

CHEMDU · COMMUNITY CHEMISTRY · LEVEL 2 ADVANCED

LECTURE L2-3

# Chemical Bonding

*Drawing Molecules at Home: Why Snowflakes Have Six Sides and Why Dry Ice Sinks*

Duration: 75 minutes (filled all gaps)

Advanced lecture script — pre-requisite: Level 1

**HOOK (3 minutes)**

Teacher holds up (or shows photos of):

A snowflake (six sides)

A piece of dry ice (fog sinking to the floor)

A bottle of vinegar and a bottle of olive oil

Teacher says: "You've seen snowflakes. They always have six sides. That comes from the shape of a water molecule — bent at about 104.5 degrees.

You've used dry ice for Halloween fog. It sinks to the floor instead of rising like smoke. That's because CO<sub>2</sub> molecules are linear — and heavier than air.

You've seen vinegar and oil separate in salad dressing. That's because vinegar is polar (mixes with water) and oil is non-polar (doesn't).

- Today's question: How can you predict a molecule's shape and behavior — starting from its chemical formula? \*

*By the end of this session, you will be able to:*

*Draw a simple Lewis dot structure for household chemicals (water, vinegar, baking soda)*

*Predict whether a molecule is polar or non-polar — and whether it will mix with water*

*Explain why snowflakes have six sides and why dry ice sinks"*

**SEGMENT 1: Review from Level 1 and Level 2-1/2-2 (8 minutes)**

Teacher says: \*"Before we go deeper, let's recall what you already know from Level 1 and what we covered in Level 2-1 and Level 2-2."\*

Review from Level 1 (Basic Concepts)

Level 1 Concept	Definition	Household Example
Ionic bond	One atom gives an electron to another	Table salt (NaCl)
Covalent bond	Atoms share electrons	Water (H <sub>2</sub> O), vinegar (acetic acid)
Valence electrons	Electrons in the outermost shell — involved in bonding	Carbon has 4 (why it can form so many compounds)
Octet rule	Atoms want 8 electrons in their outer shell	Why noble gases don't react

## Review from Level 2-1 (Atomic Structure - Advanced)

Teacher says: \*In Level 2-1, you learned about atomic number and mass number.\*

Term	Definition	Example
Atomic number	Number of protons in an atom	Carbon has 6 protons → atomic number 6
Mass number	Protons + neutrons	Carbon-12 has 6 protons + 6 neutrons = mass number 12
Isotope	Same element, different number of neutrons	Carbon-12, Carbon-13, Carbon-14

Teacher: "For Lewis dot structures, you need to know how many valence electrons an element has. That comes from the atomic number and which group it's in on the periodic table."

## Review from Level 2-2 (Periodic Table - Advanced)

Teacher says: \*In Level 2-2, you learned about electronegativity trends.\*

Concept	Definition	Trend on Periodic Table
Electronegativity	How strongly an atom pulls shared electrons	Increases left → right, decreases top → bottom
Most electronegative element	Fluorine (F) — 4.0	Top right corner (not including noble gases)

Teacher: "Here are the electronegativity values you'll need today. You don't need to memorize them — just know where to find them."

Element	Symbol	Electronegativity	Found In
Fluorine	F	4.0 (highest)	Non-stick pans (Teflon)
Oxygen	O	3.5	Water, vinegar, baking soda
Chlorine	Cl	3.0	Bleach, table salt (with sodium)
Nitrogen	N	3.0	Ammonia cleaner
Carbon	C	2.5	Vinegar, baking soda, plastic
Hydrogen	H	2.1	Water, vinegar, natural gas

## Counting Valence Electrons (Critical for Today)

Teacher says: "To draw Lewis structures, you need to know how many valence electrons each atom has. Here's the rule:

Valence electrons = Group number (for main group elements 1, 2, 13-18)

**Show this table:**

Element	Group	Valence Electrons	Example
Hydrogen (H)	1	1	H <sub>2</sub> gas, water
Carbon (C)	14	4	Methane, vinegar, plastic
Nitrogen (N)	15	5	Ammonia cleaner
Oxygen (O)	16	6	Water, vinegar
Fluorine (F)	17	7	Non-stick pans
Chlorine (Cl)	17	7	Bleach, salt

Quick check (show of hands / chat): "How many valence electrons does carbon have?" (4) "How many does oxygen have?" (6) "How many does hydrogen have?" (1)

Teacher: "Good. Now you're ready to draw molecules."

