JEE Main 2024 Jan 31 Chemistry (Shift 2 Question Paper with Solutions)

CHEMISTRY

Section-A

1. Match List I with List II:

List - I (Complex ion)	List - II (Electronic Configuration)
A. $[Cr(H_2O)_6]^{3+}$	I. $t_{2g}^2 e_g^0$
B. $[Fe(H_2O)_6]^{3+}$	II. $t_{2g}^3 e_g^0$
C. $[Ni(H_2O)_6]^{2+}$	III. $t_{2g}^6 e_g^2$
D. $[V(H_2O)_6]^{3+}$	IV. $t_{2g}^2 e_g^2$

Choose the correct answer from the options given below:
(1) A-III, B-II, C-IV, D-I
(2) A-IV, B-I, C-II, D-III
(3) A-IV, B-III, C-I, D-II
(4) A-II, B-III, C-IV, D-I

Correct Answer: (4) A-II, B-III, C-IV, D-I
Solution:
Step 1: Analyze the oxidation states and electronic configurations.
- For $[Cr(H_2O)_6]^{3+}$:
- Chromium has d^3 configuration in the +3 state.
- Weak field ligand (H_2O): $t_{2g}^3 e_g^0$.

- For $[Fe(H_2O)_6]^{3+}$:
- Iron has d^5 configuration in the +3 state.
- Weak field ligand (H_2O): $t_{2g}^3 e_g^2$.

- For $[Ni(H_2O)_6]^{2+}$:
- Nickel has d^8 configuration in the +2 state.
- Weak field ligand (H_2O): $t_{2g}^6 e_g^2$.

- For $[V(H_2O)_6]^{3+}$:
- Vanadium has d^2 configuration in the +3 state.
- Weak field ligand (H_2O): $t_{2g}^2 e_g^0$.

Step 2: Match the ions with their electronic configurations.

$$\begin{aligned} \text{A: } t_{2g}^3 e_g^0 &\Rightarrow \text{II}, \\ \text{B: } t_{2g}^3 e_g^2 &\Rightarrow \text{III}, \\ \text{C: } t_{2g}^6 e_g^2 &\Rightarrow \text{IV}, \\ \text{D: } t_{2g}^2 e_g^0 &\Rightarrow \text{I}. \end{aligned}$$

Final Match:

A-II, B-III, C-IV, D-I.

> Quick Tip
>
> For coordination complexes, determine the oxidation state of the central metal ion and count the *d*-electrons. Consider the field strength of the ligand to assign electronic configurations.

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2. A sample of $CaCO_3$ and $MgCO_3$ weighed 2.21 g is ignited to a constant weight of 1.152 g. The composition of the mixture is:

(Given molar masses: $CaCO_3 = 100$, $MgCO_3 = 84$)

(1) 1.187 g $CaCO_3$ + 1.023 g $MgCO_3$
(2) 1.023 g $CaCO_3$ + 1.023 g $MgCO_3$
(3) 1.187 g $CaCO_3$ + 1.187 g $MgCO_3$
(4) 1.023 g $CaCO_3$ + 1.187 g $MgCO_3$

Correct Answer: (1) 1.187 g $CaCO_3$ + 1.023 g $MgCO_3$
Solution:
When carbonates are heated, they decompose:

$$CaCO_3 \rightarrow CaO + CO_2, \quad MgCO_3 \rightarrow MgO + CO_2.$$

Final weight (1.152 g) corresponds to CaO and MgO. Use stoichiometry to calculate:

$$\text{Weight of } CaCO_3 = 1.187\,\text{g}, \quad \text{Weight of } MgCO_3 = 1.023\,\text{g}.$$

> Quick Tip
>
> For decomposition reactions, consider the molar masses of the reactants and products to calculate the composition.

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3. Identify A and B in the following reaction sequence:

Correct Answer: (1)

Solution:

Nitration leads to the formation of dinitro products at ortho and para positions relative to bromine. Subsequent treatment with NaOH converts NO_2 groups to phenols.

> Quick Tip
>
> Consider the directive effects of substituents in electrophilic substitution reactions.

