I.2 Chemical Bonding

Civil Services 2016–2026: **35** parts, **340** marks · IFoS 2016–2025: **23** parts, **211** marks

Syllabus. Ionic bond, characteristics of ionic compounds, lattice energy, Born-Haber cycle; covalent bond and its general characteristics, polarities of bonds in molecules and their dipole moments; valence bond theory, concept of resonance and resonance energy; molecular orbital theory (LCAO method); bonding in H_2^+, H_2, He_2^+ to Ne_2, NO, CO, HF and CN^-; comparison of valence bond and molecular orbital theories, bond order, bond strength and bond length.

Marks	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026
CSE	25	35	25	40	40	30	30	30	25	30	30
IFoS	25	10	8	10	23	18	33	33	23	28	

How to use this chapter. Read every question once and mark the ones that repeat. Pick three, write them by hand against the clock (about 7 minutes for 10 marks), then compare with the model answers on vkcscience.com.

2026

CSE 2026 · Q5(b) cis- and trans-dichloroethylene from dipole moments [5 marks]

Distinguish between *cis*- and *trans*-dichloroethylene by using dipole moments.

CSE 2026 · Q5(c) Resonance structures of the nitrate ion [5 marks]

Provide the resonance structures with formal charges for the nitrate ion.

CSE 2026 · Q6(a) Lewis structures and VSEPR shapes of SO_2, I_3^-, SF_4, BrF_5, XeF_4; MO diagram of F_2; bond order and magnetism [20 marks]

(i) Predict the Lewis structures and geometry of the following as per VSEPR theory :
(1) SO_2, (2) I_3^-, (3) SF_4, (4) BrF_5, (5) XeF_4

(ii) Draw the molecular orbital diagram for F_2 molecule, and mention its bond order and magnetic behaviour.

2025

CSE 2025 · Q1(b) Born–Haber cycle for NaCl at 298 K [5 marks]

Construct the Born-Haber cycle for the formation of sodium chloride crystal at 298 K from the elements in their normal states of existence. Mention the names of the involving processes. Indicate which of them are energy demanding and which are energy evolving.

CSE 2025 · Q1(f) Ascending order of dipole moment: NH_3, NF_3, H_2O [5 marks]

Arrange the following molecules in the ascending order of their dipole moment values. Justify your answer.
NH_3, NF_3 and H_2O

CSE 2025 · Q4(a) MO diagram of NO; NO and NO^+; NO as a radical [20 marks]

Draw the molecular orbital (MO) diagram of NO molecule. The experimental bond dissociation energy of NO is 626 kJ mol^{-1} while that of NO^+ is 1047 kJ mol^{-1} — rationalize it.

NO can also act as a reactive radical — how?

IFoS 2025 · Q1(a) Equivalent bonds in nitrate [8 marks]

The observed nitrogen-oxygen bond length in nitrate ion is 1.21 Å. However, the calculated bond lengths for N–O and N = O bonds are 1.36 Å and 1.15 Å respectively. Account for this with requisite structures.

IFoS 2025 · Q2(b)(ii) Dissociation energies of dioxygen species [10 marks]

(ii) The energies (in kJ mol^{-1}) necessary to dissociate one O atom from different dioxygen species are reported as 642, 494, 394 and 210. Correlate these values with the species O_2^{2-}, O_2^{1-}, O_2 and O_2^{1+}. Explain in the light of molecular orbital theory. 10

IFoS 2025 · Q2(c) Ordering molecular dipoles; Bonding and magnetism of B_2 [10 marks]

(i) Arrange the following molecules in the increasing order of their dipole moment values. Justify your answer: NH_3, NF_3, H_2O 5

(ii) "B_2 has a bond order of one and it is paramagnetic." Substantiate the statement. 5

2024

CSE 2024 · Q1(a)(ii) Lattice energies of NaBr and NaI above the calculated values [5 marks]

(ii) Sodium bromide and sodium iodide have higher lattice energies than expected from theoretical calculations. Justify. *5*

CSE 2024 · Q2(b) Bond order of O_2, O_2^-, O_2^{2-} and O_2^+; Molecular orbital diagram of CO [20 marks]

(i) Calculate the bond order for the following:
(I) Oxygen (II) Superoxide (III) Peroxide (IV) Dioxygenyl ion
Which will have the highest stability? *10*

(ii) Draw the molecular orbital diagram for CO. *10*

IFoS 2024 · Q5(a) Solubility of alkali-metal halides [8 marks]

Explain why LiF is less soluble than LiI in water. Using your explanation, state, between CsF and CsI, which one would be more soluble in water.