## SEGMENT 2: Lewis Dot Structures — Drawing Household Molecules (18 minutes)

Teacher says: "A Lewis dot structure (LOO-is dot STRUK-chur) is a drawing that shows valence electrons as dots around element symbols. It shows how atoms are bonded.

Lewis dot structure: A diagram showing valence electrons as dots, with lines representing shared electron pairs (bonds).

Step-by-Step Method (for neutral molecules)

Teacher writes on board or screen:

Step	What to Do
Step 1	Count total valence electrons. Add all atoms' valence electrons.
Step 2	Pick a central atom (usually the least electronegative, never hydrogen).
Step 3	Draw single bonds between central atom and outer atoms. Each bond = 2 electrons.

Step	What to Do
Step 4	Place remaining electrons as lone pairs on outer atoms first, then central.
Step 5	Check octet rule. If central atom doesn't have 8, form double or triple bonds.

Example 1: Water (H<sub>2</sub>O) — The Bent Molecule

Step	Calculation	Result
Step 1	H has 1 valence electron each (2 H = 2). O has 6 valence electrons. Total = 2 + 6 = 8 electrons	
Step 2	Central atom = O (H cannot be central — it only forms 1 bond)	O in center
Step 3	Draw H-O-H single bonds. Each bond = 2 electrons. 2 bonds × 2 electrons = 4 electrons used. Remaining = 8 - 4 = 4 electrons	H—O—H
Step 4	Place remaining 4 electrons as lone pairs on O (outer H atoms are already full with 2 electrons each). O gets 2 lone pairs (4 electrons).	H—O—H with 2 lone pairs on O
Step 5	Check O: 2 bonds (4 electrons) + 2 lone pairs (4 electrons) = 8 electrons. Octet satisfied. H: each has 2 electrons (full).	Complete

Final Lewis structure of water:

text

..

H—O—H

..

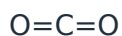
Household connection: "The two lone pairs on oxygen push the hydrogen atoms closer together. That's why water is bent (about 104.5 degrees), not linear (180 degrees). That bent shape is why snowflakes have six sides — the angle affects how water molecules arrange when freezing."

Example 2: Carbon Dioxide (CO<sub>2</sub>) — Dry Ice

Step	Calculation	Result
Step 1	C has 4 valence electrons. O has 6 each (2 O = 12). Total = 4 + 12 = 16 electrons	
Step 2	Central atom = C (less electronegative than O)	C in center
Step 3	Draw O-C-O single bonds. Each bond = 2 electrons. 2 bonds × 2 electrons = 4 electrons used. Remaining = 16 - 4 = 12 electrons	O—C—O
Step 4	Place lone pairs on outer O atoms first. Each O needs 8 electrons. Start with single bonds (each O already has 2 electrons from the bond). Each O needs 6 more electrons (3 lone pairs). 2 O × 3 lone pairs = 6 lone pairs × 2 electrons each = 12 electrons used. Remaining = 0.	O with 3 lone pairs — C—O with 3 lone pairs on each O
Step 5	Check C: C has only 4 electrons (from the two single bonds). Needs 8. Must form double bonds. Change each single bond to a double bond. Each double bond = 4 electrons (2 shared pairs).	O=C=O

Final Lewis structure of CO<sub>2</sub>:

text



(Each O also has 2 lone pairs — not shown for clarity)

Household connection: "CO<sub>2</sub> is linear (180 degrees). That's why dry ice fog sinks to the floor — the molecule is straight and heavier than air. If CO<sub>2</sub> were bent, it might float like smoke."

