. An iron nail is placed in beaker containing a solution of copper sulphate. What will you observe over time?

(I). No visible reaction

(II). A reddish-brown solid appears

(III). A green solution forms

(IV). A blue solution forms

(A). I only

(B). II and III only

(C). II and IV only

(D). IV only

Solution:

- In the reactivity series of metals, iron is higher than copper. This means that iron will displace copper from a solution of its salt.
- The specific transformation taking place here is:

$$Fe\ (s) + CuSO_4\ (aq) \longrightarrow FeSO_4\ (aq) + Cu\ (s)$$

Fe (s)	$CuSO_4$ (aq)	$FeSO_4$ (aq)	Cu (s)
silver colour	blue solution	green solution	red/brown solid

B is the correct answer.

15. Which of the following is not an assumption of the kinetic theory of gases?

(A). V_{total} *(gas)* $<<<$ *V (container)*

(B). Average kinetic energy of molecules $\propto 1/T$

(C). Average kinetic energy = constant over time

(D). The intermolecular forces of attraction are negligible

Solution:

- The kinetic theory of gases states that gases consist of a large number of molecules that are in constant random motion:

(i) The combined volume of all the individual gas molecules of a sample is negligible compared to the volume of their container. - *Option (A)*

(ii) The attractive and repulsive forces between gaseous molecules are negligible. - *Option (D)*

(iii) The average kinetic energy of the gaseous molecules at a given/ fixed temperature remains constant over time. - *Option (C)*

(iv) The average kinetic energy of the gaseous molecules is directly proportional to the absolute temperature of the system. - i.e. *Average kinetic energy of molecules* $\propto T$

B is the correct answer.

16. 1.02 moles of a non-ideal gas occupy a container of volume 2.2 L at a temperature of 300 °C. Which of the following is the most likely pressure exerted by this gas?

$$R = 0.0821 \text{ L atm mol}^{-1} \text{ K}^{-1}$$

(A). 21.81 atm
(B). 20.84 atm
(C). 1.0 atm
(D). 22.78 atm

Solution:

- Consider the ideal gas equation: PV = nRT;
where P = pressure; V = volume = 2.2 L; n = number of moles = 1.02 mol; T = absolute temperature = 300 + 273 = 573 K
- Rearranging and substituting into the equation:
P = nRT / V = (1.02 x 0.0821 x 573) / 2.2 = 21.81
- Units Check: P = (mol x L atm mol^{-1} K^{-1} x K) / L = atm
- P_{ideal} = 21.81 atm
- Consider the differences between an ideal gas and a real gas. A real gas has attractive forces between and among the gaseous molecules. This attraction will reduce the collisions of the molecules with the walls of their container, and hence result in them exerting a slightly lower pressure.
- i.e. $P_{ideal} > P_{real}$
- A: $P_{real} = P_{ideal}$
- B: $P_{real} < P_{ideal}$
- C: Too low
- D: $P_{real} > P_{ideal}$

B is the correct answer.

17. An aqueous solution contains only the following ions:

Ion	*sodium*	*sulphate*	*magnesium*
Concentration (mol dm^{-3})	*1.0*	*0.8*	*c*

What is the value of c?

(A). 0.2
(B). 0.5
(C). 0.8
(D). 0.3

Solution:

- Each ion must be balanced by a counterion
- Cations = Na^+ and Mg^{2+}; Anion = SO_4^{2-}
- Electrically neutral salts: Na_2SO_4 and $MgSO_4$
- Given that all ions are in the same volume (same solution); concentration is representative of the number of moles present
- For Na_2SO_4; 2 moles Na^+ = 1 mole SO_4^{2-}

  Therefore 1 mole Na^+ = 0.5 mole SO_4^{2-}
- Moles of SO_4^{2-} remaining = 0.8 - 0.5 = 0.3
- For $MgSO_4$; 1 mole SO_4^{2-} = 1 mole Mg^{2+}

  Therefore 0.3 moles SO_4^{2-} = 0.3 moles Mg^{2+}

D is the correct answer.

18. Given the following bond dissociation energies:

$$Cl\text{-}Cl = 242\ kJ\ mol^{-1};\ F\text{-}F = 155\ kJ\ mol^{-1};\ Cl\text{-}F = 253\ kJ\ mol^{-1}$$

What is the enthalpy of reaction for the formation of chlorine trifluoride?

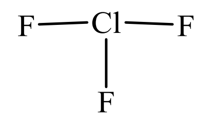
$$\text{chlorine gas} + \text{fluorine gas} \longrightarrow \text{chlorine trifluoride}$$

(A). 144 kJ mol^{-1}
(B). 811 kJ mol^{-1}
(C). 406 kJ mol^{-1}
(D). - 406 kJ mol^{-1}

Solution:

(i) Write the balanced equation. Since this question is for the formation energetics of ClF_3, 1 mole of ClF_3 alone must be present
(ii) Draw the structures of each species in the reaction and identify the bonds broken (in the reactants, requiring energy) and the bonds formed (in the products, releasing energy)
(iii) Assign values to the bonds broken and formed
(iv) Calculate the net energetic change

(i) $0.5Cl_2 + 1.5F_2 \longrightarrow ClF_3$

(ii) $0.5\,Cl{-}Cl \quad + \quad 1.5\,F{-}F \longrightarrow$ 

0.5 x 1 Cl-Cl broken 1.5 x 1 F-F 3 Cl-F formed

(iii) $(0.5 \times 242\ kJ\ mol^{-1}) + (1.5 \times 155\ kJ\ mol^{-1})$ $= 353.5\ kJ\ mol^{-1}$ $\qquad 3 \times 253\ kJ\ mol^{-1}$ $= 759\ kJ\ mol^{-1}$

(iv) Enthalpy change = Energy to break bonds - Energy released from bond formation

$= 353.5\ kJ\ mol^{-1} - 759\ kJ\ mol^{-1}$

$= -405.5\ kJ\ mol^{-1}$

D is the correct answer.

