LOGIC BLOOM · CHEMISTRY · CLASS 11

Chemical Bonding & Molecular Structure

Tier 1 for **both** NEET and JEE · Built to JEE Advanced depth

The chapter the rest of Chemistry stands on. Shapes, hybridisation and molecular orbitals, each built so you can predict an answer rather than recall it, with the comparison questions examiners keep returning to worked in full.

8 Sections | 10 Diagrams | 14 Worked Questions | NEET Marked | Fact Sheet

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Contents

0 How to Read This Set

Chemical Bonding is Tier 1 for **both** exams. So this set is built to JEE Advanced depth. Each section carries a badge. It tells a NEET student what they still need.

IN NEET AND JEE	Octet and its failures, ionic character, bond parameters, resonance, VSEPR, hybridisation, dipole moment, hydrogen bonding.
JEE MAIN AND ADVANCED	Molecular orbital theory in full, bond order comparisons, magnetic behaviour of diatomics.
JEE ADVANCED MAINLY	Back bonding, Bent's rule, and the finer bond-angle comparisons.

THINK IT THROUGH

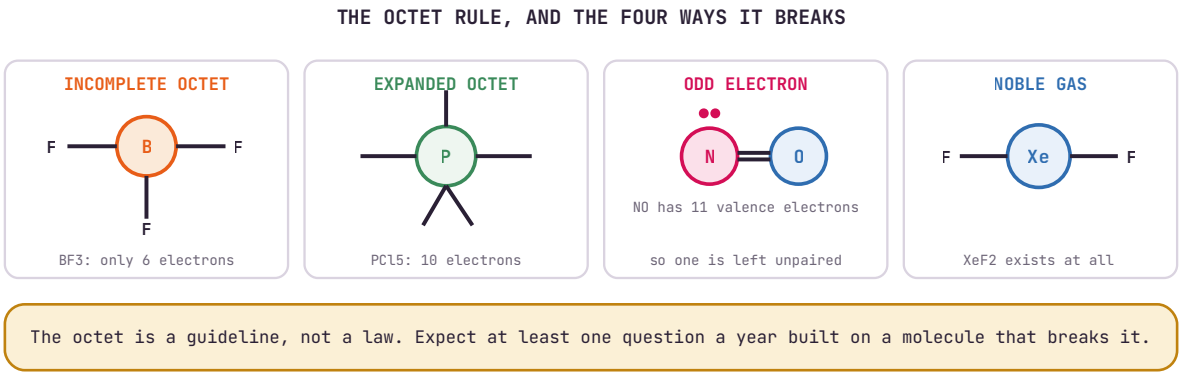
THE ONE HABIT THAT CARRIES THE WHOLE CHAPTER

Almost every question here is a **comparison**. Which bond is longer? Which molecule is more polar? Which is more stable? So do not memorise molecules one at a time. Learn the rule that puts them in order. Then apply it. Counting the steric number answers more questions than any list. So does counting bonding electrons minus antibonding ones.

1 Why Atoms Bond

IN NEET AND JEE

Atoms combine to reach a lower energy. The **octet rule** works well for the first two short periods. The interesting questions come from where it fails.



Four standard exceptions. Each one has been the subject of an exam question in its own right.

Incomplete octet	central atom with fewer than eight: $BeCl_2$, BF_3, $AlCl_3$
Expanded octet	period 3 onwards can use d orbitals: PCl_5, SF_6, IF_7
Odd electron	an unpaired electron remains: NO, NO_2, ClO_2
Formal charge	a way of choosing between Lewis structures; the best one has formal charges nearest zero

TRAP ALERT

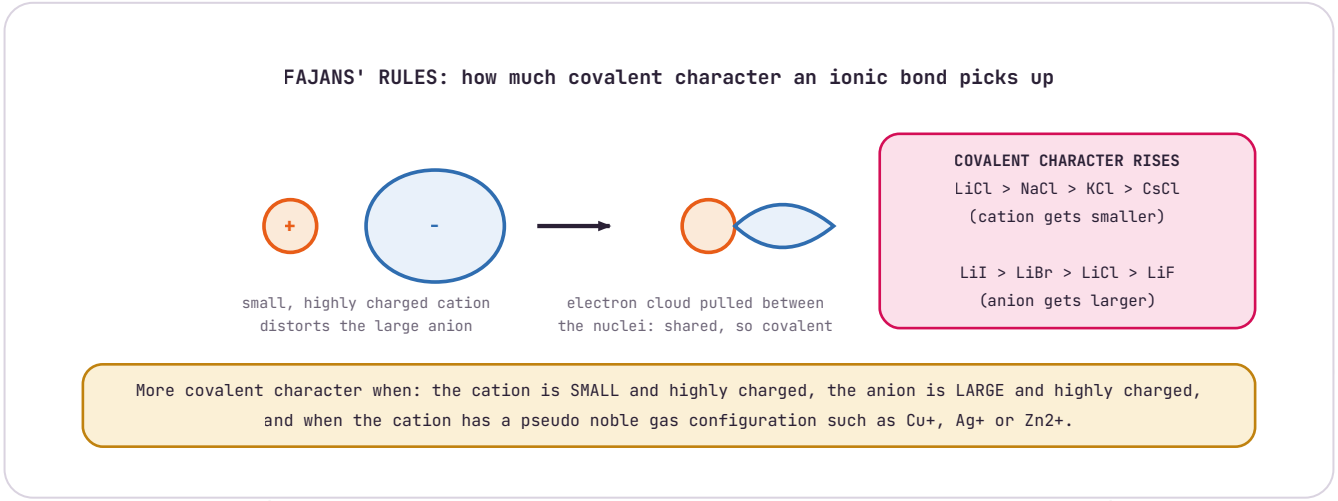
⚠ FORMAL CHARGE IS A BOOKKEEPING DEVICE, NOT A REAL CHARGE

Formal charge = valence electrons − non-bonding electrons − half the bonding electrons. Use it to rank possible structures. The best one has the smallest charges. Any negative charge should sit on the most electronegative atom. It does not tell you where the electrons really are.

