CHEMDU · COMMUNITY CHEMISTRY · LEVEL 2 ADVANCED

LECTURE L2-4

Chemical Reactions

Balancing the Volcano: Why Baking Soda + Vinegar Fizzes — and How to Predict Any Reaction

Duration: 75 minutes

Advanced lecture script — pre-requisite: Level 1

HOOK (3 minutes)

Teacher holds up (or shows photos of):

A baking soda box and vinegar bottle

A burning candle

A rusty nail

A battery

Teacher says: "You've seen baking soda and vinegar fizz. That's a chemical reaction. You've seen a candle burn — that's also a chemical reaction. You've seen a nail rust — that's a chemical reaction too, just much slower.

- Today's question: How can you predict what will happen when two chemicals mix — and how can you balance the equation so it obeys the laws of physics? *

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

Identify the five main types of chemical reactions

Balance chemical equations step by step

Predict the products of common household reactions

Write net ionic equations to see what's really happening"

SEGMENT 1: Review from Level 1 and Level 2 (5 minutes)

Teacher says: "Before we go deeper, let's recall what you already know from Level 1 and previous Level 2 lectures."

Review from Level 1 (Chemical Reactions - Basic)

Level 1 Concept	Definition	Household Example
Chemical reaction	Atoms rearrange bonds to make new substances	Baking soda + vinegar
Reactant	Starting substance(s)	Baking soda ($NaHCO_3$) + vinegar ($HC_2H_3O_2$)
Product	New substance(s) formed	CO_2 gas, water, sodium acetate
Law of conservation of mass	Mass is neither created nor destroyed	Same number of atoms before and after

Review from Previous Level 2 Lectures

L2 Lecture	Concept	Connection to Reactions
L2-1	Atomic number, mass	Counting atoms for balancing
L2-2	Groups, reactivity	Predicting if a reaction will happen
L2-3	Bonds, Lewis structures	Understanding how bonds break and form

Quick check (show of hands / chat): "What is the law of conservation of mass?" (Atoms are neither created nor destroyed — they just rearrange) "What must be true about a balanced chemical equation?" (Same number of each type of atom on both sides)

Teacher: "Good. Now let's learn the five main types of reactions — and how to balance them."

SEGMENT 2: The Five Main Types of Chemical Reactions (15 minutes)

Teacher says: "Most chemical reactions fall into one of five categories. Once you know the category, you can predict the products."

Type 1: Synthesis Reaction (Combination)

Synthesis: Two or more simple substances combine to form one more complex substance. General form: A + B → AB

Household Example: Rust Formation (Slow)

Step	What Happens
Iron (Fe) + Oxygen (O_2) → Iron oxide (rust — Fe_2O_3)	

Balanced equation:

text

$4Fe + 3O_2 \rightarrow 2Fe_2O_3$

Household Example: Burning Magnesium (Fireworks)

Step	What Happens
Magnesium (Mg) + Oxygen (O_2) → Magnesium oxide (MgO)	Bright white light

Balanced equation:

text

$2Mg + O_2 \rightarrow 2MgO$

Type 2: Decomposition Reaction

Decomposition: One complex substance breaks down into two or more simpler substances. General form: AB → A + B

Household Example: Baking Soda Decomposition (in Oven)

Step	What Happens
Sodium bicarbonate ($NaHCO_3$) → Sodium carbonate (Na_2CO_3) + CO_2 + Water	

Balanced equation:

text

$2NaHCO_3 \rightarrow Na_2CO_3 + CO_2 + H_2O$

Household Example: Hydrogen Peroxide Decomposition (Old Bottle)

Step	What Happens
Hydrogen peroxide (H_2O_2) → Water (H_2O) + Oxygen (O_2)	Bubbles form in old bottle

Balanced equation:

text

$2H_2O_2 \rightarrow 2H_2O + O_2$

Teacher: "That's why hydrogen peroxide bottles have a vent cap. The oxygen gas needs to escape."