19. Which reaction is accompanied by the largest increase in entropy?

(A). $CH_4\ (g) + 2O_2\ (g) \longrightarrow CO_2\ (g) + 2H_2O\ (g)$

(B). $2C_2H_6\ (g) + 7O_2\ (g) \longrightarrow 4CO_2\ (g) + 6H_2O\ (g)$

(C). $Na\ (s) + H_2O\ (l) \longrightarrow NaOH\ (aq) + H_2\ (g)$

(D). $NaOH\ (aq) + HCl\ (aq) \longrightarrow NaCl\ (aq) + H_2O\ (l)$

Solution:

- Entropy is a measure of the disorder in a system. Consider the freedom/restriction of motion of molecules in different physical states, and the arrangement of disorder can be represented as:
solid < liquid <<< gas
- Consider each reaction shown, and determine which is associated with the biggest difference between the products and reactants in terms of generation of disorder; based on the number and states of the species present:

Reaction		Change in Disorder
(A). $CH_4\ (g) + 2O_2\ (g) \longrightarrow$	$CO_2\ (g) + 2H_2O\ (g)$	
3 gas molecules	3 gas molecules	negligible
(B). $2C_2H_6\ (g) + 7O_2\ (g) \longrightarrow$	$4CO_2\ (g) + 6H_2O\ (g)$	
9 gas molecules	10 gas molecules	minimal
(C). $Na\ (s) + H_2O\ (l) \longrightarrow$	$NaOH\ (aq) + H_2\ (g)$	
1 solid molecule and 1 liquid molecule	1 liquid and 1 gas molecule	significant
(D). $NaOH\ (aq) + HCl\ (aq) \longrightarrow$	$NaCl\ (aq) + H_2O\ (l)$	
2 liquids	2 liquids	negligible

C is the correct answer.

20. Consider the formation of CaF_2 (s) from Ca (s) and F_2 (g). Which of the following represent exothermic reactions?

I. 2F (g) $\longrightarrow$ $2F^-$ (g)
II. Ca (s) $\longrightarrow$ Ca (g)
III. Ca (g) $\longrightarrow$ Ca^+ (g)
IV. Lattice energy of CaF_2

(A). I only
(B). I and IV only
(C). II and III only
(D). II, III and IV only

Solution:

- I: electron affinity - exothermic
- II: enthalpy of atomization - endothermic
- III: 1st Ionization energy - endothermic
- IV: Lattice energy - exothermic

B is the correct answer.

Questions 21 and 22 refer to the following information:

For the reaction: 2CO (g) + O_2 (g) $\longrightarrow$ $2CO_2$ (g)

$\Delta_r H^o$ = - 566 kJ mol^{-1}

	CO (g)	O_2 (g)	CO_2 (g)
S^o ($J\ K^{-1}\ mol^{-1}$)	198	205	214

21. What is $\Delta_r S^o$, the standard entropy change for the reaction?

(A). - 189 $J\ K^{-1}\ mol^{-1}$
(B). - 173 $J\ K^{-1}\ mol^{-1}$
(C). 189 $J\ K^{-1}\ mol^{-1}$
(D). - 214 $J\ K^{-1}\ mol^{-1}$

Solution:

- $\Delta_{reaction}S^{\Theta} = \Sigma\Delta_{products}S^{\Theta} - \Sigma\Delta_{reactants}S^{\Theta}$
  $= (2 \times 214) - [(2 \times 198) + (1 \times 205)]$
  $= -173$

B is the correct answer.

22. At 25 °C, what is $\Delta_r G^{\Theta}$?

(A). - 393 kJ mol^{-1}
(B). - 739 kJ mol^{-1}
(C). - 514 kJ mol^{-1}
(D). - 562 kJ mol^{-1}

Solution:

- Consider the Gibbs Free Energy equation: $\Delta G = \Delta H - T\Delta S$
- $\Delta_r G^{\Theta} = \Delta_r H^{\Theta} - T\Delta_r S^{\Theta}$
  $= - 566 \text{ kJ mol}^{-1} - (298 \text{ K})(- 173 \text{ J K}^{-1} \text{ mol}^{-1})$
  $= - 566 \text{ kJ mol}^{-1} - (- 51554 \text{ J mol}^{-1})$
  $= - 566 \text{ kJ mol}^{-1} + 51.554 \text{ kJ mol}^{-1}$
  $= - 514.446 \text{ kJ mol}^{-1}$

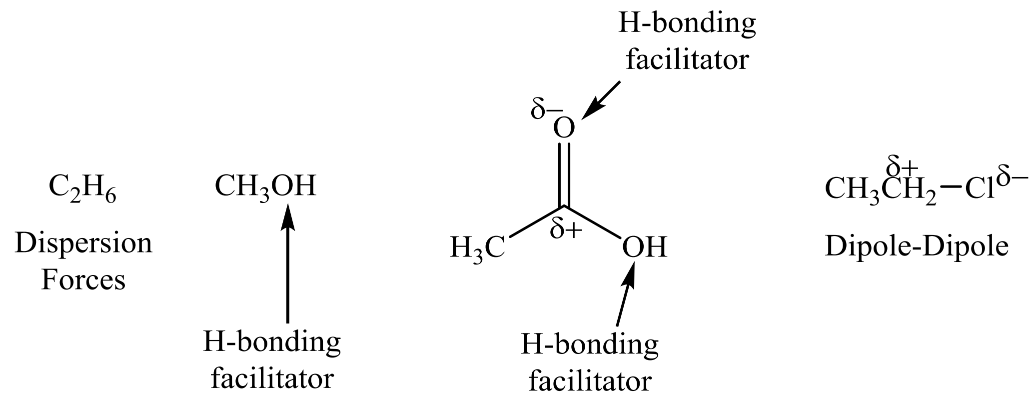
C is the correct answer

23. Which of the following compounds would you expect to have the highest boiling point?

(A). C_2H_6
(B). CH_3OH
(C). CH_3COOH
(D). CH_3CH_2Cl

Solution:

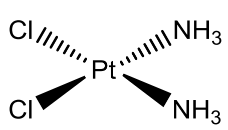
- The relative magnitude of boiling points is a function the intermolecular forces of attraction.
- Greater intermolecular forces = higher boiling point.
- Van der Waals < Dipole-dipole < H-bonding < Electrostatic

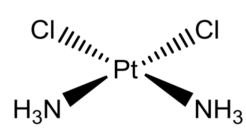


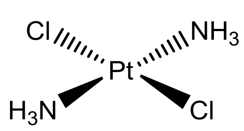
- Increasing boiling point: $C_2H_6 < CH_3CH_2Cl < CH_3OH < CH_3COOH$

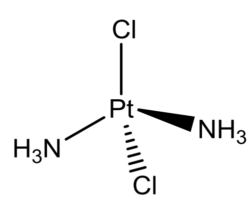
C is the correct answer.

