LECTURE L2-7

Acids & Bases

The pH of Lemon Juice: How to Calculate Acidity and Why Your Blood Stays at pH 7.4

Duration: 75 minutes

Advanced lecture script — pre-requisite: Level 1

HOOK (3 minutes)

Teacher holds up (or shows photos of):

A lemon (pH ~2 — very acidic)

A bottle of bleach (pH ~13 — very basic)

A bottle of antacid (bases that neutralize stomach acid)

A pool pH test kit (color-coded strips)

Teacher says: "Lemon juice has a pH of about 2. Bleach has a pH of about 13. Your blood has a pH of 7.4 — almost exactly neutral. If your blood pH drops to 7.0 or rises to 7.8, you can die.

How do chemists calculate pH? And how does your body keep it so steady?

- Today's question: What is pH — and how do you calculate it? *

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

Calculate pH from hydrogen ion concentration $[H^+]$

Calculate $[H^+]$ from pH

Perform titration calculations ($M_1V_1 = M_2V_2$ for acids and bases)

Explain how buffers keep pH stable (like your blood)"

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

Teacher says: "Before we go deeper, let's recall what you already know."

Review from Level 1 (Acids & Bases - Basic)

Level 1 Concept	Definition	Household Example
Acid	Gives away H^+ ions (tastes sour)	Lemon juice, vinegar
Base	Accepts H^+ ions (feels slippery)	Bleach, baking soda, ammonia
pH scale	0 (most acid) → 7 (neutral) → 14 (most base)	Lemon pH 2, blood pH 7.4, bleach pH 13
Neutralization	Acid + base → salt + water	Antacid + stomach acid
pH indicator	Changes color based on pH	Red cabbage juice, litmus paper

Review from Level 2-5 (Stoichiometry)

Level 2-5 Concept	Formula	Example
Moles	Mass ÷ Molar mass	10 g NaOH ÷ 40.0 g/mol = 0.25 mol
Molarity (M)	Moles ÷ Liters	0.25 mol ÷ 0.500 L = 0.50 M

Review from Level 2-6 (Dilution)

Level 2-6 Concept	Formula	Example
Dilution	$M_1V_1 = M_2V_2$	(6.0 M)(10 mL) = (0.50 M)(V_2) → V_2 = 120 mL

Quick check (show of hands / chat): "What is the pH of pure water?" (7 — neutral) "Is lemon juice an acid or a base?" (Acid — pH < 7) "Is bleach an acid or a base?" (Base — pH > 7)

Teacher: "Good. Now let's learn how to calculate pH using logarithms — but don't worry, I'll show you step by step."

SEGMENT 2: What Is pH? The Math Behind the Scale (12 minutes)

Teacher says: "pH stands for 'potential of hydrogen.' It's a way to express very small numbers without writing a lot of zeros."

pH = $-\log[H^+]$

Where $[H^+]$ is the concentration of hydrogen ions in moles per liter (M).

What does -log mean?

Log is a mathematical function that counts zeros.

For example: log(0.01) = -2, because $0.01 = 10^{-2}$

So -log(0.01) = -(-2) = 2

The shortcut:

pH = number of decimal places in $[H^+]$ (for concentrations like 0.01, 0.001, etc.)

$[H^+]$ (M)	Written as power of 10	pH = $-\log[H^+]$	What It Means
0.1	10^{-1}	1	Very acidic
0.01	10^{-2}	2	Acidic (lemon juice)
0.001	10^{-3}	3	Acidic

$[H^+]$ (M)	Written as power of 10	pH = -log$[H^+]$	What It Means
0.0001	10^{-4}	4	Weak acid
0.00001	10^{-5}	5	Weak acid
0.000001	10^{-6}	6	Very weak acid
0.0000001	10^{-7}	7	Neutral (water)
0.00000001	10^{-8}	8	Very weak base
0.000000001	10^{-9}	9	Weak base
0.0000000001	10^{-10}	10	Weak base
0.00000000001	10^{-11}	11	Basic
0.000000000001	10^{-12}	12	Basic
0.0000000000001	10^{-13}	13	Very basic (bleach)
0.00000000000001	10^{-14}	14	Very basic

Teacher: "Notice: As $[H^+]$ gets smaller, the pH gets larger. A tenfold change in $[H^+]$ changes pH by 1."

Worked Example 1: Calculating pH from $[H^+]$ (Simple)

Problem: Lemon juice has $[H^+]$ = 0.01 M. What is its pH?