Example 3: Methane (CH<sub>4</sub>) — Natural Gas

Step	Calculation	Result
Step 1	C has 4 valence electrons. H has 1 each (4 H = 4). Total = 4 + 4 = 8 electrons	
Step 2	Central atom = C (H cannot be central)	C in center
Step 3	Draw 4 C-H single bonds. Each bond = 2 electrons. 4 bonds × 2 electrons = 8 electrons used. Remaining = 0.	H-C-H with 4 bonds (all used)
Step 4	No electrons left for lone pairs.	
Step 5	Check C: 4 bonds = 8 electrons (each bond counts as 2 for C). Octet satisfied. H: each has 2 electrons (full).	Complete

Final Lewis structure of methane:

text

H

|

H—C—H

|

H

Household connection: "Methane is the main component of natural gas — what powers your stove and furnace. The tetrahedral shape (109.5 degrees) makes it symmetrical and non-polar."

Example 4: Ammonia (NH<sub>3</sub>) — Glass Cleaner

Step	Calculation	Result
Step 1	N has 5 valence electrons. H has 1 each (3 H = 3). Total = 5 + 3 = 8 electrons	
Step 2	Central atom = N	N in center

Step	Calculation	Result
Step 3	Draw 3 N-H single bonds. Each bond = 2 electrons. 3 bonds $\times$ 2 electrons = 6 electrons used. Remaining = $8 - 6 = 2$ electrons	H-N-H with 3 bonds
Step 4	Place remaining 2 electrons as one lone pair on N.	H-N-H with 1 lone pair on N
Step 5	Check N: 3 bonds (6 electrons) + 1 lone pair (2 electrons) = 8 electrons. Octet satisfied. H: each has 2 electrons (full).	Complete

Final Lewis structure of ammonia:

text

H

|

H—N:

|

H

(The colon represents the lone pair)

Household connection: "Ammonia is in many glass and window cleaners. The lone pair on nitrogen makes the molecule polar and gives it that sharp smell."

Partner Talk (2 minutes)

- "Draw the Lewis structure for hydrogen gas ( $H_2$ ). H has 1 valence electron each (2 H = 2 total). Central atom? There's only two atoms — neither is central. Just draw H—H single bond. Both H have 2 electrons. Done."\*

## SEGMENT 3: VSEPR Theory — Predicting Molecular Shape (12 minutes)

Teacher says: "Now that you can draw molecules, you need to know their shape. Shape determines:

*Whether a molecule is polar or non-polar*

*Whether it mixes with water or oil*

*Why snowflakes have six sides*

VSEPR theory (VES-per THEE-uh-ree) stands for Valence Shell Electron Pair Repulsion. The idea: electron pairs (bonds and lone pairs) repel each other and try to get as far apart as possible.

Household analogy: Imagine four people holding hands in a circle. They naturally spread out evenly — that's tetrahedral (like methane). Now imagine two of the people are too shy to hold hands (lone pairs) — the other two get pushed closer together — that's bent (like water).

### How to Determine Shape

*Teacher: "Count the number of electron groups around the central atom. An electron group can be:*

*A single bond*

*A double bond (counts as ONE group)*

*A triple bond (counts as ONE group)*

*A lone pair*

*Then use this table:"*

Electron Groups	Lone Pairs	Shape Name	Bond Angle	Household Example
2	0	Linear	180°	CO <sub>2</sub> (dry ice)
3	0	Trigonal planar	120°	Borax (laundry booster)
3	1	Bent	~118°	SO <sub>2</sub> (not household — but shows the pattern)
4	0	Tetrahedral	109.5°	CH <sub>4</sub> (natural gas)
4	1	Trigonal pyramidal	~107°	NH <sub>3</sub> (ammonia cleaner)
4	2	Bent	~104.5°	H <sub>2</sub> O (water — ice, snowflakes)