Type 3: Single Displacement (Replacement) Reaction

Single displacement: One element replaces another in a compound. General form: A + BC → AC + B

Household Example: Zinc in Battery

Step	What Happens
Zinc (Zn) + Hydrochloric acid (HCl) → Zinc chloride ($ZnCl_2$) + Hydrogen gas (H_2)	

Balanced equation:

text

$Zn + 2HCl \rightarrow ZnCl_2 + H_2$

Household Example: Iron Nail in Copper Sulfate (Blue Solution)

Step	What Happens
Iron (Fe) + Copper sulfate ($CuSO_4$) → Iron sulfate ($FeSO_4$) + Copper metal (Cu)	Blue solution fades; copper coats the nail

Balanced equation:

text

$Fe + CuSO_4 \rightarrow FeSO_4 + Cu$

Teacher: *"The iron 'displaces' the copper because iron is more reactive than copper (see periodic table trends from L2-2)."*

Type 4: Double Displacement (Metathesis) Reaction

Double displacement: Two compounds exchange partners. General form: AB + CD → AD + CB

Household Example: Baking Soda + Vinegar (The Classic Volcano)

Step	What Happens
Sodium bicarbonate ($NaHCO_3$) + Acetic acid ($HC_2H_3O_2$) → Sodium acetate ($NaC_2H_3O_2$) + Carbonic acid (H_2CO_3)	Carbonic acid immediately decomposes into CO_2 + H_2O (fizz)

Overall reaction:

text

$NaHCO_3 + HC_2H_3O_2 \rightarrow NaC_2H_3O_2 + H_2O + CO_2$

Household Example: Baking Soda + Any Acid (Lemon Juice, Buttermilk)

Step	What Happens
Same pattern as above — acid + bicarbonate → CO_2 gas	Bubbles!

Type 5: Combustion Reaction

Combustion: A substance reacts rapidly with oxygen, releasing heat and light (fire). General form: Fuel + O_2 → CO_2 + H_2O (for hydrocarbons)

Household Example: Burning a Candle (Wax = $C_{25}H_{52}$)

Step	What Happens
Wax ($C_{25}H_{52}$) + Oxygen (O_2) → Carbon dioxide (CO_2) + Water vapor (H_2O) + Heat + Light	

Unbalanced:

text

$C_{25}H_{52} + O_2 \rightarrow CO_2 + H_2O$

Balanced:

text

$C_{25}H_{52} + 38O_2 \rightarrow 25CO_2 + 26H_2O$

Household Example: Burning Natural Gas (Methane — CH_4)

Step	What Happens
Methane (CH_4) + Oxygen (O_2) → CO_2 + H_2O + Heat	Your stove burner

Balanced:

text

$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$

Safety Note:

> *"If there's not enough oxygen, combustion produces carbon monoxide (CO) instead of CO_2. Carbon monoxide is invisible, odorless, and deadly. That's why you need good ventilation when burning anything — and why you need a CO detector in your home."*

SEGMENT 3: Balancing Chemical Equations — Step by Step (15 minutes)

Teacher says: "Balancing equations ensures that the law of conservation of mass is obeyed. Same number of each atom on both sides."

The Method (No Guessing — Use These Steps)

Step	What to Do
Step 1	Write the unbalanced equation with correct formulas.
Step 2	Count atoms of each element on both sides.
Step 3	Add coefficients (numbers in front) to balance one element at a time.
Step 4	Repeat until all elements balance.
Step 5	Check your work.

Worked Example 1: Burning Methane (Natural Gas)

Step 1: Write unbalanced equation

text

$CH_4 + O_2 \rightarrow CO_2 + H_2O$

Step 2: Count atoms

Element	Left Side	Right Side
C	1	1
H	4	2
O	2	3

Step 3: Balance hydrogen first (H)

Put a 2 in front of H_2O:

text

$CH_4 + O_2 \rightarrow CO_2 + 2H_2O$

New count:

Element	Left	Right
C	1	1
H	4	4 (balanced)
O	2	4 (2 from CO_2 + 2 from $2H_2O$)