IFoS 2024 · Q7(a) Why CO and N_2 differ as ligands [15 marks]

N_2 and CO are isoelectronic but their Molecular Orbitals (MOs) are different from each other. Drawing the MOs of both the molecules, state with reasons the differences of these two MOs and their coordinating ability.

2023

CSE 2023 · Q1(b) Lewis structures of $[Br_3]^-$ and thiourea; the most polar bond [10 marks]

Draw Lewis dot structure of $[Br_3]^-$ and H_2NCSNH_2 (central C atom is bonded to both the N atoms and to the S atom). Does thiourea contain polar bonds? If yes, which is the most polar bond?

CSE 2023 · Q3(a) Electronic and molecular geometry of BrF_5 and $[ICl_2]^-$ [10 marks]

Determine the electronic and molecular geometry of $[BrF_5]$ and $[ICl_2]^-$ interhalogen compounds.

CSE 2023 · Q5(c) Geometry and hybridisation of carbon in cytosine and thymine [10 marks]

Assign a geometry and hybridization to each carbon atom present in cytosine and thymine nucleotide bases.

IFoS 2023 · Q1(b) Formation enthalpy of lithium fluoride [8 marks]

Use the Born-Haber cycle to calculate the enthalpy of formation of LiF. Use the following data in the calculation:

$$\Delta H_{sub} = 161 \text{ kJ/mol}, \quad \Delta H_{dis} = 79 \text{ kJ/mol}, \quad \Delta H_{ion} = 531 \text{ kJ/mol}$$
$$\Delta H_{EA} = -328 \text{ kJ/mol}, \quad \Delta H_{xtal} = -1239 \text{ kJ/mol}$$

IFoS 2023 · Q2(b) NO and the nitrosonium ion [15 marks]

Draw the molecular orbital diagram for NO molecule. Predict the magnetic behaviour and bond order. Comment on the stability of NO^+ ion.

IFoS 2023 · Q2(c) Bond orders of oxygen and carbon monoxide [10 marks]

Calculate the bond order of the following molecules: O_2 and CO

2022

CSE 2022 · Q1(b) Non-bonding interactions between orbitals of A and B [10 marks]

Consider the following atomic orbitals of *A* and *B* atoms in a heterodiatomic *AB* molecule.

A	B
$2s$	$2p_y$
$2p_x$	$2p_z$

Depict the nonbonding interactions among these atomic orbitals with reason.

CSE 2022 · Q3(a) The least stable of OCN^-, ONC^- and SCN^- [10 marks]

Identify the least stable ion of the following ions and justify your answer.

OCN^- ONC^- SCN^-

CSE 2022 · Q4(e) Percentage ionic character of the Br–Cl bond [10 marks]

Determine the percentage of ionic character (bond polarity) of BrCl and comment on the nature of Br–Cl bond.
(Dipole moment of BrCl = 1.42×10^{-30} cm,
bond length, $d_{Br-Cl} = 214 \times 10^{-14}$ m,
charge of an electron = 1.6×10^{-19} C)

IFoS 2022 · Q1(b) Dipole moments of ammonia and nitrogen trifluoride [8 marks]

Between NH_3 and NF_3, which one possesses higher dipole moment? Explain.

IFoS 2022 · Q2(b) Second ionisation energy of sodium [15 marks]

The lattice energies (U_0) for the formation of NaCl and hypothetical $NaCl_2$ from Cl_2 gas and Na-metal are -757 kJ mol^{-1} and -2180 kJ mol^{-1} and their enthalpies of formation (ΔH_f) are -381 kJ mol^{-1} and $+2530$ kJ mol^{-1}, respectively. From these data, calculate the 2nd ionization energy of Na.
(Given that ΔH_{EA} for Cl and $\Delta H_{(\text{atomization of } Cl_2 \longrightarrow 2\,Cl)}$ are -349 kJ mol^{-1} and $+242$ kJ mol^{-1}, respectively)

IFoS 2022 · Q3(a) Molecular orbitals of linear BeH_2 [10 marks]

Draw the MO diagram of BeH_2. Sketch the electron density boundary surface for $\sigma_g(\psi_1)$ and $\sigma_u^*(\psi_6)$. Show the combination of atomic orbitals of H atoms and Be atom for the σ_g and σ_u^* orbitals.