24. The square planar complex $Pt(NH_3)_2Cl_2$ has two stereoisomers. The cis isomer is a potent chemotherapy drug, while the other isomer is not. What is the structure of the ineffective isomer?

(A). 

(B). 

(C). 

(D). 

Solution:

- The ineffective isomer is the trans isomer
- A: cis
- B: cis
- C: trans
- D: tetrahedral, incorrect structure

C is the correct answer

25. Arrange the following 1 M solutions in terms of decreasing pH:

(A). $KOH > CH_3CH_2NH_2 > H_3PO_4 >$ Phenol
(B). $KOH > CH_3CH_2NH_2 >$ Phenol $> H_3PO_4$
(C). Phenol $> H_3PO_4 > CH_3CH_2NH_2 > KOH$
(D). Phenol $> H_3PO_4 > KOH > CH_3CH_2NH_2$

Solution:

- Organic acids typically have a higher pH than mineral acids, therefore pH of: phenol > H_3PO_4
- Mineral bases typically have a higher pH than organic bases, therefore pH of KOH > $CH_3CH_2NH_2$

B is the correct answer

26. Calculate the pH of 0.025 M CH_3CH_2COOH
pK_a (propanoic acid) = 4.88

(A). 4.88
(B). 0.69
(C). 3.25
(D). 0.19

Solution:

- Propanoic acid a carboxylic acid, and is therefore not fully ionized in solution. The equilibrium state has to be considered:

$$CH_3CH_2COOH \rightleftharpoons CH_3CH_2COO^- + H^+$$

	CH_3CH_2COOH	$CH_3CH_2COO^-$	H^+
[Initial]	0.025 M	0 M	0 M
[Change]	- X M	+ X M	+ X M
[Equilibrium]	(0.025 - X) M	X M	X M

- $pK_a = -\log K_a$
- $-\log K_a = 4.88$
- $\log K_a = -4.88$
- $K_a = 10^{-4.88}$
- Because propanoic acid is weakly ionized in solution: X is small,
0.025 >>> X
0.025 - X ≈ 0.025
- $K_a = [CH_3CH_2COO^-][H^+] / [CH_3CH_2COOH] = (X)(X) / 0.025$
- $X^2 = 0.025 \times K_a$
- $X = (0.025 \times 10^{-4.88})^{1/2} = [H^+]$
- $pH = -\log[H^+] = -\log (0.025 \times 10^{-4.88})^{1/2} = 3.25$

C is the correct answer

27. Consider the table below:

	(A)	*(B)*	*(C)*	*(D)*
Indicator	*Thymol blue*	*Methyl orange*	*Bromothymol blue*	*Thymophthalein*
pH range of colour change	*1.2 - 2.8*	*3.0 - 4.4*	*6.0 - 7.6*	*9.3 - 10.5*

Which indicator would be the most suitable for titrating dil. NaOH (aq) against dil. HCl (aq)?

Solution:

- NaOH is a strong base and HCl is a strong acid
- At the equivalence point for this reaction, the pH = 7
- A suitable indicator is one whose colour change occurs in the vicinity of this pH

C is the correct answer

Questions 28 - 30 refer to the following information:

The K_{sp} of copper hydroxide at 20 °C = 2.20 x 10^{-20}

28. What is hydroxide ion concentration of a saturated copper hydroxide solution?

(A). 5.5 x 10^{-21} M
(B). 1.77 x 10^{-7} M
(C). 1.48 x 10^{-10} M
(D). 3.53 x 10^{-7} M

Solution:

- For a saturated solution, the system of a sparingly soluble salt is represented by an equilibrium:

$$Cu(OH)_2\ (s) \rightleftharpoons Cu^{2+}\ (aq) + 2OH^-\ (aq)$$

- 1 mole $Cu(OH)_2$ = 1 mole Cu^{2+} = 2 moles OH^-
- If $[Cu^{2+}]$ = X M, then $[OH^-]$ = 2X M
- $K_{sp} = [Cu^{2+}][OH^-]^2$
$= (X) \times (2X)^2$
$= 4X^3$
- $4X^3 = 2.20 \times 10^{-20}$
- $X = ((2.20 \times 10^{-20})/4))^{1/3}$
$= 1.77 \times 10^{-7}$ M

- $[OH^-] = 2X\ M = 2 \times 1.77 \times 10^{-7}\ M = 3.53 \times 10^{-7}\ M$

D is the correct answer

29. What is the pH of a saturated copper hydroxide solution?

(A). 6.75
(B). 7.25
(C). 7.55
(D). 6.45

Solution:

- pH + pOH = 14
- pH = 14 - pOH
- $pH = 14 - -\log[OH^-] = 14 - \log(3.53 \times 10^{-7}) = 7.55$

- A: pOH based on $[OH^-] = X\ M$
- B: pH based on $[OH^-] = X\ M$
- D: pOH

C is the correct answer

30. What would you expect the pH of a saturated $CuCl_2$ solution to be?

(A). Strongly acidic
(B). Slightly acidic
(C). Neutral
(D). Slightly basic

Solution:

- $CuCl_2$ may be regarded as being made from the reaction of a strong acid (HCl) and a weak base ($Cu(OH)_2$)

B is the correct answer

31. At 100 °C, $K_w = 51.3 \times 10^{-14}$. What is the pH of water at this temperature?

(A). 7.00
(B). 7.86
(C). 6.14
(D). 12.29

Solution:

- In the ionization of water:

$$H_2O \rightleftharpoons H^+ + OH^-$$

- 1 mole H^+ = 1 mole OH^-
- $K_w = [H^+][OH^-] = [H^+]^2$
- $[H^+]^2 = 51.3 \times 10^{-14}$
- $[H^+] = (51.3 \times 10^{-14})^{1/2}$
- pH = - log[H^+] = - log(((51.3 x $10^{-14})^{1/2}$) =

- A: pH at RT
- B: pOH
- D: pK_w

C is the correct answer

32. In cold climates, salt is added to roads in order to melt snow by lowering its freezing point. Which of the following equations can be used to quantify the magnitude of this depression of freezing point?