Step 4: Balance oxygen

Need 4 O on left. Put a 2 in front of O_2:

text

$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$

Step 5: Final check

Element	Left	Right
C	1	1
H	4	4
O	4	4

Balanced! ✓

Worked Example 2: Baking Soda + Vinegar (The Volcano)

Step 1: Write unbalanced equation

text

$NaHCO_3 + HC_2H_3O_2 \rightarrow NaC_2H_3O_2 + H_2O + CO_2$

Step 2: Count atoms

Element	Left Side	Right Side
Na	1	1
H	1 + 4 = 5	(from $HC_2H_3O_2$: $C_2H_4O_2$? Wait — write carefully)

Teacher: "Acetic acid is $HC_2H_3O_2$. The H is written first, but it's one of the hydrogens. Let's list systematically."

Better approach — write all atoms:

$HC_2H_3O_2$ means: H (from the beginning) + C_2 + H_3 + O_2 = $C_2H_4O_2$ (total)

So:

Left: $NaHCO_3$ = Na, H, C, O_3

Left: $HC_2H_3O_2$ = H (1) + $C_2H_3O_2$ = $C_2H_4O_2$ (total 2C, 4H, 2O)

Let's make a table:

Element	Left ($NaHCO_3$)	Left ($HC_2H_3O_2$)	Left Total	Right (Na $C_2H_3O_2$)	Right (H_2O + CO_2)	Right Total
Na	1	0	1	1	0	1
H	1	4	5	3	2	5
C	1	2	3	2	1	3
O	3	2	5	2	1 + 2 = 3	5

Step 3: Already balanced!

The equation is already balanced as written:

text

$NaHCO_3 + HC_2H_3O_2 \rightarrow NaC_2H_3O_2 + H_2O + CO_2$

Step 4: Final check

Element	Left	Right
Na	1	1
H	5	5
C	3	3
O	5	5

Balanced! ✓

Worked Example 3: Rust Formation (Iron + Oxygen)

Step 1: Unbalanced

text

$Fe + O_2 \rightarrow Fe_2O_3$

Step 2: Count

Element	Left	Right
Fe	1	2
O	2	3

Step 3: Balance Fe first

Put 2 in front of Fe:

text

$2Fe + O_2 \rightarrow Fe_2O_3$

Step 4: Balance O

Need 3 O on left. O_2 has 2 O. Lowest common multiple of 2 and 3 is 6. Put 3 in front of O_2 (6 O) and 2 in front of Fe_2O_3 (6 O):

text

$2Fe + 3O_2 \rightarrow 2Fe_2O_3$

Step 5: Balance Fe again

Right: 2 × Fe_2 = 4 Fe. Left: 2 Fe. Need 4 Fe. Put 4 in front of Fe:

text

$4Fe + 3O_2 \rightarrow 2Fe_2O_3$

Final check:

Element	Left	Right
Fe	4	4
O	6	6

Balanced! ✓

Worked Example 4: Burning Wax ($C_{25}H_{52}$) — Challenge Problem

Step 1: Unbalanced

text

$C_{25}H_{52} + O_2 \rightarrow CO_2 + H_2O$

Step 2: Balance C first

Right: need 25 CO_2:

text

$C_{25}H_{52} + O_2 \rightarrow 25CO_2 + H_2O$

Step 3: Balance H

Right: need 26 H_2O (52 H total):

text

$C_{25}H_{52} + O_2 \rightarrow 25CO_2 + 26H_2O$

Step 4: Balance O

Right: 25 CO_2 = 50 O; 26 H_2O = 26 O; Total O = 76 Left: O_2 has 2 O per molecule. Need 76 O → 38 O_2:

text

$C_{25}H_{52} + 38O_2 \rightarrow 25CO_2 + 26H_2O$

Final check:

Element	Left	Right
C	25	25
H	52	52
O	76	76

Balanced! ✓

> Partner talk (2 minutes): "Balance this simple reaction: $H_2 + O_2 \rightarrow H_2O$"

Answer: $2H_2 + O_2 \rightarrow 2H_2O$

SEGMENT 4: Predicting Products — Using the Five Types (10 minutes)

> Teacher says: "Once you know the reaction type, you can predict the products — even if you've never seen that reaction before."