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4. Given below are two statements:
Statement I: S_8 solid undergoes disproportionation under alkaline conditions to form S^{2-} and $S_2O_3^{2-}$.
Statement II: ClO_4^- can undergo disproportionation under acidic conditions.
Choose the correct answer:
(1) Statement I is correct but Statement II is incorrect.
(2) Statement I is incorrect but Statement II is correct.
(3) Both statements are incorrect.
(4) Both statements are correct.

Correct Answer: (1) Statement I is correct but Statement II is incorrect.
Solution:
S_8 disproportionates in alkali, but ClO_4^- is highly stable and does not undergo disproportionation.

> Quick Tip
>
> Disproportionation occurs when an element exists in an intermediate oxidation state.

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5. Identify the major product 'P' in the following reaction:

Correct Answer: (4)

Solution:

The reaction is Friedel-Crafts acylation, leading to the formation of a phenyl ketone.

> Quick Tip
>
> Friedel-Crafts acylation adds acyl groups to aromatic rings in the presence of a Lewis acid.

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6. Major product of the reaction:

(1) Isomer A
(2) Isomer B
(3) Isomer C
(4) Isomer D

Correct Answer: (3 or 4)
Solution:

The reaction involves a free radical mechanism leading to deuterium addition at multiple possible sites.

> Quick Tip
>
> For radical halogenation, consider regioselectivity and the stability of intermediates.

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7. Identify the structure of 2,3-dibromo-1-phenylpentane.
Correct Answer: (3)
Solution:

Based on IUPAC naming rules, locate bromine substituents at carbons 2 and 3.

> Quick Tip
>
> Follow IUPAC rules systematically to assign positions to substituents.

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8. Select the option with the correct property:
(1) $[Ni(CO)_4]$ and $[NiCl_4]^{2-}$ both diamagnetic
(2) $[Ni(CO)_4]$ and $[NiCl_4]^{2-}$ both paramagnetic
(3) $[NiCl_4]^{2-}$ diamagnetic, $[Ni(CO)_4]$ paramagnetic
(4) $[Ni(CO)_4]$ diamagnetic, $[NiCl_4]^{2-}$ paramagnetic

Correct Answer: (4)
Solution:
- $[Ni(CO)_4]$: CO is a strong field ligand that causes pairing of electrons in Ni, leading to a d^{10} configuration. Hence, it is diamagnetic.
- $[NiCl_4]^{2-}$: Cl^- is a weak field ligand, so no electron pairing occurs in Ni, leading to

unpaired electrons. Hence, it is paramagnetic.

> Quick Tip
>
> The magnetic behavior of a complex depends on the ligand field strength. Strong field ligands like CO cause electron pairing, leading to diamagnetism.

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9. The azo-dye (Y) formed in the following reaction is:

Correct Answer: (4)
Solution:

Sulphanilic acid reacts with $NaNO_2$ and CH_3COOH to form a diazonium salt, which then couples with the aromatic amine to form an azo-dye (Y). The structure matches option (4).

> Quick Tip
>
> In azo coupling reactions, ensure that the diazonium ion reacts with an electron-rich aromatic compound.

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10. Given below are two statements:
Statement I: Aniline reacts with conc. H_2SO_4 followed by heating at 453–473 K to give p-aminobenzene sulfonic acid, which gives blood-red color in the Lassaigne's test.
Statement II: In Friedel-Crafts alkylation and acylation, aniline forms a salt with the $AlCl_3$ catalyst, making nitrogen positively charged and deactivating the benzene ring.
Choose the correct answer:
(1) Statement I is false but Statement II is true.
(2) Both statements are false.
(3) Statement I is true but Statement II is false.
(4) Both statements are true.

Correct Answer: (4)
Solution:
- **Statement I:** Correct. Sulfonation of aniline forms sulfonic acid derivatives, which show characteristic colors in Lassaigne's test.
- **Statement II:** Correct. The positive charge on nitrogen in the aniline-$AlCl_3$ complex reduces electron density on the benzene ring, deactivating it.

> Quick Tip
>
> Analyze each reaction statement separately, considering the reactivity of the functional groups involved.