2021

CSE 2021 · Q1(b) Born–Haber cycle: can $NaCl_2$ form? [10 marks]

The enthalpy of formation of an ionic compound can be calculated with accuracy by Born-Haber cycle. Predict, giving valid reasons, the possibility of formation of $NaCl_2$ salt. The following thermodynamic data are given for NaCl and $NaCl_2$:

NaCl	$NaCl_2$
$U_0 = -757$ kJ mol^{-1}	$U_0 = -2155$ kJ mol^{-1}
$\Delta H_{(IE)} = +495$ kJ mol^{-1}	$\Delta H_{(IE_2)} = +4561$ kJ mol^{-1}
$\Delta H_{(EA)} = -348$ kJ mol^{-1}	
$\frac{1}{2}\Delta H_{(diss)} = +121$ kJ mol^{-1}	
$\Delta H_{(sub)} = +108$ kJ mol^{-1}	

CSE 2021 · Q2(b) Shapes of the sp^3d, sp^3d^2, dsp^2 and sd^3 hybrids and the d orbitals used [20 marks]

Draw the geometrical arrangements for the following hybridized systems and identify the type of *d*-orbitals involved in each system:

$$sp^3d, \quad sp^3d^2, \quad dsp^2, \quad sd^3$$

IFoS 2021 · Q1(c) C–F and C–I potential-energy curves [8 marks]

Draw an energy level diagram (with energy on the y-axis and internuclear distance *r*, on the x-axis) plotting a C – F and C – I bond. You should include numbers on y-axis. No numbers are needed on x-axis, but relative distances should be correct. Bond dissociation energies are 238 kJ/mol and 484 kJ/mol for C – I and C – F, respectively.

IFoS 2021 · Q2(b) Dissociation of an ionic KF molecule [10 marks]

The ionic bond length for KF is 0.217 nm. Calculate the energy (in units of kJ/mol) required to dissociate a single molecule of KF into neutral atoms, K and F, using information provided below. Assume that potassium and fluorine ions are point charges.

Element	Ionization Energy	Electron Affinity
Potassium (K)	418 kJ/mol	48 kJ/mol
Fluorine (F)	1680 kJ/mol	328 kJ/mol

2020

CSE 2020 · Q1(a) Dissociation energies of N_2^+ and O_2^+ [10 marks]

The dissociation energy decreases on going from N_2 to N_2^+ whereas it increases on going from O_2 to O_2^+. Explain.

CSE 2020 · Q3(c) Linear SiH_3-NCS, bent CH_3-NCS [10 marks]

Why SiH_3-NCS is linear, whereas CH_3-NCS is bent?

CSE 2020 · Q3(d) Hybridisation and shapes of SO_3 and PF_5 [10 marks]

What type of hybridization is expected for SO_3^- and PF_5? Explain the shapes of these molecules.

CSE 2020 · Q4(a) LCAO; bonding, non-bonding and antibonding orbitals of H_2 [10 marks]

What is LCAO? What are bonding, non-bonding and anti-bonding orbitals? Illustrate with a suitable diagram with an example of H_2 molecule within the framework of molecular orbital (MO) theory.

IFoS 2020 · Q1(b) O–O bond lengths in O_2, O_2^- and O_2^{2-} from MO theory [8 marks]

The O–O bond distances in O_2, O_2^- and O_2^{2-} are found respectively to be 1·21 Å, 1·28 Å and 1·49 Å. Justify in the light of molecular orbital energy level diagram.

IFoS 2020 · Q4(b) Born–Haber cycle of NaCl [15 marks]

What is the Born-Haber cycle? Construct the Born-Haber cycle of NaCl mentioning the names of the various parameters involved in it.

2019

CSE 2019 · Q1(a)(i) Covalent character of NaBr and $MgBr_2$ [5 marks]

In which of the following compounds do the bonds have greater covalent character :
(a) NaBr or (b) $MgBr_2$?
Give reasons to support your answer.

CSE 2019 · Q1(a)(ii) Order of lattice energies: LiCl, KCl, KBr, $MgBr_2$ [5 marks]

Order the following compounds according to their expected lattice energies :
LiCl, KCl, KBr, $MgBr_2$.
Give reasons to support your answer.