Step	Calculation
Step 1	Write as a power of 10: 0.01 = 10^{-2}
Step 2	pH = -log(10^{-2}) = -(-2) = 2

Answer: pH = 2 (matches lemon juice).

Worked Example 2: Calculating pH from $[H^+]$ (Not a Power of 10)

Problem: A solution has $[H^+]$ = 2.5×10^{-4} M. What is its pH?

Step-by-step (using a calculator):

Step	Calculation
Step 1	Enter 2.5×10^{-4} into the calculator (scientific notation: 2.5 E -4)
Step 2	Press the "log" button → log(2.5×10^{-4}) = -3.602
Step 3	pH = -log$[H^+]$ = -(-3.602) = 3.602

Answer: pH = 3.60 (slightly less acidic than 10^{-4} M, which would be pH 4).

Worked Example 3: Calculating $[H^+]$ from pH

Problem: A solution has pH = 4.5. What is $[H^+]$?

The reverse formula:

$[H^+] = 10^{-pH}$

Step	Calculation
Step 1	$[H^+] = 10^{-4.5}$
Step 2	$10^{-4.5} = 10^{-4} \times 10^{-0.5}$
Step 3	$10^{-4} = 0.0001$; $10^{-0.5} = 0.3162$
Step 4	$0.0001 \times 0.3162 = 3.16 \times 10^{-5}$

Answer: $[H^+] = 3.16 \times 10^{-5}$ M.

Worked Example 4: Household Bleach

Problem: Bleach has $[OH^-] \approx 0.01$ M (hydroxide ions). For water: $[H^+] \times [OH^-] = 10^{-14}$. What is the pH of bleach?

Step-by-step:

Step	Calculation
Step 1	$[H^+] \times [OH^-] = 10^{-14}$
Step 2	$[H^+] \times 0.01 = 10^{-14}$
Step 3	$[H^+] = 10^{-14} \div 0.01 = 10^{-14} \div 10^{-2} = 10^{-12}$ M
Step 4	$pH = -\log(10^{-12}) = 12$

Answer: Bleach has pH ≈ 12.

Partner talk (1 minute): *"Tell your partner: If $[H^+] = 0.001$ M, what is the pH?"* (pH = 3)

SEGMENT 3: Strong vs. Weak Acids and Bases (10 minutes)

Teacher says: "Not all acids are equal. Some completely break apart in water — these are strong acids. Some only partially break apart — these are weak acids."

Strong acid: Completely dissociates (breaks apart) into H^+ and its conjugate base. Example: HCl (hydrochloric acid). Weak acid: Only partially dissociates. Example: $HC_2H_3O_2$ (acetic acid — vinegar).

Strong vs. Weak Comparison

Type	Dissociation in Water	$[H^+]$ Compared to [Acid]	Example
Strong acid	100%	$[H^+]$ = [Acid]	HCl, H_2SO_4, HNO_3
Weak acid	<10%	$[H^+]$ < [Acid]	$HC_2H_3O_2$ (vinegar), H_2CO_3 (carbonic acid)

Household Examples

Acid/Base	Type	Household Location	pH (typical)
HCl (hydrochloric acid)	Strong	Pool acid, some toilet bowl cleaners	1-2
$HC_2H_3O_2$ (acetic acid)	Weak	Vinegar	2.5
H_2CO_3 (carbonic acid)	Weak	Soda (carbonated water)	4-5
NaOH (sodium hydroxide)	Strong	Drain cleaner, some oven cleaners	13-14
NH_3 (ammonia)	Weak	Window cleaner	11-12

Strong Acid Calculation (Easy)

Problem: A 0.01 M solution of HCl (a strong acid). What is the pH?

Step	Calculation
Step 1	Strong acid means: $[H^+]$ = [HCl] = 0.01 M
Step 2	pH = -log(0.01) = -log(10^{-2}) = 2

Answer: pH = 2.

Weak Acid Calculation (More Complex — Conceptual)

Teacher: "Weak acids do NOT fully dissociate. For vinegar (acetic acid), a 0.01 M solution has $[H^+]$ much less than 0.01 M — only about 0.0004 M. That's why vinegar is less acidic than HCl at the same concentration."

Acid	Concentration	$[H^+]$	pH
HCl (strong)	0.01 M	0.01 M	2.0
Vinegar (weak)	0.01 M	~0.0004 M	~3.4

Teacher: "The strength of a weak acid is measured by its K_a (acid dissociation constant). You don't need to memorize these — just know that weak acids don't fully break apart."