### Worked Examples

Example: Water (H<sub>2</sub>O)

Central atom: O

Electron groups: 2 bonds + 2 lone pairs = 4 groups

Lone pairs: 2

From table: 4 groups, 2 lone pairs = Bent

Bond angle: ~104.5°

Example: CO<sub>2</sub>

Central atom: C

Electron groups: 2 double bonds = 2 groups (double bond counts as one)

Lone pairs: 0

From table: 2 groups, 0 lone pairs = Linear

Bond angle: 180°

Example: Methane (CH<sub>4</sub>)

Central atom: C

Electron groups: 4 single bonds = 4 groups

Lone pairs: 0

From table: 4 groups, 0 lone pairs = Tetrahedral

Bond angle: 109.5°

Example: Ammonia (NH<sub>3</sub>)

Central atom: N

Electron groups: 3 bonds + 1 lone pair = 4 groups

Lone pairs: 1

From table: 4 groups, 1 lone pair = Trigonal pyramidal

Bond angle: ~107°

Household connection — why water is bent (104.5°) and snowflakes have six sides: *"Water has 4 electron groups (2 bonds + 2 lone pairs). That gives a bent shape with a 104.5° angle. That specific angle is why snowflakes form six-sided crystals. The water molecules lock together at that angle, creating hexagonal (six-sided) ice crystals."*

Physical action (optional — for fun):

*"Linear: arms straight out (180°)"*

*"Bent: arms at 104.5° (like a small jumping jack)"*

*"Tetrahedral: arms up, down, left, right"*

Quick check (show of hands): "How many electron groups does ammonia (NH<sub>3</sub> — glass cleaner) have? What shape?" (4 groups, trigonal pyramidal) "Does ammonia have a bent shape like water?" (No — it's pyramidal because only 1 lone pair, not 2)

## SEGMENT 4: Polarity — Will It Mix with Water? (12 minutes)

Teacher says: \*Now let's answer a practical question: Will this household chemical dissolve in water? \*

Electronegativity (e-lek-tro-NEG-a-tiv-i-tee) is a number that measures how strongly an atom pulls shared electrons. Higher number = stronger pull.

Electronegativity Values (from Level 2-2)

Element	Electronegativity	Found In
Fluorine (F)	4.0 (highest)	Non-stick pans (Teflon)
Oxygen (O)	3.5	Water, vinegar, baking soda
Chlorine (Cl)	3.0	Bleach, table salt
Nitrogen (N)	3.0	Ammonia cleaner
Carbon (C)	2.5	Vinegar, baking soda, plastic
Hydrogen (H)	2.1	Water, vinegar, natural gas

### Bond Polarity

Teacher: \*A bond is non-polar if the electronegativity difference is small (less than 0.4). A bond is polar if the difference is larger (0.4 to 1.7). A bond is ionic if the difference is greater than 1.7.\*

### Worked examples:

Bond	Electronegativity Difference	Calculation	Bond Type
H-H	$2.1 - 2.1 = 0.0$	Same atom	Non-polar covalent
C-H	$2.5 - 2.1 = 0.4$	Small difference	Non-polar covalent (borderline)
O-H	$3.5 - 2.1 = 1.4$	Larger difference	Polar covalent
C-O	$3.5 - 2.5 = 1.0$	Medium difference	Polar covalent
N-H	$3.0 - 2.1 = 0.9$	Medium difference	Polar covalent
Na-Cl	$3.0 - 0.9 = 2.1$ (Na is 0.9)	Large difference	Ionic

### Molecular Polarity (Overall)

Teacher: "A molecule can have polar bonds but still be non-polar overall — if the polar bonds cancel out (like  $\text{CO}_2$ )."