(A). $\Pi V = nRT$
(B). $P_A = x_A P_A^*$
(C). $\Delta T_f = K_f m$
(D). $\Delta T_b = K_b m$

Solution:

- A: Osmotic pressure
- B: Raoult's Law
- C: Depression of freezing point
- D: Elevation of boiling point
- The above equations of Colligative Properties; they depend only upon the number of solute particles present, and not their chemical identity.

C is the correct answer

33. 0.1 moles of a non-volatile solute is added to 10 moles of ethanol at 25 °C, to create a homogenous solution.

Vapour pressure of pure ethanol = 5.95 kPa

What is the vapour pressure of this solution?

(A). 5.95 kPa
(B). 0.595 kPa
(C). 59.5 kPa
(D). 5.89 kPa

Solution:

- Apply Raoult's Law
- $P_A = x_A P_A^*$; where P_A = vapour pressure of solution = ?;

  x_A = mole fraction of solvent = no. of moles of solvent / total no. of moles in solution
  = 10 / (10 + 0.1) = 0.99;

  P_A^* = vapour pressure of pure solvent = 5.95 kPa
- P_A = 0.99 x 5.95 kPa = 5.89 kPa

D is the correct answer

Questions 34 - 35 refer to the following equilibrium:

$$CH_3COOH\ (l) + C_2H_5OH\ (l) \rightleftharpoons CH_3COOC_2H_5\ (l) + H_2O\ (l) \quad \Delta H = -6\ kJ\ mol^{-1}$$

34. Which of the following will increase the % yield of the ester?

(I). Lowering the temperature
(II). Increasing the temperature
(III). Adding a desiccant
(IV). Increasing the pressure on the system

(A). II only
(B). I and III only
(C). II and III only
(D). II, III and IV only

Solution:

- I: This is an exothermic reaction; lowering the temperature will favour product formation
- II: Increasing the temperature will favour the reactants
- III: A desiccant will absorb water, effectively removing it from the system, and hence favouring product formation
- IV: No gaseous species, negligible effect of altering pressure

B is the correct answer

35. What will happen to the position of the equilibrium and the value of K_C, when more alcohol is added at room temperature?

	Position of equilibrium	K_c
(A).	*shifts to the right*	*no change*
(B).	*shifts to the left*	*no change*
(C).	*shifts to the right*	*increases*
(D).	*shifts to the left*	*decreases*

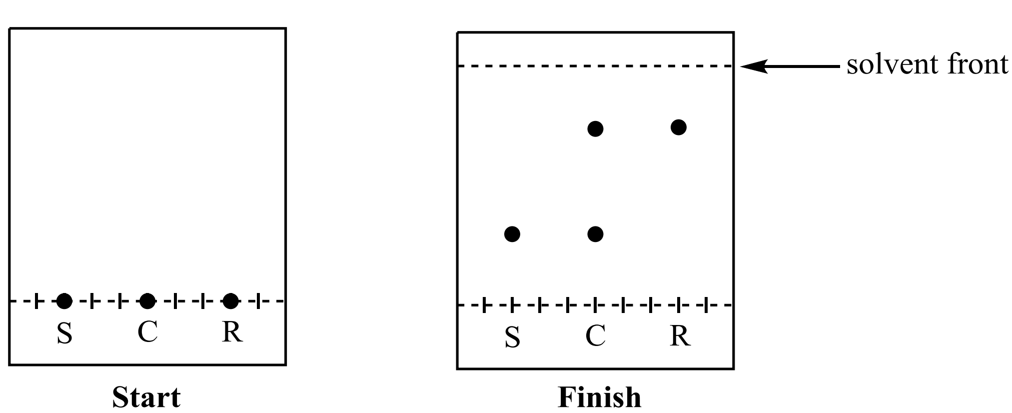
Solution:

- K_c is only affected by temperature
- The alcohol is a reactant, adding more of it will favour product formation

A is the correct answer

Questions 36 - 39 refer to the following information:

TLC is a useful method for following the progress of a reaction. You perform a reaction, and the TLC plate is shown below,
where S = Starting material, R = Reaction mixture, C = Co-spot i.e. both the starting material and reaction mixture have been spotted here.



36. What is the R_f of the starting material?

(A). 0.29
(B). 0.72
(C). 0.00
(D). 1.20

Solution:

- R_f = distance moved by spot / distance moved by solvent from the starting position of the spot
  = 0.95 cm / 3.1 cm = 0.29

- B: R_f of reaction mixture
- C: Distance relative to starting position

A is the correct answer

37. Assuming that any product formed is detectable via TLC, what is the most likely yield of this reaction?

(A). 50 %
(B). 75 %
(C). 100 %
(D). Insufficient information provided to make this determination

Solution:

- Consider the reaction mixture lane: no starting material is observed. One can therefore infer that there has been complete consumption of starting material.
- Since there is only one spot in the reaction mixture lane, it can be inferred that there has been complete conversion of starting material into a single product.

C is the correct answer

38. What is the best method for visualization of the TLC spots of this reaction mixture?

(A). UV light
(B). Ninhydrin
(C). Methyl orange
(D). Phenolphthalein

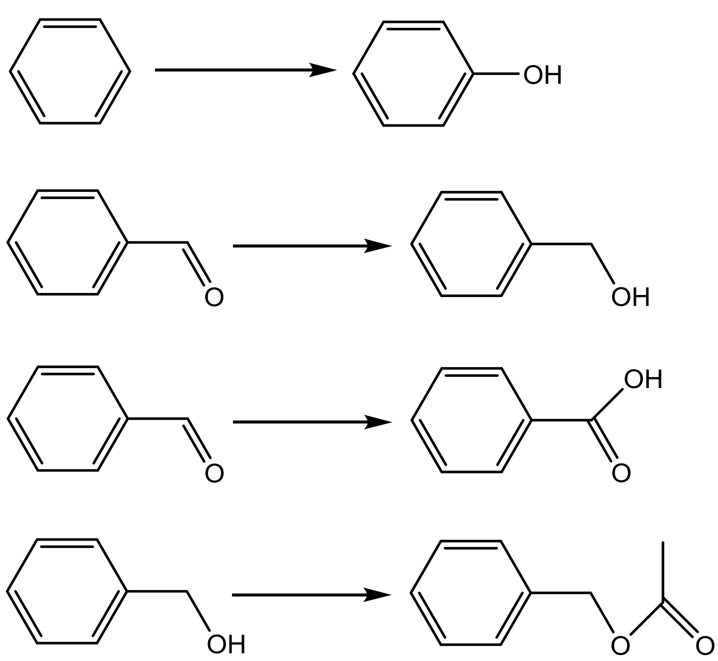
Solution:

- A: Useful for compounds that absorb UV light, for example - aromatic compounds
- B: Useful for the detection of amino acids
- C: Titration indicator
- D: Titration indicator
- Consider the possible reactions presented in Question 39 below - all involve aromatic compounds

A is the correct answer

39. Given that the stationary phase is silica gel, a polar substance, which of the following is likely to be the reaction that was performed?

(A). (B). (C). (D).



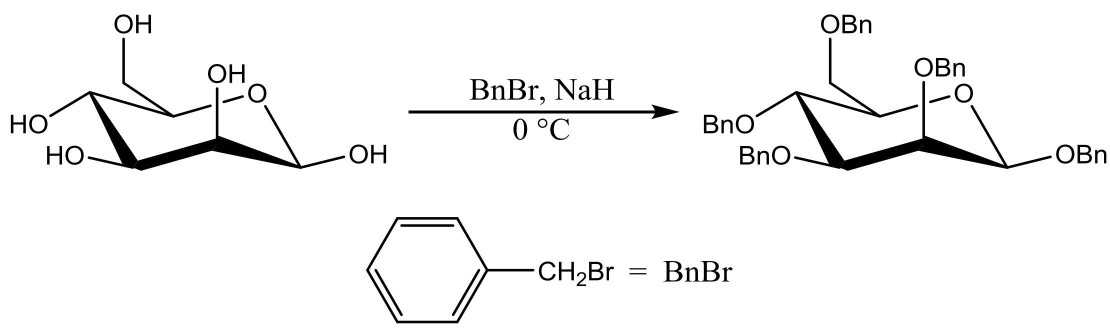
Solution:

- Because the stationary phase is polar, polar substances will strongly adhere to it and move only a short distance on the TLC plate.
- Look at each reaction and determine whether the product is more or less polar than the starting material
- From the TLC plate, the product moves higher up the TLC plate than the starting material, and therefore is less polar

- A: introduction of hydroxyl group: more polar
- B: conversion of carbonyl to hydroxyl: more polar
- C: conversion of a carbonyl to a carboxylic acid: more polar
- D: conversion of an alcohol to an ester: less polar

D is the correct answer

Questions 40 - 42 refer to the following reaction:



40. What are the major by-products from this reaction?

(A). BnBr and NaH

(B). NaBn

(C). NaBr and H^+

(D). NaBr and H_2

Solution:

- Consider the ionic species of each reagent: BnBr = Bn^+Br^-; NaH = Na^+H^-
- Consider what is occurring in the reaction: H is being replaced by Bn, i.e. H^+ is being replaced by Bn^+.
- The remaining ionic species present are therefore: Br^-, Na^+, H^+, H^-

- A: Reactants
- B: Two positively charged species
- C: Does not account for H^-

D is the correct answer

41. It is known that the pure product is a viscous oil. You wish to purify the product from any unreacted starting material, by-products, and side products. What would be the correct sequence of techniques for you to be able to purify and confirm the identity of the product?

(A). Recrystallization → Column Chromatography → Thin Layer Chromatography

(B). Use of a Separatory Funnel → Column Chromatography → Mass Spectrometry

(C). Recrystallization → Column Chromatography → Mass Spectrometry

(D). Use of a Separatory Funnel → Column Chromatography → Thin Layer Chromatography

Solution:

- Given that the product is an oil, recrystallization is not applicable.
- Mass spectrometry can confirm identity, TLC cannot. TLC is effective at monitoring the course of a reaction.
- A separatory funnel, with the use of water and an organic solvent (immiscible with each other), is effective at separating an organic product from water soluble inorganic by-products (such as NaBr).
- Column chromatography is effective at purifying compounds.

B is the correct answer

42. What type of reaction is this?

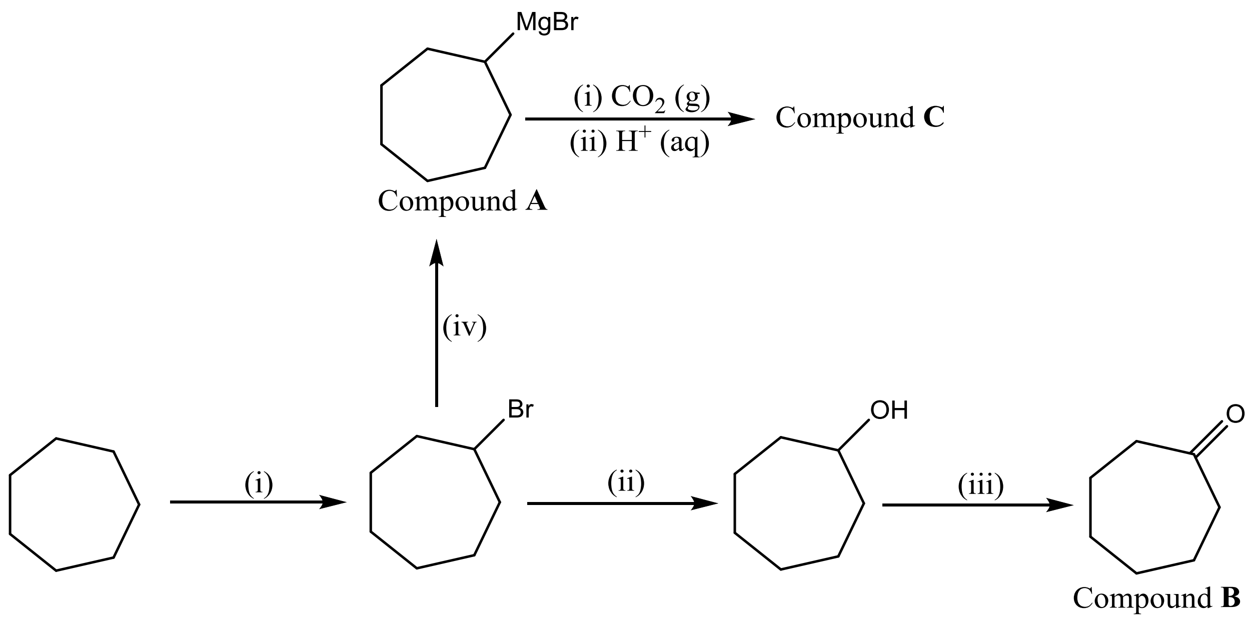
(A). Halogenation
(B). Substitution
(C). Hydrogenation
(D). Friedel-Crafts Acylation