2 The Ionic Bond

IN NEET AND JEE

Electrons transfer completely. The ions are then held together by electrostatic attraction. But no bond is purely ionic. Questions almost always ask **how much covalent character** has crept in.



A small, highly charged cation distorts a large anion. That distortion is covalent character.

★ FAJANS' RULES

Covalent character rises with a **smaller cation**. It rises with a **larger anion**. It rises with a **higher charge** on either ion. It also rises when the cation has a **pseudo noble gas** shell, such as Cu^{+}, Ag^{+} or Zn^{2+}.

Lattice enthalpy	energy released when gaseous ions form one mole of solid; it rises with higher charge and smaller ions
Born-Haber cycle	applies Hess's law to obtain lattice enthalpy, which cannot be measured directly
Melting point	tracks lattice enthalpy, so MgO melts far above NaCl (higher charges, smaller ions)
Solubility	generally falls as covalent character rises, which is why AgCl is insoluble but NaCl is not

MYTH CHECK

MYTH

Ionic and covalent are two separate kinds of bond, and every compound is one or the other.

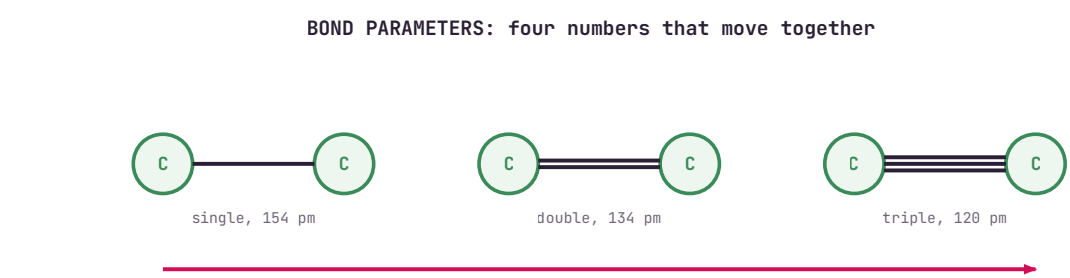
THE SCIENCE

They are the two ends of one continuous scale. Every ionic bond has some covalent character (Fajans) and every bond between unlike atoms has some ionic character. Asking *how much* is the right question; asking *which one* usually is not.

3 The Covalent Bond

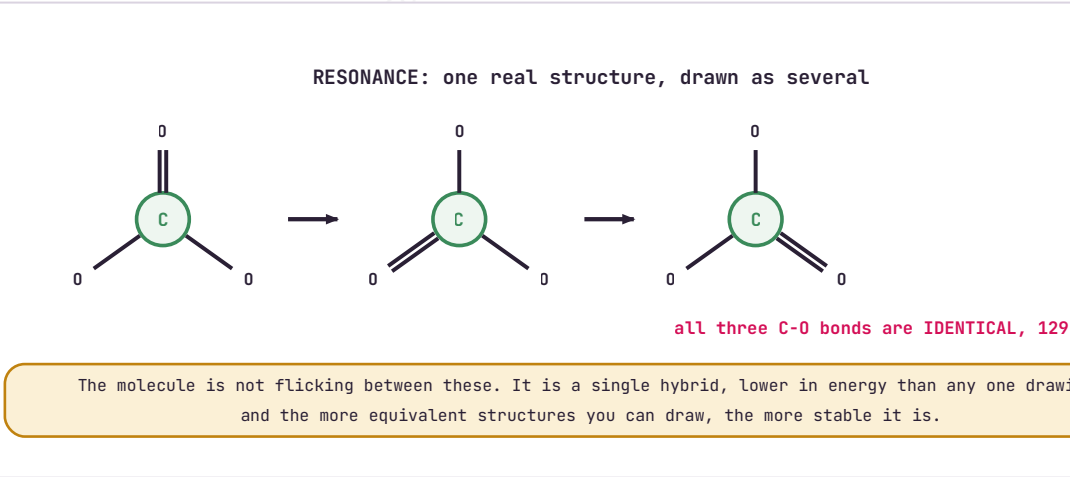
IN NEET AND JEE

Shared pairs. Four measurable parameters describe the result, and they all move together in a way you can reason from.



Higher bond order means shorter and stronger. This single trend answers a surprising number of questions.

Bond length	falls as bond order rises and as the atoms get smaller
Bond enthalpy	rises with bond order; it is the energy needed to break one mole of bonds in the gas phase
Bond angle	set by the geometry, then squeezed by lone pairs
Bond order	number of shared pairs; in molecular orbital terms, half of bonding minus antibonding



Carbonate. All three C-O bonds are identical in length, which no single Lewis structure can show.