Step-by-step to determine overall polarity:

Identify all polar bonds (electronegativity difference > 0.4)

Look at the molecular shape (from VSEPR)

If the polar bonds are arranged symmetrically, they cancel → non-polar

If asymmetrical, they don't cancel → polar

Table of household molecules:

Molecule	Polar Bonds?	Shape	Overall Polarity	Household Behavior
Water (H <sub>2</sub> O)	Yes (O-H)	Bent (asymmetrical)	Polar	Dissolves salt, sugar, vinegar
CO <sub>2</sub>	Yes (C=O)	Linear (symmetrical)	Non-polar	Does NOT mix with water (fizzy soda uses pressure)
Methane (CH <sub>4</sub> )	No (C-H is 0.4)	Tetrahedral (symmetrical)	Non-polar	Natural gas — does not dissolve in water
Ammonia (NH <sub>3</sub> )	Yes (N-H)	Trigonal pyramidal (asymmetrical)	Polar	Mixes with water (ammonia cleaner)
Vinegar (acetic acid)	Yes (O-H, C=O)	Mostly asymmetric	Polar	Mixes completely with water
Olive oil	No (mostly C-H)	Long chain	Non-polar	Does NOT mix with water

Worked Example: Why CO<sub>2</sub> is Non-Polar Despite Polar Bonds

Teacher: *"CO<sub>2</sub> has two polar C=O bonds (difference 1.0). But the molecule is linear (180°). The two bonds point in exactly opposite directions. They pull equally in opposite directions — the pulls cancel out. Net dipole = zero."*

Worked Example: Why Water is Polar

Teacher: *"Water has two polar O-H bonds (difference 1.4). But the molecule is bent (104.5°). The two bonds do NOT point opposite. They pull at an angle. The pulls do NOT cancel. Net dipole = not zero — the oxygen end is more negative, the hydrogen end is more positive."*

Household Test You Can Do At Home

*"Get three small cups. Put water in each. Add a few drops of vinegar to one — it mixes (polar + polar). Add a few drops of olive oil to another — it separates (non-polar does*

*not mix with polar). Add a few drops of rubbing alcohol to the third — it mixes (alcohol has O-H bond — polar). Polarity predicts the result before you try it."*

Partner talk (2 minutes): "Tell your partner: Why does vinegar mix with water but olive oil does not? Use the words 'polar' and 'non-polar.'"

Answer: Vinegar has O-H bonds (polar). Water is polar. Polar dissolves polar. Olive oil has mostly C-H bonds (non-polar). Water is polar. Non-polar and polar do not mix.

## SEGMENT 5: Formal Charge — Optional (5 minutes — can skip if time is short)

Teacher says: *"Formal charge (FOR-mul CHARJ) is a tool chemists use to check if their Lewis structure is correct. For household chemicals, you rarely need it — the correct structure is already known. But here's the idea in 2 minutes for those who are curious."*

Formal charge formula:  $\text{Formal charge} = (\text{Valence electrons}) - (\text{Lone pair electrons}) - (\frac{1}{2} \times \text{Shared electrons})$

Teacher: "The best Lewis structure has formal charges as close to zero as possible, and negative charges on more electronegative atoms."

Worked Example: CO<sub>2</sub> (Two Possible Structures)

Structure	Formal Charge on C	Formal Charge on each O	Best?
O=C=O (double bonds)	C: $4 - 0 - 4 = 0$	O: $6 - 4 - 2 = 0$	Yes — all zeros
O≡C-O (triple + single)	C: $4 - 0 - 6 = -2$	Triple O: $6 - 4 - 3 = -1$ ; Single O: $6 - 6 - 1 = -1$	No — charges not zero

Teacher: "For household purposes, you don't need to calculate formal charge. Just know that the Lewis structures in this lecture are the correct ones."

## SEGMENT 6: Putting It All Together — Household Molecule Analysis (10 minutes)

Teacher says: "Let's analyze vinegar (acetic acid — CH<sub>3</sub>COOH) as our final example. This molecule has two carbons, but we'll focus on the part that makes it polar."