Partner talk (1 minute): "Tell your partner: Why is vinegar less acidic than hydrochloric acid at the same concentration?" (Vinegar is a weak acid — it doesn't fully dissociate into

H^+ ions.)

SEGMENT 4: Titration — Finding the Concentration of Vinegar (15 minutes)

Teacher says: "Titration (ty-TRAY-shun) is a lab technique to find the concentration of an acid or base by reacting it with a known concentration of base or acid."

Titration: A controlled neutralization reaction used to find unknown concentration.

The Titration Formula (Same as Dilution!)

For acid-base neutralization: M_acid × V_acid = M_base × V_base *(But only if the acid and base react in a 1:1 ratio, like HCl + NaOH)*

For vinegar (acetic acid) + sodium hydroxide (NaOH):

text

$HC_2H_3O_2 + NaOH \rightarrow NaC_2H_3O_2 + H_2O$

1 mole of acetic acid reacts with 1 mole of NaOH → 1:1 ratio.

Worked Example 1: Titrating Vinegar

Problem: A 25.0 mL sample of vinegar is titrated with 0.100 M NaOH. It takes 40.0 mL of NaOH to reach the endpoint (when all acid is neutralized). What is the molarity of acetic acid in the vinegar?

Step 1: Identify knowns

Variable	Value
M_base (NaOH)	0.100 M
V_base (NaOH)	40.0 mL = 0.0400 L
V_acid (vinegar)	25.0 mL = 0.0250 L
M_acid	?

Step 2: Use M_acid × V_acid = M_base × V_base (for 1:1 reaction)

Step	Calculation
M_acid × 0.0250 L = 0.100 M × 0.0400 L	
M_acid × 0.0250 = 0.00400	
M_acid = 0.00400 ÷ 0.0250	
M_acid = 0.160 M	

Answer: The vinegar is 0.160 M acetic acid.

Step 3: Convert to percent by mass (optional — to match the label)

Vinegar label says "5% acetic acid." Does 0.160 M equal 5%?

Step	Calculation
Molar mass acetic acid = 60.05 g/mol	
Grams per liter = 0.160 mol/L × 60.05 g/mol	= 9.61 g/L
Assume vinegar density ≈ 1.00 g/mL, so 1 L vinegar ≈ 1000 g	
Percent by mass = (9.61 ÷ 1000) × 100%	= 0.96%

Wait — that's not 5%!

Teacher: *"That's because kitchen vinegar is actually about 0.8 M, not 0.16 M. The problem used made-up numbers. Real vinegar is about 5% acetic acid, which is about 0.83 M."*

Worked Example 2: Real Vinegar

Problem: A 25.0 mL sample of real vinegar (5% acetic acid) is titrated with 0.500 M NaOH. About how many mL of NaOH will be needed? (Assume vinegar is 0.83 M acetic acid)

Step	Calculation
M_acid × V_acid = M_base × V_base	
(0.83 M) × (0.0250 L) = (0.500 M) × V_base	
0.02075 = 0.500 × V_base	
V_base = 0.02075 ÷ 0.500 = 0.0415 L = 41.5 mL	

Answer: About 41.5 mL of NaOH is needed.

Worked Example 3: Titrating Stomach Acid (Antacid Testing)

Problem: An antacid tablet neutralizes HCl in your stomach. In a lab test, a tablet is dissolved and titrated with 0.100 M HCl. It takes 25.0 mL of HCl to neutralize the tablet. How many moles of base (antacid) were in the tablet?

Step	Calculation
M_acid × V_acid = moles of acid used	
Moles HCl = 0.100 M × 0.0250 L = 0.00250 mol	

Answer: The tablet contains 0.00250 moles of base (enough to neutralize 0.00250 moles of stomach acid).

Household connection: That's why antacids work — the base neutralizes excess stomach acid.

Partner talk (1 minute): *"Tell your partner: If it takes 30.0 mL of 0.100 M NaOH to neutralize 15.0 mL of an acid, what is the acid concentration? (M_acid = (0.100 × 0.0300) ÷ 0.0150 = 0.200 M)."*

SEGMENT 5: Buffers — Why Your Blood Stays at pH 7.4 (12 minutes)

Teacher says: *"Your blood must stay at pH 7.35-7.45. If it drops to 7.0, you get acidosis (can cause coma). If it rises to 7.8, you get alkalosis (can cause muscle spasms, death). Your body uses buffers to keep pH stable."*

Buffer: A solution that resists changes in pH when small amounts of acid or base are added.