TRAP ALERT

⚠ RESONANCE IS NOT OSCILLATION

The molecule does not flip between the drawings. It is one structure, called the resonance hybrid. It is **more stable** than any single drawing. That extra stability is the resonance energy. It grows with the number of equivalent structures you can draw.

▶ PLAY

BOND DIAGRAMS STILL ABSTRACT?

Build the molecule and watch the bond lengths settle.

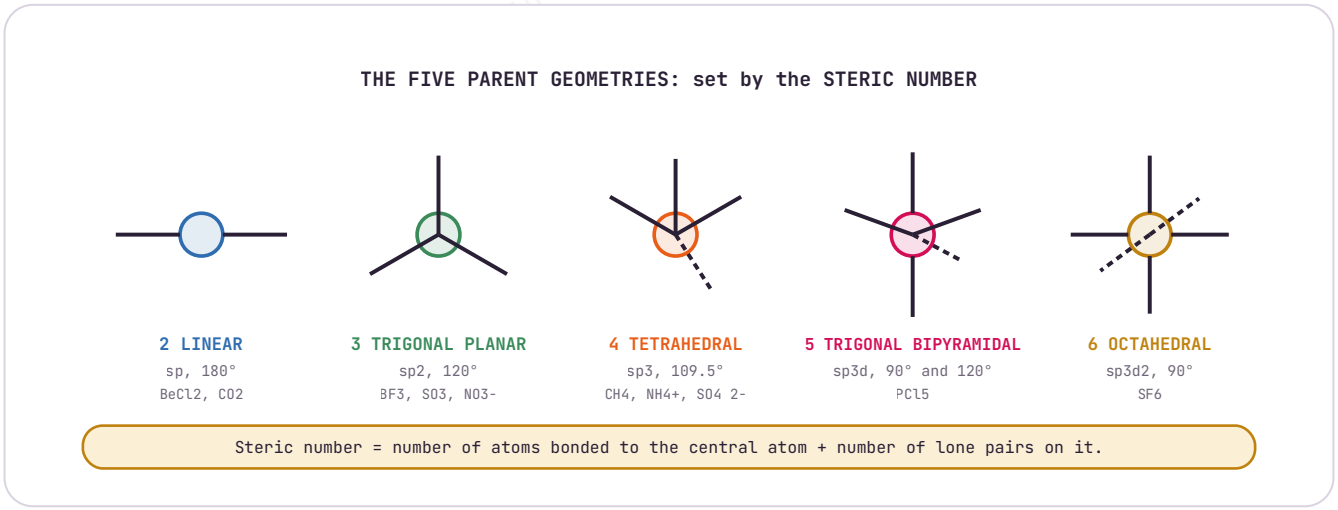
Add and remove shared pairs. Watch the bond shorten as the order rises. Then drill the comparison questions while it is fresh. **logicbloom.co.in/download** · Free to start.

SCAN

4 VSEPR: Predicting Shape

IN NEET AND JEE

The highest-yield section in the chapter. Electron pairs around the central atom repel each other. They settle as far apart as they can. So counting them gives you the shape, with nothing to memorise.

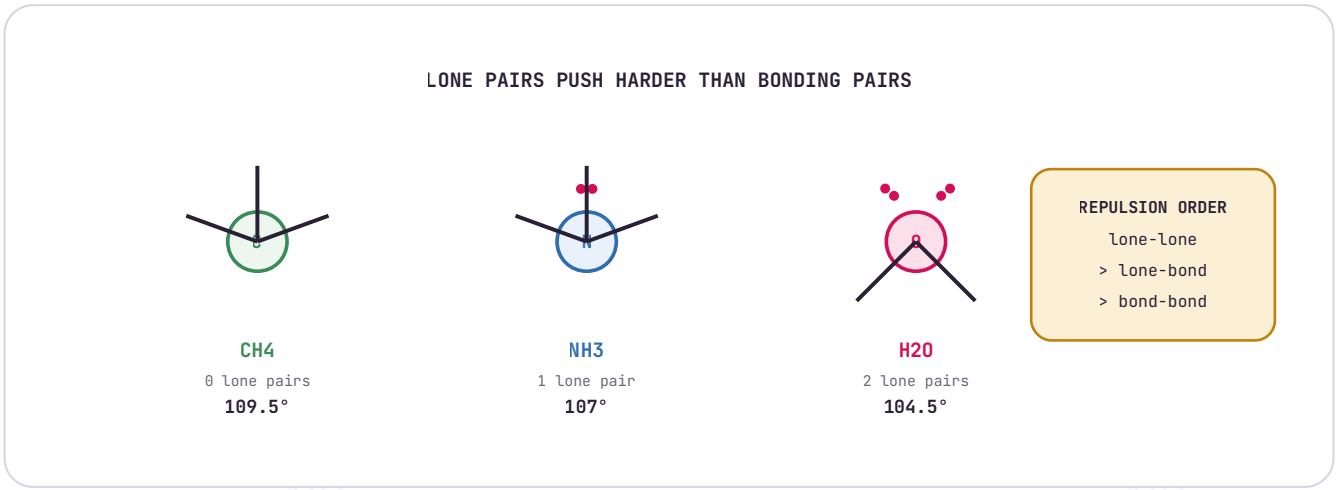


The five parent geometries. Everything else is one of these with lone pairs taking some of the positions.