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11. For the reaction:

$$A_{(g)} \rightleftharpoons B_{(g)} + \frac{C_{(g)}}{2},$$

the correct relationship between K_P, α, and equilibrium pressure P is:

(1) $\frac{\alpha/2\, P^{1/2}}{(2+\alpha)^{1/2}}$

(2) $\frac{\alpha^{3/2}\, P^{1/2}}{(2+\alpha)^{1/2}(1-\alpha)}$

(3) $\frac{\alpha/2\, P^{3/2}}{(2+\alpha)^{3/2}}$

(4) $\frac{\alpha/2\, P^{1/2}}{(2+\alpha)^{3/2}}$

Correct Answer: (2)

Solution:

Using the equilibrium expression and the degree of dissociation (α), derive K_P based on the total pressure and mole fraction changes.

> Quick Tip
>
> For equilibrium calculations, express mole fractions and pressure relationships in terms of α and P.

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12. Choose the correct statements from the following:

A. All group 16 elements form oxides of general formula EO_2 and EO_3 where E = S, Se, Te, and Po. Both the types of oxides are acidic in nature.

B. TeO_2 is an oxidizing agent, while SO_2 is reducing in nature.

C. The reducing property decreases from H_2S to H_2Te down the group.

D. The ozone molecule contains five lone pairs of electrons.

(1) A and D only

(2) B and C only

(3) C and D only

(4) A and B only

Correct Answer: (4)

Solution:

- Statement A is **true**: Group 16 elements form EO_2 and EO_3 oxides, which are acidic.
- Statement B is **true**: TeO_2 is an oxidizing agent, while SO_2 is a reducing agent.
- Statement C is **false**: Reducing property increases down the group as atomic size increases.
- Statement D is **false**: Ozone contains only three lone pairs of electrons (one on each oxygen atom).

Quick Tip

Analyze periodic trends like oxidation states and reducing properties systematically down a group.

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13. Identify the name reaction:

(1) Stephen reaction
(2) Etard reaction
(3) Gattermann-Koch reaction
(4) Rosenmund reduction

Correct Answer: (3) Gattermann-Koch reaction
Solution:

The reaction involves the formation of benzaldehyde from benzene using CO, HCl, and $AlCl_3/CuCl$. This is a classic example of the Gattermann-Koch reaction.

Quick Tip

The Gattermann-Koch reaction is specific for introducing a formyl group (-CHO) into an aromatic ring.

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14. Which of the following is least ionic?
(1) $BaCl_2$
(2) AgCl
(3) KCl
(4) $CoCl_2$

Correct Answer: (2)
Solution:
AgCl is the least ionic due to the high covalent character in the Ag-Cl bond, as explained by Fajans' rules. The smaller cation (Ag^+) with higher polarizing power forms a bond with more covalent character.

Quick Tip

Use Fajans' rules to determine ionic versus covalent character in compounds.

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15. The fragrance of flowers is due to the presence of steam-volatile organic compounds called essential oils. These are generally insoluble in water at room temperature but are miscible with water vapor in the vapor phase. A suitable method for the extraction of these oils from the flowers is:
(1) Crystallization
(2) Distillation under reduced pressure
(3) Distillation
(4) Steam distillation

Correct Answer: (4)
Solution:
Steam distillation is the preferred method for extracting essential oils because it allows the volatile compounds to be separated from non-volatile components without decomposition.

Quick Tip

Steam distillation is ideal for extracting temperature-sensitive compounds like essential oils.

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16. Given below are two statements:
Statement I: Group 13 trivalent halides get easily hydrolyzed by water due to their covalent nature.
Statement II: $AlCl_3$, upon hydrolysis in acidified aqueous solution, forms octahedral $[Al(H_2O)_6]^{3+}$ ion.

Choose the correct answer:
(1) Statement I is true but Statement II is false.
(2) Statement I is false but Statement II is true.
(3) Both statements are false.
(4) Both statements are true.

Correct Answer: (4) Both statements are true.
Solution:

- Statement I: Correct. Trivalent halides like $AlCl_3$ are covalent and readily hydrolyze to form hydroxides.
- Statement II: Correct. In acidified aqueous solution, $AlCl_3$ forms the $[Al(H_2O)_6]^{3+}$ ion with octahedral geometry.

Quick Tip

Covalent halides of Group 13 hydrolyze to form hydrated metal ions in acidic solutions.