CSE 2019 · Q2(a) Dipole moments of NOF and NO_2F; resonance in NO_2F [20 marks]

Of the two compounds NOF and NO_2F, one has a resultant dipole moment of μ = 1.81 D, and the other, μ = 0.47 D. Which dipole moment do you predict for each compound? Explain.
Also write resonance structures of NO_2F and identify the dominant structure.

CSE 2019 · Q7(c) Why N_2^+ is weaker but O_2^+ stronger than the neutral molecule [10 marks]

When an electron is removed from an N_2 molecule, forming N_2^+ ion, the bond between the N atoms is weakened. When an O_2 molecule is similarly ionized to O_2^+, the bond between O atoms is strengthened. Explain this difference.

IFoS 2019 · Q4(b) Longest bond among CN^+, CN, CN^-, NO^+; σ and π bonds in TCNE [10 marks]

(i) Which one of the following species would you expect to have the longest bond length?
A – CN^+
B – CN
C – CN^-
D – NO^+

(ii) How many σ and π bonds are there in tetracyanoethylene molecule? 5+5=10

2018

CSE 2018 · Q1(d)(i) BeF_2 linear, SF_2 angular [5 marks]

Explain the following on the basis of VBT and hybridization:
(i) BeF_2 is linear whereas SF_2 is angular.

CSE 2018 · Q1(d)(ii) P forms PCl_3 and PCl_5; N forms only NCl_3 [5 marks]

(ii) P forms two chlorides PCl_5 and PCl_3 whereas N forms only one NCl_3.

CSE 2018 · Q2(c) Bond orders of H_2^+, Ne_2, CN^-, NO and HF; order of stability [15 marks]

Calculate the bond order for the following molecules/ions. Arrange them as per the increasing order of their stability. Give reasons.
(i) H_2^+ (ii) Ne_2 (iii) CN^- (iv) NO (v) HF

IFoS 2018 · Q1(b) Dipole moments of ortho- and meta-dichlorobenzene [8 marks]

Estimate the ratio of the electric dipole moments of *ortho* and *meta* dichlorobenzenes.

2017

CSE 2017 · Q1(a) Resonance energy; resonance in the carbonate ion [10 marks]

What is resonance energy? What are the conditions which permit structures to have resonance? Discuss resonance taking the example of CO_3^{2-} ion.

CSE 2017 · Q4(b) Paramagnetism of NO from its MO diagram [10 marks]

Explain the paramagnetism of NO with its molecular orbital diagram.

CSE 2017 · Q4(c) Two lone pairs on Xe in XeF_4 from valence bond theory [15 marks]

Using valence bond theory justify the presence of two lone electron pairs in XeF_4.

IFoS 2017 · Q4(a) O–O bond lengths in O_2, O_2^- and O_2^{2-} from MO theory [10 marks]

Considering molecular-orbital energy level diagram, justify the O – O bond distances in O_2, O_2^- and O_2^{2-} as 1·21, 1·28 and 1·49 Å, respectively.

2016

CSE 2016 · Q1(a)(i) Bond angles of CH_4, NH_3 and H_2O [5 marks]

The bond angles in CH_4, NH_3 and H_2O molecules are 109.5°, 107° and 104.5° respectively. Explain.

CSE 2016 · Q1(a)(ii) Dipole moments of BF_3 and PF_3 [5 marks]

Comment on the dipole moments of BF_3 and PF_3 molecules.

CSE 2016 · Q2(a)(i) MO diagram of NO; NO^+, CN^- and CO; bond order of NO and NO^+ [15 marks]

Draw the molecular orbital diagram of NO molecule. Show that NO^+, CN^- and CO are isoelectronic, and the bond order of NO is lower than that of NO^+.

IFoS 2016 · Q1(a)(i) Bond angle of F_2O smaller than that of H_2O [5 marks]

Explain why the bond angle in F_2O is smaller than that in H_2O;

IFoS 2016 · Q2(a)(i) Dipole moments of CF_4 and CH_2F_2 [5 marks]

Explain the following: The dipole moment of CF_4 is less than that of CH_2F_2.

IFoS 2016 · Q2(a)(ii) CO_2 linear, SO_2 bent [5 marks]

Explain the following: Carbon dioxide has a linear structure whereas sulphur dioxide is a bend molecule.

IFoS 2016 · Q2(a)(iii) Bond order of NO and NO^+; magnetic behaviour [10 marks]

Explain the following: The bond order of NO is lower than that of NO^+. Comment on their magnetic behaviour.