★ THE WHOLE METHOD IN ONE LINE

Steric number = atoms bonded to the central atom + lone pairs on it

The steric number gives the parent geometry. The lone pairs then tell you the actual shape.



Same tetrahedral parent, three different shapes and three different angles, because lone pairs push harder.

SN 4, 0 lone pairs	tetrahedral, 109.5°: CH_4, NH_4^+, SO_4^{2-}
SN 4, 1 lone pair	trigonal pyramidal, about 107°: NH_3, ClO_3^-, XeO_3
SN 4, 2 lone pairs	bent, about 104.5°: H_2O
SN 5, 1 / 2 / 3 lone pairs	see-saw (SF_4), T-shaped (ClF_3), linear (XeF_2, I_3^-)
SN 6, 1 / 2 lone pairs	square pyramidal (BrF_5), square planar (XeF_4, ICl_4^-)

TRAP ALERT

⚠ IN A TRIGONAL BIPYRAMID, LONE PAIRS ALWAYS TAKE EQUATORIAL POSITIONS

An equatorial site has only two neighbours at 90°. An axial site has three. So a lone pair feels less repulsion in the equator. This is why SF_4 is a see-saw, not a trigonal pyramid. It is also why ClF_3 is T-shaped.

5 Hybridisation

IN NEET AND JEE

Valence bond theory mixes atomic orbitals of similar energy. This makes new, identical orbitals called hybrids. They point exactly where VSEPR said they would. The two theories agree. Hybridisation explains the **why**.

★ STERIC NUMBER GIVES THE HYBRIDISATION DIRECTLY

2 → **sp** · 3 → **sp²** · 4 → **sp³** · 5 → **sp³d** · 6 → **sp³d²** · 7 → **sp³d³**

Sigma bond	head-on overlap, strong, and it allows free rotation
Pi bond	sideways overlap of unhybridised p orbitals, weaker, and it locks the geometry
Counting	a single bond is one sigma; a double is one sigma and one pi; a triple is one sigma and two pi
s-character	sp has 50%, sp^2 has 33%, sp^3 has 25%; more s-character means shorter, stronger bonds and larger angles

THINK IT THROUGH

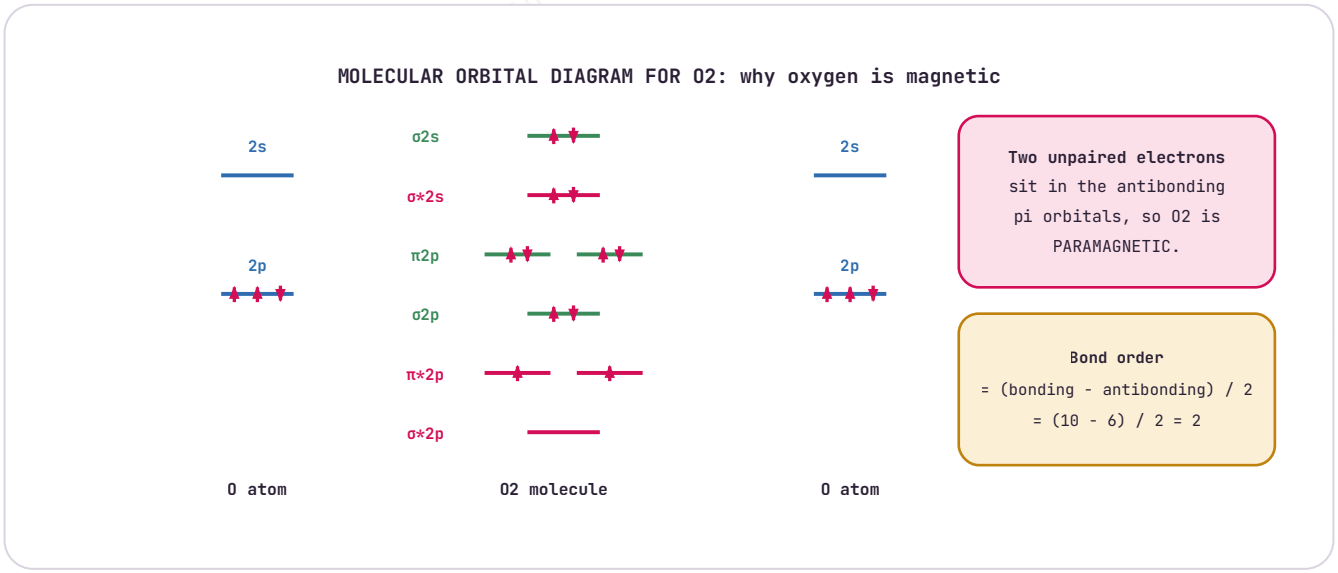
WHY BOND ANGLE TRACKS S-CHARACTER

An s orbital is spherical. It holds its electrons closer to the nucleus. So more s-character pulls the bonding pair in closer. The other orbitals then spread wider apart. That is why the angle runs 180° for sp, 120° for sp^2 and 109.5° for sp^3. It is also why an sp C-H bond is shorter than an sp^3 one.

6 Molecular Orbital Theory

JEE MAIN AND ADVANCED

Valence bond theory cannot explain why oxygen is attracted to a magnet. Molecular orbital theory can. It combines the atomic orbitals into new ones. These new orbitals spread over the whole molecule.



The MO diagram for oxygen. Two electrons sit unpaired in the antibonding pi orbitals, which is paramagnetism.