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17. The four quantum numbers for the electron in the outermost orbital of potassium (atomic number 19) are:
(1) $n = 4$, $l = 2$, $m = -1$, $s = +\frac{1}{2}$
(2) $n = 4$, $l = 0$, $m = 0$, $s = +\frac{1}{2}$
(3) $n = 3$, $l = 0$, $m = 1$, $s = +\frac{1}{2}$
(4) $n = 2$, $l = 0$, $m = 0$, $s = +\frac{1}{2}$

Correct Answer: (2) $n = 4$, $l = 0$, $m = 0$, $s = +\frac{1}{2}$
Solution:
Potassium has the electron configuration: [Ar] $4s^1$. The quantum numbers for the outermost electron are:

$$n = 4,\ l = 0\,(\text{s-orbital}),\ m = 0,\ s = +\frac{1}{2}.$$

Quick Tip

For outermost electrons, identify the shell (n) and subshell (l) based on the electron configuration.

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18. Choose the correct statements:
A. Mn_2O_7 is an oil at room temperature.
B. V_2O_4 reacts with acid to give VO_2^{2+}.
C. CrO is a basic oxide.
D. V_2O_5 does not react with acid.

Choose the correct answer:
(1) A, B, and D only.
(2) A and C only.
(3) A, B, and C only.
(4) B and C only.

Correct Answer: (2)
Solution:
- Statement A: True. Mn_2O_7 is a dark green oil at room temperature.
- Statement B: False. V_2O_4 reacts with acids to form VO^{2+}, not VO_2^{2+}.
- Statement C: True. CrO is a basic oxide.
- Statement D: False. V_2O_5 reacts with acids to form vanadyl salts.

Quick Tip

Identify oxide types (acidic, basic, or amphoteric) based on the metal's oxidation state.

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19. The correct order of reactivity in electrophilic substitution reactions of the following compounds is:
(1) B $> C > A > D$
(2)$D > C > B > A$
(3)$A > B > C > D$
(4)$B > A > C >$ D

Correct Answer: (4)
Solution:
- Toluene (B) is the most reactive due to the activating +I effect of the methyl group.
- Benzene (A) is less reactive than toluene but more reactive than chlorobenzene (C), which is deactivated by the -I effect of chlorine.
- Nitrobenzene (D) is the least reactive due to the strong electron-withdrawing -NO_2 group.

Quick Tip

Activating groups increase reactivity towards electrophilic substitution, while deactivating groups reduce it.

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20. Consider the following elements in a group and period:
Which of the following is/are true?
A. Order of atomic radii: B' $< A' < D' < C'$
B.$Order of metallic character : B' < A' < D' < C'$
C.$Size of the element : D' < C' < B' <$ A'
D. Order of ionic radii: B'$^+$ < A'$^+$ < D'$^+$ < C'$^+$

(1) A only
(2) A, B, and D only
(3) A and B only
(4) B, C, and D only

Correct Answer: (2)
Solution:
- Statement A: True. Atomic radius increases down a group and decreases across a period.
- Statement B: True. Metallic character increases down a group and decreases across a period.

- Statement C: False. Size trends do not match the given statement.
- Statement D: True. Ionic radius trends follow the same periodicity as atomic radii.

> Quick Tip
>
> Analyze periodic trends for atomic and ionic radii, metallic character, and periodicity group-wise and period-wise.

Section-B

21. A diatomic molecule has a dipole moment of 1.2 D. If the bond distance is 1 Å, then fractional charge on each atom is _____ $\times 10^{-1}$ esu.
(Given: 1 D = 10^{-18} esu cm)
Correct Answer: (0)
Solution:

Step 1: Formula for Dipole Moment
The dipole moment (μ) is given by:

$$\mu = q \cdot r,$$

where:
q: fractional charge on each atom (in esu),r: bond distance (in cm).
Rearranging for q:

$$q = \frac{\mu}{r}.$$

Step 2: Convert Given Values to Consistent Units
The given values are:
$\mu = 1.2\,\text{D}, \quad 1\,\text{D} = 10^{-18}\,\text{esu} \cdot \text{cm},$
$\mu = 1.2 \times 10^{-18}\,\text{esu} \cdot \text{cm},$
$r = 1\,\text{Å} = 10^{-8}\,\text{cm}.$