Prediction Flowchart

Question	If Yes →	If No →
Does it involve oxygen + heat/light?	Combustion (CO_2 + H_2O)	Continue

Question	If Yes →	If No →
Is there one reactant breaking apart?	Decomposition	Continue
Are there two reactants?	See below	
Is one reactant an element and the other a compound?	Single displacement	Double displacement

Worked Example 1: Predict the products of Mg + O_2

Step 1: Identify type — two elements combining → Synthesis Step 2: Product will be a compound of Mg and O Step 3: Mg has +2 charge, O has -2 charge → MgO Balanced: 2Mg + O_2 → 2MgO

Worked Example 2: Predict the products of H_2O_2 (alone)

Step 1: Identify type — one reactant breaking apart → Decomposition Step 2: H_2O_2 breaks into H_2O + O_2 Balanced: $2H_2O_2$ → $2H_2O$ + O_2

Worked Example 3: Predict the products of Zn + $CuSO_4$

Step 1: Identify type — element + compound → Single displacement Step 2: Zn is more reactive than Cu (from L2-2 trends) → Zn replaces Cu Step 3: Products: $ZnSO_4$ + Cu Balanced: Zn + $CuSO_4$ → $ZnSO_4$ + Cu

Worked Example 4: Predict the products of $AgNO_3$ + NaCl

Step 1: Identify type — two compounds → Double displacement Step 2: Exchange partners: Ag with Cl, Na with NO_3 Step 3: Products: AgCl + $NaNO_3$ Balanced: $AgNO_3$ + NaCl → AgCl + $NaNO_3$

Household connection: AgCl is insoluble — it forms a solid (precipitate). This is how some water filters remove silver.

SEGMENT 5: Net Ionic Equations — Seeing What Really Happens (10 minutes)

> Teacher says: "Sometimes, not all atoms in a reaction actually change. Spectator ions (SPEK-tay-ter EYE-ons) just watch — they don't participate. A net ionic equation shows only the particles that actually react."

Spectator ion: An ion that appears on both sides of the equation and does not change. Net ionic equation: The equation with spectator ions removed.

Steps to Write a Net Ionic Equation

Step	What to Do
1	Write the balanced molecular equation.
2	Split all soluble ionic compounds into their ions.
3	Cancel spectator ions (same on both sides).
4	Write what remains.

Worked Example: Silver Nitrate + Sodium Chloride

Step 1: Molecular equation

text

$AgNO_3(aq) + NaCl(aq) \rightarrow AgCl(s) + NaNO_3(aq)$

Step 2: Split into ions

text

$Ag^+(aq) + NO_3^-(aq) + Na^+(aq) + Cl^-(aq) \rightarrow AgCl(s) + Na^+(aq) + NO_3^-(aq)$

Step 3: Cancel spectator ions

NO_3^- appears on both sides → spectator

Na^+ appears on both sides → spectator

Step 4: Net ionic equation

text

$Ag^+(aq) + Cl^-(aq) \rightarrow AgCl(s)$

Teacher: "That's it. The silver ion and chloride ion come together to form solid silver chloride. The sodium and nitrate just watched."

Worked Example: Baking Soda + Vinegar (Simplified)

Step 1: Molecular equation

text

$NaHCO_3(aq) + HC_2H_3O_2(aq) \rightarrow NaC_2H_3O_2(aq) + H_2O(l) + CO_2(g)$

Step 2: Identify what ionizes

$NaHCO_3$ dissociates into Na^+ and HCO_3^-

$HC_2H_3O_2$ is a weak acid — mostly stays together

$NaC_2H_3O_2$ dissociates into Na^+ and $C_2H_3O_2^-$

Step 3: Write the net ionic (simplified)

text

$HCO_3^-(aq) + HC_2H_3O_2(aq) \rightarrow C_2H_3O_2^-(aq) + H_2O(l) + CO_2(g)$

Teacher: "The sodium ions (Na^+) are spectators. They don't participate in the fizz."