★ BOND ORDER AND MAGNETISM

$$\text{Bond order} = \frac{N_b - N_a}{2}$$

Any unpaired electron makes the species paramagnetic. All paired means diamagnetic.

Filling order up to N_2	σ1s, σ*1s, σ2s, σ*2s, **π2p, π2p, σ2pz**, then the antibonding set
From O_2 onwards	σ2pz drops **below** the π2p pair, because s-p mixing weakens
Paramagnetic examples	O_2 (2 unpaired), B_2 (2 unpaired), NO and O_2^+ (1 each)
Diamagnetic examples	N_2, C_2, F_2, CO and NO^+

THE OXYGEN SERIES: add electrons and the bond weakens

SPECIES	BOND ORDER	MAGNETISM	BOND LENGTH (pm)
O2+	2.5	paramagnetic	112
O2	2.0	paramagnetic	121
O2-	1.5	paramagnetic	133
O2 2-	1.0	diamagnetic	149

Every electron added goes into an ANTIBONDING orbital, so bond order falls and the bond gets longer.

Adding electrons to oxygen fills antibonding orbitals, so the bond order falls and the bond lengthens.

TRAP ALERT

⚠ REMOVING AN ELECTRON DOES NOT ALWAYS WEAKEN THE BOND

From N_2 you remove a *bonding* electron. The bond order falls from 3 to 2.5, so the bond weakens. From O_2 you remove an *antibonding* electron. The bond order rises from 2 to 2.5. The bond gets stronger and shorter. Same action, opposite result. It is asked almost every year.

▶ PLAY

MO DIAGRAMS FEEL LIKE BOOKKEEPING?

Fill the orbitals yourself and watch the magnetism flip.

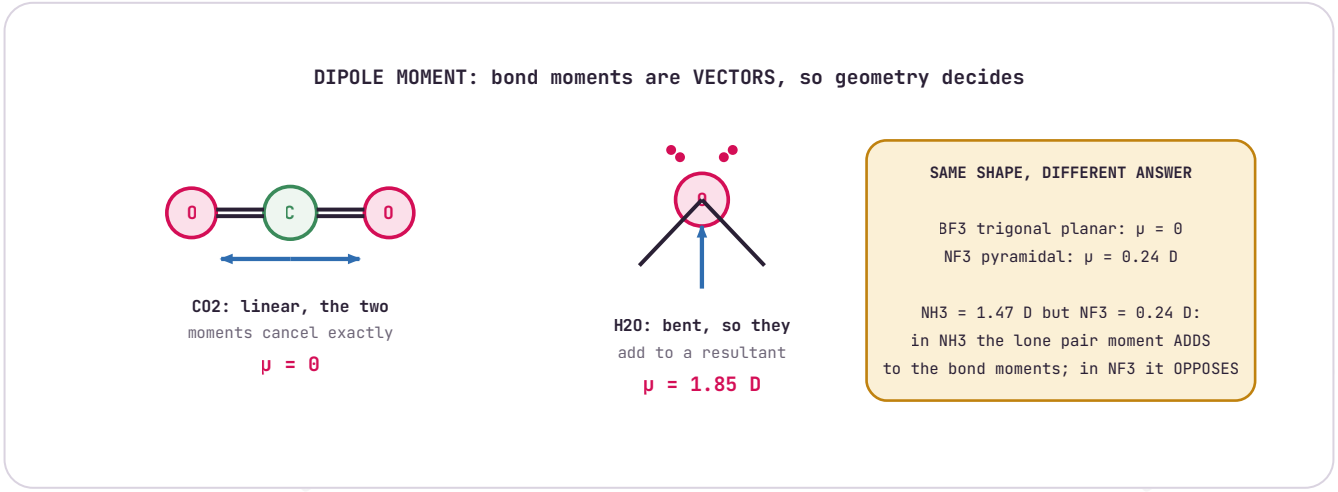
Add and remove electrons and see the bond order and the unpaired count update live. The N2 versus O2 contrast becomes obvious instead of something to memorise. **logicbloom.co.in/download** · Free to start.

SCAN

7 Polarity and Hydrogen Bonding

IN NEET AND JEE

Individual bonds can be polar while the molecule is not. Dipole moments are vectors, so the shape from Section 4 decides the answer.



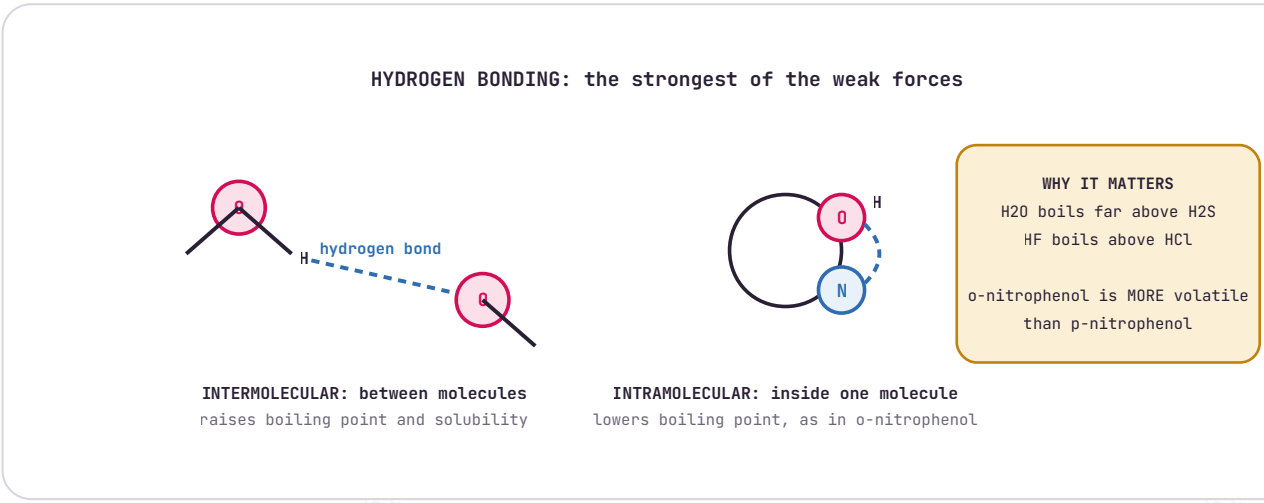
Identical bonds, opposite outcomes. In CO2 the moments cancel; in the bent water molecule they add.