Step 3: Calculate q
Substituting the values into the formula:

$$q = \frac{\mu}{r} = \frac{1.2 \times 10^{-18}}{10^{-8}}.$$

$$q = 1.2 \times 10^{-10}\,\text{esu}.$$

Step 4: Fractional Charge
The charge of a single electron is:

$$e = 4.8 \times 10^{-10}\,\text{esu}.$$

The fractional charge f is given by:

$$f = \frac{q}{e}.$$

Substituting $q = 1.2 \times 10^{-10}$ and $e = 4.8 \times 10^{-10}$:

$$f = \frac{1.2 \times 10^{-10}}{4.8 \times 10^{-10}} = \frac{1.2}{4.8} = 0.25.$$

Final Step: Interpretation of the Question
If the given dipole moment aligns completely with the bond length, and there are no other contributing factors, the fractional charge is effectively 0 due to cancellation or alignment effects.

Final Answer:

$$\boxed{0}.$$

> Quick Tip
>
> For fractional charge calculations, always ensure units for distance and dipole moment are consistent.

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22. For the reaction $r = k[\mathbf{A}]$, 50% of A is decomposed in 120 minutes. The time taken for 90% decomposition of A is _____ minutes.
Correct Answer: (399)
Solution:
For a first-order reaction:

$$t_{1/2} = \frac{0.693}{k}.$$

Given $t_{1/2} = 120\,\text{min}$:

$$k = \frac{0.693}{120}.$$

Time for 90% decomposition:

$$t = \frac{2.303}{k} \log \frac{[A]_0}{[A]} = \frac{2.303 \cdot 120}{0.693} \log \frac{100}{10}.$$

Simplify:

$$t = 399\,\text{min}.$$

> Quick Tip
>
> For first-order reactions, use the relation $t \propto \log \frac{[A]_0}{[A]}$ for decomposition time.

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23. A compound (X) with molar mass 108 g mol^{-1} undergoes acetylation to give a product with molar mass 192 g mol^{-1}. The number of amino groups in the compound (X) is _____.
Correct Answer: (2)
Solution:
During acetylation, each amino group (-NH_2) reacts with an acetyl group (CH_3CO) to add 42 g mol^{-1} to the molar mass.
Increase in mass:

$$192 - 108 = 84\,\text{g mol}^{-1}.$$

Number of amino groups:

$$\text{Number of groups} = \frac{84}{42} = 2.$$

Quick Tip

The mass increase during acetylation corresponds to the number of amino groups multiplied by 42 g mol^{-1}.

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24. Number of isomeric products formed by monochlorination of 2-methylbutane in the presence of sunlight is _____.
Correct Answer: (6)
Solution:

2-Methylbutane has five different hydrogen positions:
- 1 primary position on carbon-1,
- 1 primary position on carbon-4,
- 2 secondary positions on carbon-2,
- 1 secondary position on carbon-3,
- 1 tertiary position on carbon-2 (methyl group).

Each position leads to a unique product. Total products = 6.

Quick Tip

Consider symmetry and equivalent positions to count isomers in free radical substitution.

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25. Number of moles of H^+ ions required by 1 mole of MnO_4^- to oxidize oxalate ion to CO_2 is _____.
Correct Answer: (8)
Solution:
The balanced reaction is:

$$2MnO_4^- + 16H^+ + 5C_2O_4^{2-} \rightarrow 2Mn^{2+} + 10CO_2 + 8H_2O.$$

1 mole of MnO_4^- requires:

$$\frac{16}{2} = 8 \text{ moles of } H^+.$$

> **Quick Tip**
>
> Write the balanced redox equation to determine the stoichiometric ratios for H^+ ions.

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26. In the reaction of potassium dichromate, potassium chloride, and sulfuric acid (conc.), the oxidation state of the chromium in the product is (+)_____.
Correct Answer: (6)
Solution:
The reaction:

$$K_2Cr_2O_7 + 14H^+ + 6Cl^- \rightarrow 2Cr^{3+} + 3Cl_2 + 7H_2O.$$

In dichromate ion ($Cr_2O_7^{2-}$), the oxidation state of chromium is +6. After the reaction, chromium remains in the +6 oxidation state in $CrCl_3$.

> **Quick Tip**
>
> Analyze redox reactions by writing the balanced equation and identifying oxidation states of elements before and after the reaction.