SEGMENT 6: Household Reaction Prediction Practice (10 minutes)

Teacher says: "Let's practice predicting reactions you might actually see at home."

Practice 1: Baking Soda + Lemon Juice (Citric Acid)

Question	Answer
Type of reaction	Double displacement (acid + bicarbonate)
Products	Sodium citrate + H_2O + CO_2 (fizz)
Balanced equation	$3NaHCO_3 + C_6H_8O_7 \rightarrow Na_3C_6H_5O_7 + 3H_2O + 3CO_2$

Practice 2: Burning Wood (Cellulose — simplified as $C_6H_{10}O_5$)

Question	Answer
Type of reaction	Combustion
Products	CO_2 + H_2O (plus ash/minerals)
Balanced equation	$C_6H_{10}O_5 + 6O_2 \rightarrow 6CO_2 + 5H_2O$

Practice 3: Battery (Zinc + Manganese Dioxide — simplified)

Question	Answer
Type of reaction	Redox (oxidation-reduction) — a type of single displacement
What happens	Zinc is oxidized (loses electrons); MnO_2 is reduced (gains electrons)
Result	Electrical current flows

Practice 4: Bleach + Dirt (Stain Removal — simplified)

Question	Answer
Type of reaction	Oxidation-reduction (redox)
What happens	Bleach (contains hypochlorite, ClO^-) steals electrons from stain molecules
Result	Stain molecules break apart into smaller, colorless pieces

Safety note (repeat from Level 1): "Bleach is an oxidizer. Never mix bleach with acid (vinegar) or ammonia. That creates deadly chlorine or chloramine gas."

CLOSING — The 60-Second Challenge (5 minutes)

Teacher says: *"Pair up. Person A: 60 seconds — name the five types of reactions and give a household example of each. Person B: 60 seconds — balance this equation: $C_3H_8 + O_2 \rightarrow CO_2 + H_2O$ (propane — grill fuel)."*

Answer for Person B: $C_3H_8 + 5O_2 \rightarrow 3CO_2 + 4H_2O$

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

You learned…	Household Example
Synthesis (A + B → AB)	Rust: $4Fe + 3O_2 \rightarrow 2Fe_2O_3$
Decomposition (AB → A + B)	$H_2O_2 \rightarrow H_2O + O_2$
Single displacement (A + BC → AC + B)	$Zn + 2HCl \rightarrow ZnCl_2 + H_2$
Double displacement (AB + CD → AD + CB)	$NaHCO_3 + HC_2H_3O_2 \rightarrow CO_2 + H_2O + NaC_2H_3O_2$
Combustion (Fuel + O_2 → CO_2 + H_2O)	$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$
Balancing equations	Same number of each atom on both sides
Spectator ions	Ions that don't change — removed in net ionic equations
Never mix bleach with acid or ammonia	Deadly gas

Final line (preview of L2-5): "Next session: Stoichiometry (Advanced) — the mole concept, molar mass, and why 'just a little more' pool chlorine can burn your skin. Bring a calculator if you want — but no grades, no pressure."

SUPPLEMENTARY MATERIALS FOR L2-4 (No Grade)

Resource	Household Connection	Description	How to Find It
PhET "Balancing Chemical Equations" simulation	Interactive balancing practice	Drag coefficients to balance	Search "PhET balancing chemical equations"
Video: "Types of Chemical Reactions"	Bozeman Science	5-minute overview with demos	Search "Bozeman Science types of reactions"
Combustion of methane demo	Your stove	Video of blue flame	Search "methane combustion reaction"

Resource	Household Connection	Description	How to Find It
Baking soda + vinegar explanation	Classic volcano	Why it fizzes	Search "baking soda vinegar reaction equation"

"*This week, look at the ingredients on a bottle of bleach. Find 'sodium hypochlorite' (NaClO or NaOCl). Then find a bottle of window cleaner. If it says 'ammonia' or 'ammonium hydroxide,' store them far apart. Never mix them.*"