★ DIPOLE MOMENT

$$\mu = q \times d$$

Measured in debye (D). A symmetrical molecule has μ = 0 no matter how polar its individual bonds are.

μ = 0 despite polar bonds	CO_2, BF_3, CCl_4, SF_6, XeF_4: all symmetrical
μ ≠ 0	H_2O, NH_3, SO_2, $CHCl_3$: lone pairs or asymmetry break the cancellation
The NH_3 versus NF_3 case	1.47 D against 0.24 D, because in NF_3 the lone pair moment opposes the bond moments
Percentage ionic character	the ratio of the observed dipole moment to the value calculated for complete transfer



Hydrogen bonding needs H attached to N, O or F. Whether it forms between molecules or inside one changes the physical properties completely.

TRAP ALERT

⚠ INTRAMOLECULAR HYDROGEN BONDING DOES THE OPPOSITE OF WHAT YOU EXPECT

Normal hydrogen bonding between molecules **raises** boiling point and solubility. But sometimes the bond forms *inside* one molecule. **o-nitrophenol** does this. That molecule can then no longer bond to its neighbours. So o-nitrophenol is more volatile and less soluble than p-nitrophenol. This is the reverse of the usual rule.

8 Important Questions

Fourteen questions, tagged by exam. Every one is a comparison or a prediction that needs a rule applied, not a fact recalled. Try each before reading the working.

Q1 Three shapes from one parent geometry

NEET

Predict the shape and bond angle of CH_4, NH_3 and H_2O, and explain why they differ although all three have the same steric number.

CORE Count the steric number for each, then let the lone pairs squeeze the angle.

WORKING

$$\text{All three: SN} = 4 \Rightarrow \text{tetrahedral parent, } sp^3$$

$$CH_4 : \ 0 \text{ lp} \Rightarrow \text{tetrahedral, } \mathbf{109.5^\circ}$$

$$NH_3 : \ 1 \text{ lp} \Rightarrow \text{pyramidal, } \mathbf{107^\circ}, \quad H_2O : \ 2 \text{ lp} \Rightarrow \text{bent, } \mathbf{104.5^\circ}$$

TRAP The hybridisation is sp^3 for all three, so hybridisation alone never explains the difference. Lone pair repulsion does. Note NH_4^+ is back to 109.5° because the lone pair is used up.

Q2 Shapes of the interhalogens

JEE MAIN

Give the shape and hybridisation of ClF_3, SF_4, XeF_2, BrF_5 and XeF_4.

CORE Steric number from the central atom's valence electrons plus the bonded atoms, then place the lone pairs.

WORKING

$$\text{SN} = 5 : \ ClF_3 \ (2 \text{ lp}) \rightarrow \text{T-shaped}, \quad SF_4 \ (1 \text{ lp}) \rightarrow \text{see-saw}, \quad XeF_2 \ (3 \text{ lp}) \rightarrow \text{linear}$$

$$\text{SN} = 6 : \ BrF_5 \ (1 \text{ lp}) \rightarrow \text{square pyramidal}, \quad XeF_4 \ (2 \text{ lp}) \rightarrow \text{square planar}$$

$$sp^3d \text{ for SN 5}, \qquad sp^3d^2 \text{ for SN 6}$$

TRAP In the trigonal bipyramid the lone pairs must go equatorial, which is what turns SF_4 into a see-saw rather than a pyramid. In the octahedron two lone pairs go opposite each other, giving square planar.

Q3 Which chloride is most covalent

NEET

Arrange LiCl, NaCl, KCl and CsCl in order of increasing covalent character, and explain.

CORE Fajans: a smaller cation polarises the anion more, so it gives more covalent character.

WORKING

$$\text{cation size: } Li^+ < Na^+ < K^+ < Cs^+$$

$$\text{polarising power is largest for the smallest cation}$$

$$CsCl < KCl < NaCl < LiCl$$

TRAP The order of covalent character is the **reverse** of the order of cation size, so read the question carefully: increasing covalent character means decreasing cation size.

Q4 Bond order, magnetism and length together

JEE MAIN

For O_2, O_2^+, O_2^- and O_2^{2-}, find the bond order and the magnetic behaviour, and arrange them by bond length.

CORE Fill the MO diagram; every extra electron goes into an antibonding π* orbital.