Solution:

- A: Introduction of halogen
- B: Replacement of one atom / group of atoms by another
- C: Addition of hydrogen
- D: Introduction of an ester group unto an aromatic ring
- In the above reaction, H is substituted for Bn

B is the correct answer

Questions 43 - 48 refer to the following scheme:



43. What is the identity of reagent / reactant (i)?

(A). HBr

(B). CH_3Br / $FeBr_3$

(C). limiting Br_2 / hv

(D). Excess Br_2 / heat

Solution:

- Substitution of an H in a cycloalkane by a Br

- A: No reaction; an alkene will react with HBr
- B: Friedel-Crafts alkylation conditions; require aromatic substrate
- C: Will result in partial substitution by a free radical process
- D: Will result in complete substitution by a free radical process

C is the correct answer

44. What is the identity of reagent / reactant (ii)?

(A). dil. NaOH (aq)

(B). conc. NaOH (aq) / Δ

(C). HCl (aq)

(D). H_3PO_4 (aq)

Solution:

- Substitution of a Br by an OH

- B: Elimination to form an alkene
- C: No reaction
- D: No reaction

A is the correct answer

45. What is the identity of reagent / reactant (iii)?

(A). $LiAlH_4$
(B). $NaBH_4$
(C). PCC
(D). O_3

Solution:

- Oxidation of a 2° OH to a ketone

- A: Very strong reducing agent
- B: Reducing agent
- C: Oxidizing agent
- D: Will cleave an alkene, to yield either aldehydes or carboxylic acids, depending upon the conditions.

C is the correct answer

46. What is the identity of reagent / reactant (iv)?

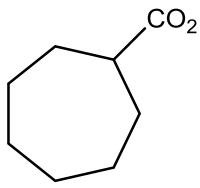
(A). $MgBr_2$
(B). Mg / Et_2O
(C). Mg / HCl (aq)
(D). Mg / Br_2 (g)

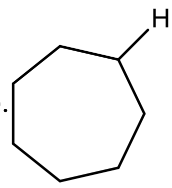
Solution:

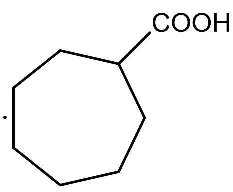
- Formation of a Grignard reagent from an alkyl bromide. Requires magnesium in the presence of an ethereal solvent.

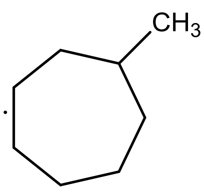
B is the correct answer

*47. What is the identity of Compound **C**?*

(A). 

(B). 

(C). 

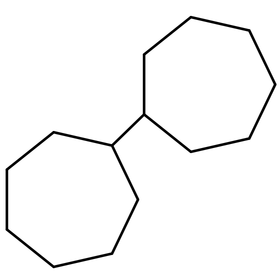
(D). 

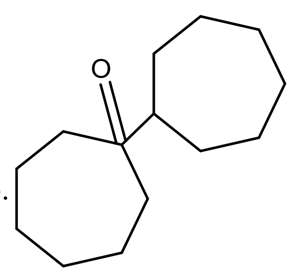
Solution:

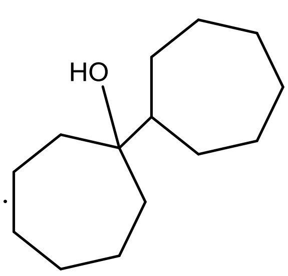
- Reaction of a Grignard reagent with CO_2 (g) will yield a carboxylate salt. Subsequent addition of H^+ (aq) results in a carboxylic acid.

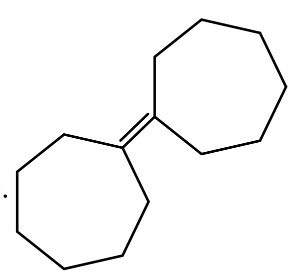
C is the correct answer

*48. What is the product that results from the reaction of Compound **A** with Compound **B***

(A). 

(B). 

(C). 

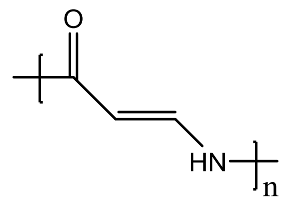
(D). 

Solution:

- Reaction of a Grignard reagent with a ketone yields a 3° alcohol

C is the correct answer

49. Examine the structure of the polymer shown below:



Which of the following accurately describes it?

(A). A polyalkene formed via an addition process

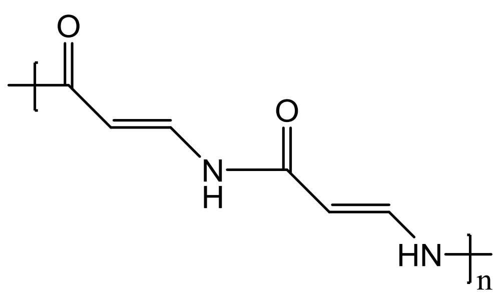
(B). A polyamide formed via an addition process

(C). A polyalkene formed via a substitution process

(D). A polyamide formed via a condensation process

Solution:

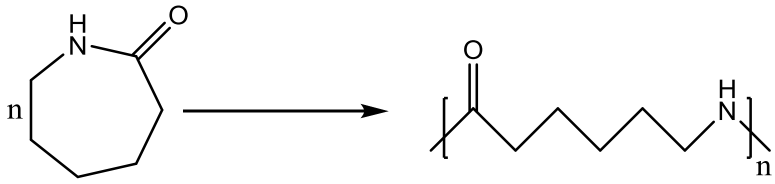
- Drawing out the extended structure:



- Each monomer residue is connected to the other via an amide linkage
- This amide linkage arises as a result of the reaction between an amine and an acid chloride (or carboxylic acid), accompanied by the elimination of a small molecule (either HCl or H_2O)
- The polymer can also be described as a polyalkene, but none of the options, (A) or (C), have the correct mechanism for its formation.