Structure of Acetic Acid (Simplified)

**Teacher draws:**

text

H O

| ||

H—C—C—O—H

|

H

**Analysis table:**

Question	Answer
What atoms are bonded?	C, H, and O
How many valence electrons total?	C (4) × 2 = 8; H (1) × 4 = 4; O (6) × 2 = 12; Total = 24
What is the shape around the O-H oxygen?	Bent (2 bonds + 2 lone pairs) — same as water
Does it have polar bonds?	Yes — O-H (difference 1.4) and C=O (difference 1.0)
Is the molecule overall polar?	Yes — the polar bonds do not cancel
Will it mix with water?	Yes — vinegar is completely soluble in water
Household use	Salad dressing (if you add oil, it separates — oil is non-polar)

## Quick Reference Table for Common Household Chemicals

Household Item	Chemical Formula	Shape (around key atom)	Polar or Non-Polar?	Mixes with Water?
Water	H <sub>2</sub> O	Bent	Polar	Yes (itself)
Vinegar	CH <sub>3</sub> COOH	Bent (at O-H)	Polar	Yes
Olive oil	Long chain C-H	Long chain	Non-polar	No
Rubbing alcohol	C <sub>3</sub> H <sub>8</sub> O	Bent (at O-H)	Polar	Yes
Baking soda	NaHCO <sub>3</sub>	Ionic (not a molecule)	Ionic	Yes (dissolves into ions)
Table salt	NaCl	Ionic	Ionic	Yes (dissolves into ions)
Natural gas	CH <sub>4</sub>	Tetrahedral	Non-polar	No
Ammonia cleaner	NH <sub>3</sub>	Trigonal pyramidal	Polar	Yes

Household Item	Chemical Formula	Shape (around key atom)	Polar or Non-Polar?	Mixes with Water?
Dry ice	CO <sub>2</sub>	Linear	Non-polar	No (but fizzes under pressure)

### CLOSING — The 60-Second Challenge (5 minutes)

Teacher says: "Pair up. Person A: 60 seconds — explain why water is bent and why that matters for snowflakes. Person B: 60 seconds — explain why vinegar mixes with water but olive oil does not."

Final takeaway table (show on screen / read aloud):

You learned...	Household Example
Lewis dot structures	Draw water (bent shape explains snowflakes)
VSEPR theory	Predict shape: CO <sub>2</sub> is linear (dry ice sinks to floor)
Electronegativity	O-H bond is polar (vinegar mixes with water)
Overall polarity	C-H bond is non-polar (oil separates from water)
Formal charge (optional)	CO <sub>2</sub> double bonds are correct
Symmetry matters	CO <sub>2</sub> is linear → non-polar; Water is bent → polar

Final line (preview of L2-4): "Next session: Chemical Reactions (Advanced) — balancing the baking soda + vinegar volcano equation and predicting products of burning a candle. Bring a calculator if you want — but no grades, no pressure."

### SUPPLEMENTARY MATERIALS FOR L2-3 (No Grade)

Resource	Household Connection	Description	How to Find It
Lewis structure practice	Water, methane (natural gas)	Interactive problems with step-by-step	Search "Khan Academy Lewis structures"
VSEPR simulation	Build water, ammonia, methane	See shapes in 3D	Search "PhET molecule shapes"
Electronegativity table	Compare elements in household products	Printable periodic table	Search "Pauling electronegativity periodic table"
Kitchen polarity test	Vinegar, oil, water, alcohol	Do at home — see what mixes	Search "polarity test kitchen chemistry"

*"This week, look at the ingredients on a bottle of rubbing alcohol. It may say 'isopropyl alcohol' or 'ethanol.' Both have O-H bonds — they are polar. Next time you have water and rubbing alcohol, try mixing a few drops. Predict what will happen before you try."*