WORKING

$$O_2^+ : 2.5,\ \text{para} \quad O_2 : 2.0,\ \text{para (2 unpaired)}$$

$$O_2^- : 1.5,\ \text{para} \quad O_2^{2-} : 1.0,\ \text{diamagnetic}$$

$$\text{bond length} \propto \frac{1}{\text{bond order}} \Rightarrow O_2^+ < O_2 < O_2^- < O_2^{2-}$$

TRAP Only the peroxide ion is diamagnetic, because that is the point at which both π* orbitals finally fill. Bond length runs opposite to bond order, so the shortest is the one with the highest order.

Q5 Same action, opposite result

JEE ADVANCED

Explain why removing one electron from N_2 weakens the bond, while removing one electron from O_2 strengthens it.

CORE Ask which orbital the electron leaves from: a bonding orbital or an antibonding one.

WORKING

$$N_2 : \text{the highest occupied MO is } \sigma 2p_z, \text{ BONDING}$$

$$3.0 \rightarrow 2.5, \text{ bond lengthens } 110 \rightarrow 112 \text{ pm} \Rightarrow \text{weaker}$$

$$O_2 : \text{the highest occupied MO is } \pi^* 2p, \text{ ANTIBONDING}$$

$$2.0 \rightarrow 2.5, \text{ bond shortens } 121 \rightarrow 112 \text{ pm} \Rightarrow \text{stronger}$$

TRAP The instinct that ionisation always weakens a bond is wrong. What matters is only whether the electron came out of a bonding or an antibonding orbital, which is exactly what MO theory is for.

Q6 Why NH3 is far more polar than NF3

JEE ADVANCED

Both NH_3 and NF_3 are pyramidal, yet their dipole moments are 1.47 D and 0.24 D. Explain.

CORE The lone pair on nitrogen has its own moment. Compare its direction with the resultant of the bond moments in each case.

WORKING

NH_3 : N is more electronegative than H, so bond moments point TOWARD N

the lone pair moment also points away from N on the same axis $\Rightarrow$ they ADD

NF_3 : F is more electronegative, so bond moments point AWAY from N $\Rightarrow$ they OPPOSE the lone pair

$$\boldsymbol{\mu(NH_3) = 1.47 \text{ D} \gg \mu(NF_3) = 0.24 \text{ D}}$$

TRAP Judging by electronegativity difference alone would predict NF_3 to be the more polar, since N-F is more polar than N-H. The lone pair is what flips the answer.

Q7 Zero dipole from polar bonds

NEET

Explain why CO_2 has zero dipole moment while H_2O has 1.85 D, although both contain polar bonds and the same central-atom family.

CORE Dipole moments add as vectors, so the shape decides whether they cancel.

WORKING

$$CO_2 : SN = 2, \text{linear} \Rightarrow \text{two equal moments at } 180^\circ \Rightarrow \boldsymbol{\mu = 0}$$

$$H_2O : SN = 4 \text{ with 2 lp, bent at } 104.5^\circ \Rightarrow \boldsymbol{\mu \neq 0}$$

TRAP Zero dipole moment never means non-polar bonds. It means a symmetrical arrangement. The same logic makes BF_3, CCl_4, SF_6 and XeF_4 all non-polar overall.

Q8 The volatile isomer

JEE ADVANCED

o-nitrophenol boils lower and is less soluble in water than p-nitrophenol, even though they have the same formula and mass. Explain.

CORE Ask whether the hydrogen bonding is between molecules or inside one.

WORKING

ortho: the -OH and $-NO_2$ are adjacent $\Rightarrow$ INTRAmolecular H bond (chelation)

para: they are far apart $\Rightarrow$ INTERmolecular H bonding between molecules

ortho is more volatile and less soluble; para is the opposite

TRAP This reverses the usual rule that hydrogen bonding raises boiling point. An intramolecular bond uses up the OH internally, so the molecule cannot bond to its neighbours or to water.

Q9 Bond angle from s-character

JEE ADVANCED

Explain why the bond angle falls along NH_3 (107°), PH_3 (93.5°), AsH_3 (91.8°) and SbH_3 (91.3°).

CORE As the central atom gets larger and less electronegative, the extent of hybridisation falls and the bonding pairs move further from the central atom.

WORKING

$$\text{N is small and electronegative} \Rightarrow \text{good } sp^3 \text{ hybridisation}$$

$$\text{down the group the atom is larger, hybridisation is poorer}$$

$$\text{bonds become nearly pure } p \Rightarrow \text{angle approaches } \mathbf{90^\circ}$$

TRAP The angles converge on 90°, the angle between pure p orbitals, rather than falling without limit. The same reasoning explains H_2O 104.5° against H_2S 92°.

Q10 The weaker Lewis acid

JEE ADVANCED

BF_3 is a weaker Lewis acid than BCl_3, even though fluorine is far more electronegative than chlorine. Explain.

CORE Consider back bonding: donation from a filled halogen p orbital into the empty p orbital on boron.

WORKING

$$\text{B is } sp^2 \text{ with an empty } 2p \text{ orbital}$$

$$\text{F } 2p \text{ overlaps well with B } 2p \text{ (same shell) so back bonding is STRONG}$$

$$\text{Cl } 3p \text{ overlaps poorly with B } 2p \Rightarrow \text{weak back bonding}$$

$$\mathbf{BF_3} \text{ has less empty orbital left, so it is the weaker acid}$$

TRAP Electronegativity alone predicts the opposite order. Back bonding is also why the B-F bond is shorter than a pure single bond, and why BF_3 is planar rather than pyramidal.