D is the correct answer

50. Consider the ring opening polymerization of caprolactam:



Which of the following polymers would you expect to have similar physical properties to the polymer above?

(A). Nylon-6,6
(B). PTFE
(C). PVC
(D). Cellulose

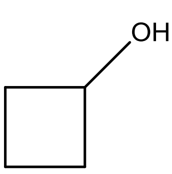
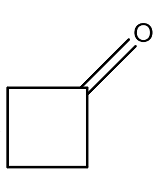
Solution:

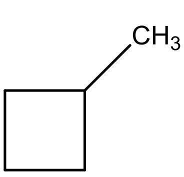
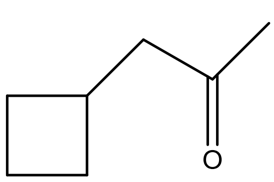
- The polymer with similar physical properties can be expected to have a similar structure.
- Polycaprolactam is a linear polyamide

- A: Linear polyamide
- B: Linear polyalkane with fluorine substituents
- C: Linear polyalkane with one chlorine substituent per monomer residue
- D: Polysaccharide

A is the correct answer

51. Which of the following compounds would be expected to undergo oxidation with $K_2Cr_2O_7$ / H^+ (aq)?

(A).  (B). 

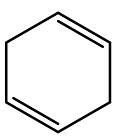
(C).  (D). 

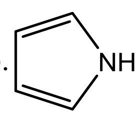
Solution:

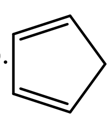
- $K_2Cr_2O_7$ / H^+ (aq) will react with compounds capable of undergoing oxidation: 1° and 2° alcohols, aldehydes
- A: 2° OH
- B: Ketone
- C: Alkane
- D: Ketone

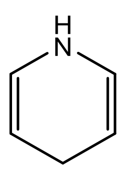
A is the correct answer

52. Which of the following compounds has delocalized π electrons over its entire structure?

(A). 

(B). 

(C). 

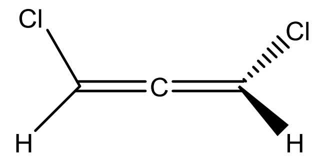
(D). 

Solution:

- A delocalized structure may be identified by the presence of alternating double and single bonds, or alternating double bonds with a lone pair of electrons.
- A: The two double bonds are separated by two sets of two single bonds
- B: Nitrogen has a lone pair of electrons
- C: The two double bonds are separated by two single bonds
- D: The two double bonds are separated by two single bonds

B is the correct answer

53. Examine the structure of the allene below:



Which of the following statements is / are true?

(I). The molecule is chiral

(II). The molecule has a chiral carbon

(III). The molecule exhibits cis/trans isomerism

(IV). The molecule has an alkyne structural isomer

(A). I and II only

(B). III and IV only

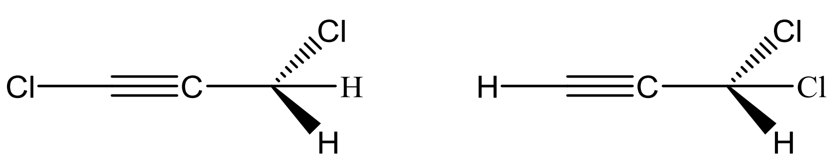
(C). I and IV only

(D). I, II and IV only

Solution:

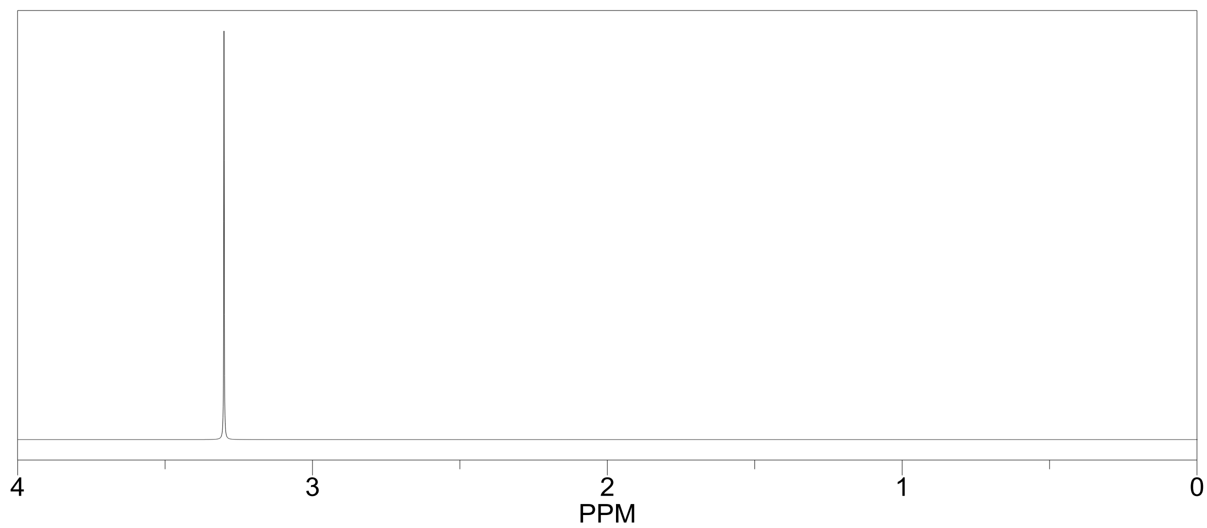
- A chiral compound is not defined by the presence of a chiral carbon.
- A chiral compound is one which has a non-superimposable mirror image

- I: This compound has a non-superimposable mirror image
- II: A chiral carbon is one with four different groups attached
- III: The non-terminal carbon of the double bond is also part of another double bond
- IV: Actually has two alkyne isomers:



C is the correct answer

54. Nuclear Magnetic Resonance (NMR) Spectroscopy is a powerful tool for the structural elucidation of unknown compounds. In ^{1}H NMR, protons which have identical chemical (and magnetic) properties will appear as a single peak in the NMR spectra. For example, the following is a low resolution spectra of dimethyl ether:

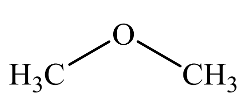


How many peaks would you expect to see in the NMR spectra of ethanol?