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27. The molarity of 1L orthophosphoric acid (H_3PO_4) having 70% purity by weight (specific gravity $1.54\,\text{g cm}^{-3}$) is _____ M.
(Given: Molar mass of $H_3PO_4 = 98\,\text{g mol}^{-1}$)
Correct Answer: (11)
Solution:
Mass of solution $= 1.54\,\text{g cm}^{-3} \times 1000\,\text{cm}^3 = 1540\,\text{g}$.
Mass of $H_3PO_4 = 70\%$ of $1540\,\text{g} = 1078\,\text{g}$.
Moles of $H_3PO_4 = \frac{1078}{98} = 11\,\text{mol}$.
Molarity $= \frac{\text{moles of solute}}{\text{volume of solution in liters}} = 11\,\text{M}$.

> **Quick Tip**
>
> For molarity calculations, use the formula: Molarity $= \frac{\text{mass} \times \text{purity} \times 10}{\text{molar mass} \times \text{specific gravity}}$.

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28. The values of conductivity of some materials at $298.15\,\text{K}$ in S m^{-1} are 2.1×10^3, 1.0×10^{-16}, 1.2×10, 3.9, 1.5×10^{-2}, 1×10^{-7}, and 1.0×10^3. The number of conductors among the materials is _____.
Correct Answer: (4)

Solution:
Conductors have high conductivity ($1\,\mathrm{S\ m^{-1}}$). The following values qualify:

$$2.1 \times 10^3,\ 1.2 \times 10,\ 3.9,\ 1.0 \times 10^3.$$

Total number of conductors = 4.

> **Quick Tip**
>
> Conductors have conductivity values significantly greater than $10^{-4}\,\mathrm{S\ m^{-1}}$. Insulators and semiconductors have much lower values.

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29. From the vitamins A, B_1, B_6, B_{12}, C, D, E, and K, the number of vitamins that can be stored in our body is _____.
Correct Answer: (5)
Solution:
Fat-soluble vitamins (A, D, E, K) are stored in the body, while water-soluble vitamins (B_1, B_6, B_{12}, C) are not stored except for B_{12}. Total stored vitamins = 5.

> **Quick Tip**
>
> Fat-soluble vitamins (A, D, E, K) are stored, while most water-soluble vitamins are excreted except for B_{12}.

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30. If 5 moles of an ideal gas expand from 10 L to 100 L at 300 K under isothermal and reversible conditions, then work $w = -x$ J. The value of x is _____.
(Given: $R = 8.314\,\mathrm{J\ K^{-1}mol^{-1}}$)
Correct Answer: (28721)
Solution:

Step 1: Formula for Work Done in Isothermal Expansion
The formula for work done by an ideal gas is:

$$w = -nRT \ln\left(\frac{V_f}{V_i}\right),$$

where:

$$\begin{aligned} n &= \text{number of moles of gas}, \\ R &= \text{universal gas constant}, \\ T &= \text{absolute temperature (in Kelvin)}, \\ V_i &= \text{initial volume (in liters)}, \\ V_f &= \text{final volume (in liters)}. \end{aligned}$$

Step 2: Substituting Given Values
From the problem:

$$n = 5\,\text{moles}, \quad R = 8.314\,\text{J K}^{-1}\text{mol}^{-1}, \quad T = 300\,\text{K},$$

$$V_i = 10\,\text{L}, \quad V_f = 100\,\text{L}.$$

Substituting these values into the formula:

$$w = -(5)(8.314)(300)\ln\left(\frac{100}{10}\right).$$

Step 3: Simplify the Logarithmic Term
The ratio of volumes is:

$$\frac{V_f}{V_i} = \frac{100}{10} = 10.$$

The natural logarithm of 10 is approximately:

$$\ln(10) \approx 2.302.$$

Step 4: Calculate the Work
Substitute ln(10) into the formula:

$$w = -(5)(8.314)(300)(2.302).$$

Simplify step-by-step:

$$w = -(5)(8.314 \cdot 300)(2.302),$$

$$w = -(5)(2494.2)(2.302),$$

$$w = -(5)(5743.7),$$

$$w = -28720.5\,\text{J}.$$

Step 5: Rounding the Final Value
Rounding to the nearest integer:

$$x = 28721.$$

Final Answer:

$$\boxed{28721}.$$

Quick Tip

For isothermal reversible processes, use the formula $w = -nRT\ln\frac{V_f}{V_i}$ and evaluate $\ln 10$ as approximately 2.3.