Q11 Counting sigma and pi

NEET

How many sigma and pi bonds are present in (a) $CH_2=CH-C\equiv N$ and (b) benzene?

CORE Every bond, single or multiple, contains exactly one sigma. The rest are pi.

WORKING

$$\text{(a) } CH_2=CH-C\equiv N:\ \text{bonds} = 3\ \text{C-H} + 3\ \text{skeletal} = 6\ \sigma$$

$$\text{extras: one from C=C, two from C}\equiv\text{N} \Rightarrow \mathbf{6\ \sigma,\ 3\ \pi}$$

$$\text{(b) benzene: 6 C-C} + 6\ \text{C-H} = 12\ \sigma,\ \mathbf{3\ \pi}$$

TRAP A double bond is one sigma plus one pi, not two pi. Counting bonds rather than counting lines is the reliable method here.

Q12 Which is more stable

JEE MAIN

Explain, using resonance, why the carbonate ion has three identical C-O bonds of 129 pm, between a single bond (143 pm) and a double bond (122 pm).

CORE Draw the contributing structures and note that the double bond is not fixed on any one oxygen.

WORKING

$$\text{three equivalent structures, each with one C=O and two C-O}^-$$

$$\text{bond order} = \frac{4\ \text{bonds shared}}{3\ \text{positions}} = 1.33$$

$$\mathbf{129}\ \text{pm, between a single and a double bond}$$

TRAP The hybrid is not an average of the drawings in a loose sense, it is a single real structure lower in energy than any of them. The equal bond lengths are the experimental proof.

Q13 Magnetic behaviour across the second period

JEE ADVANCED

Which of B_2, C_2, N_2, O_2 and F_2 are paramagnetic? Give bond orders.

CORE Remember the filling order changes at O_2: before it, π2p lies below σ2pz.

WORKING

$$B_2:\ \text{BO } 1,\ 2 \text{ unpaired in } \pi 2p \Rightarrow \text{paramagnetic}$$

$$C_2:\ 2,\ N_2:\ 3,\ F_2:\ 1 \Rightarrow \text{all diamagnetic}$$

$$O_2:\ \text{BO } 2,\ 2 \text{ unpaired in } \pi^{*} 2p \Rightarrow \text{paramagnetic}$$

TRAP B_2 is the one students miss. Its two electrons enter the **degenerate π2p pair** singly by Hund's rule, so it is paramagnetic despite a bond order of only 1.

Q14 Assertion and reason on hybridisation

JEE ADVANCED

Assertion: H_2O has a smaller bond angle than NH_3. **Reason:** Oxygen is sp^2 hybridised while nitrogen is sp^3. Judge both statements.

CORE Check the steric number of each central atom before accepting the reason.

WORKING

$$H_2O: 2 \text{ bonds} + 2 \text{ lp} = \text{SN } 4 \Rightarrow sp^3$$

$$NH_3: 3 \text{ bonds} + 1 \text{ lp} = \text{SN } 4 \Rightarrow sp^3$$

$$\text{Assertion true, Reason false}$$

TRAP Both are sp^3. The angle difference comes from the **number of lone pairs** (two against one), not from different hybridisation. Questions that offer hybridisation as the reason are usually wrong on purpose.

★ Chemical Bonding · Fact Sheet

Every rule for revision day. Print this page alone.

OCTET EXCEPTIONS

Incomplete: BF3, BeCl2

Expanded: PCl5, SF6, IF7
Odd electron: NO, NO2.

FAJANS

Small cation, large anion,

high charge, pseudo noble gas = more covalent.

BOND PARAMETERS

Order up: length down,

enthalpy up.
single 154, double 134, triple 120 pm.

STERIC NUMBER

SN = bonded atoms + lone pairs

2 sp, 3 sp^2, 4 sp^3,
5 sp^3d, 6 sp^3d^2.

LONE PAIR ANGLES

CH4 109.5°, NH3 107°,

H2O 104.5°
lp-lp > lp-bp > bp-bp.

SN 5 SHAPES

1 lp see-saw (SF4)

2 lp T-shaped (ClF3)
3 lp linear (XeF2, I3-).

SN 6 SHAPES

1 lp square pyramidal (BrF5)

2 lp square planar (XeF4)
lone pairs go opposite.

BOND ORDER

BO = (Nb − Na) / 2

Unpaired electron = paramagnetic.

MO FILLING

Up to N2: π2p below σ2pz

From O2: σ2pz below π2p because s-p mixing weakens.

PARAMAGNETIC LIST

O2, B2, NO, O2+, O2−

Diamagnetic: N2, C2, F2, CO, NO+, O2 2−.

N2 VS O2 ON IONISING

N2 → N2+ : 3 → 2.5, weaker

O2 → O2+ : 2 → 2.5, stronger bonding vs antibonding.

DIPOLE MOMENT

μ = 0: CO2, BF3, CCl4, SF6

NH3 1.47 D but NF3 0.24 D
lone pair adds, then opposes.

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★ SHAPES STILL NOT OBVIOUS?

Play it. Then practice it.

Open Chemical Bonding in the Logic Bloom app: count the steric number and watch the molecule build itself, fill an MO diagram and see the magnetism flip, then drill the comparison questions. Free to start.

SCAN → PLAY · READ · PRACTICE