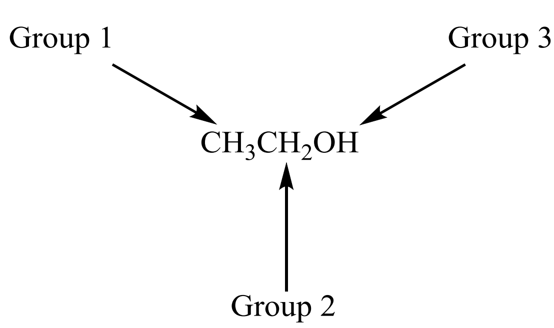
(A). 2
(B). 3
(C). 4
(D). 6

Solution:

- Consider the structure of dimethyl ether, it is a symmetrical molecule, with the two methyl groups indistinguishable from each other, hence the single peak observed:

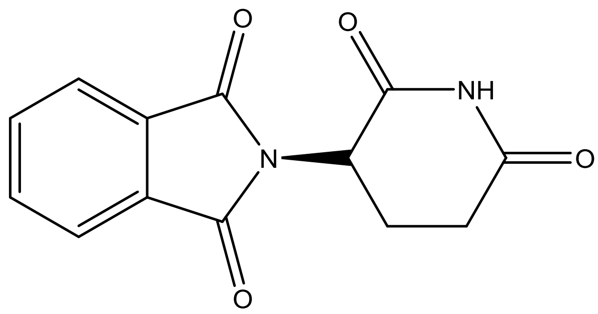


- Consider the structure of ethanol, there are three distinct groups of protons:

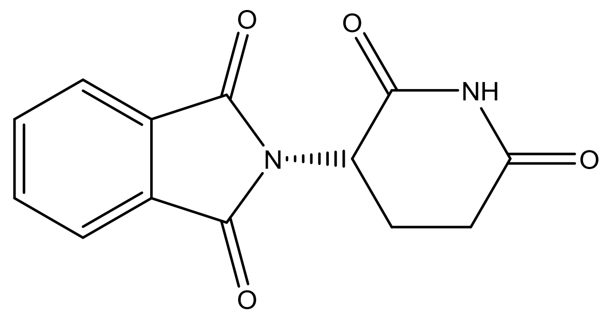


B is the correct answer

*55. The Thalidomide disaster occurred in the 1950s and resulted in 1000s of babies being born with severe birth defects. Isomer **C** was used for the treatment of morning sickness in pregnant women, while isomer **D** was responsible for the birth defects. However, even if a pregnant woman took exclusively isomer **C**, birth defects still arose.*



C



D

Which of the following statements is correct?

*I. **C** and **D** are structural isomers*
*II. **C** and **D** enantiomers*
*III. **C** is converted into a racemic mixture once ingested*
*IV. **C** has two chiral carbons*

(A). I only
(B). II only
(C). II and III only
(D). III and IV only

Solution:

- I: They are stereoisomers
- II: Yes, they are non-superimposable mirror images
- III: Explains how adverse effects were observed even if pure **C** was used
- IV: Has only one chiral carbon

C is the correct answer

Questions 56 - 60 refer to the following information:

*You are provided with two salts, labelled as **A**, and **B**.*

Salt	***A***	***B***
Appearance	*White*	*Pale violet*
Composition	*Simple salt: one cation and one anion*	*Double salt: two cations and one anion*

*56. A flame test on **A** yields a lilac colour. Which cation is present?*

(A). K^+
(B). Cu^{2+}
(C). Mn^{7+}
(D). Fe^{2+}

Solution:

- A: Lilac
- B: Green to blue-green
- C: Yellow-green
- D: Gold

A is the correct answer

*57. **A** forms a colourless solution when dissolved in water. Treating this solution with acidified silver nitrate followed by dilute ammonia results in a colourless solution once more. What is the identity of **A**?*

(A). KCl
(B). $FeCl_2$
(C). KI
(D). $FeCl_3$

Solution:

- A: Cl^- will form a precipitate with Ag^+; the resulting AgCl is soluble in dilute ammonia
- B: No K present; iron (II) solutions are typically green
- C: I^- will form a precipitate with Ag^+; the resulting AgI is insoluble in ammonia
- D: No K present; iron (III) solutions are typically orange-brown

A is the correct answer

*58. A solution of **B** yields an intense blood red colour with potassium thiocyanate solution. What ion must be present, based on this observation?*

(A). Fe^{2+}
(B). Fe^{3+}
(C). Cu^{2+}
(D). Mn^{2+}

Solution:

- Formation of a blood red solution with SCN^- (aq) is a confirmatory test for the presence of Fe^{3+}

$$Fe^{3+} (aq) + SCN^- (aq) \longrightarrow [FeSCN]^{2+} (aq)$$

B is the correct answer

59. Adding NaOH (aq) to a solution of ***B****, and warming, yields a colourless pungent gas. What ion is present, based on this observation?*

(A). NO_3^-
(B). Cl^-
(C). NH_4^+
(D). CO_3^{2-}

Solution:

- A: Requires Devarda's alloy to be present for ammonia to be liberated
- B: No gas liberated
- C: Liberates ammonia; stronger base displacing a weaker base from its salt
- D: No gas liberated

C is the correct answer

60. Adding acidified barium chloride solution to a solution of ***B*** *yields a white precipitate. What is the likely formula of* ***B****?*

(A). $NH_4Fe(SO_4)_2$
(B). $(NH_4)_2FeSO_4$
(C). $NH_4Fe(NO_3)_4$
(D). $NH_4Fe(NO_3)_3$

Solution:

- A white precipitate with acidified barium chloride is indicative of the presence of sulphate ions
- From questions 58 - 60, the ions present are: Fe^{3+}, NH_4^+, SO_4^{2-}
- B: Sum of the charges of the different ions does not lead to a neutral compound (as depicted)
- C: No nitrate present
- D: No nitrate present

A is the correct answer