How a buffer works: A buffer contains a weak acid and its conjugate base (the salt of that weak acid).

Component	What It Does
Weak acid (HA)	Neutralizes added base (OH^-) → $HA + OH^- \rightarrow A^- + H_2O$
Conjugate base (A^-)	Neutralizes added acid (H^+) → $A^- + H^+ \rightarrow HA$

Household Example: Baking Soda (Sodium Bicarbonate)

Teacher: "Baking soda ($NaHCO_3$) is a buffer. It contains bicarbonate (HCO_3^-), which can act as a weak base, and its conjugate acid (H_2CO_3 — carbonic acid) is also present in small amounts."

Why baking soda fizzes with acid:

text

HCO_3^- + H^+ (from acid) → H_2CO_3 → H_2O + CO_2 (fizz)

Why baking soda can also neutralize base:

text

HCO_3^- + OH^- (from base) → CO_3^{2-} + H_2O

Teacher: "That's why baking soda is so useful — it can buffer against both acids and bases."

The Blood Buffer (Bicarbonate Buffer System)

Teacher: "Your blood contains the bicarbonate buffer system:

H_2CO_3 (carbonic acid) ⇌ H^+ + HCO_3^- (bicarbonate)

What Happens	Buffer Response
Too much acid (H^+)	HCO_3^- absorbs H^+ → forms H_2CO_3
Too much base (OH^-)	H_2CO_3 releases H^+ → neutralizes OH^-

Your lungs and kidneys help too:

Lungs: Breathe faster to remove CO_2 (which lowers acidity)

Kidneys: Remove excess H^+ or HCO_3^- in urine

Household Example: Swimming Pool Buffer

Teacher: "Pool water contains a buffer (usually bicarbonate or cyanuric acid) to keep pH between 7.2 and 7.8. If pH gets too high (too basic), pool stores sell 'pH decreaser' (an acid). If pH gets too low (too acidic), they sell 'pH increaser' (a base). The buffer helps prevent sudden changes."

Partner talk (1 minute): "Tell your partner: Why is your blood able to stay at pH 7.4 even when you drink acidic soda or eat basic antacids?" (Buffers absorb the extra H^+ or OH^-, preventing pH change.)

SEGMENT 6: Putting It All Together — Complete Acid-Base Problem (6 minutes)

Teacher says: "Let's do one complete problem that uses everything from today's lecture."

Problem: You have a 0.100 M HCl solution (strong acid). You take 50.0 mL of this acid and titrate it with 0.200 M NaOH (strong base). Answer the following:

What is the initial pH of the HCl solution?

How many moles of HCl are present?

What volume of NaOH is needed to neutralize the HCl?

What is the pH at the equivalence point (when all acid is neutralized)?

Part 1: Initial pH of 0.100 M HCl

Step	Calculation
HCl is a strong acid, so $[H^+]$ = 0.100 M	
pH = -log(0.100) = $-\log(10^{-1})$	= 1.00

Part 2: Moles of HCl

Step	Calculation
Moles = M × V = 0.100 mol/L × 0.0500 L	= 0.00500 mol

Part 3: Volume of NaOH needed

Reaction: HCl + NaOH → NaCl + H_2O (1:1 ratio)

Step	Calculation
M_base × V_base = moles NaOH needed	
0.200 M × V_base = 0.00500 mol	
V_base = 0.00500 ÷ 0.200	= 0.0250 L = 25.0 mL

Part 4: pH at equivalence point

Step	Calculation
At equivalence, only NaCl (table salt) and water remain	
NaCl does not affect pH (salt of strong acid + strong base)	
The solution is neutral	pH = 7.00

Answer:

Initial pH = 1.00

Moles HCl = 0.00500 mol

Volume NaOH = 25.0 mL

pH at equivalence = 7.00

CLOSING — The 60-Second Challenge (5 minutes)

Teacher says: *"Pair up. Person A: 60 seconds — explain how to calculate pH from [H^+] (use lemon juice as an example). Person B: 60 seconds — a 0.010 M solution of a strong acid has pH = ? (pH = 2). A 0.010 M solution of a weak acid has pH higher or lower than 2? (Higher, because weak acids don't fully dissociate)."*

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

You learned...	Household Example
pH = -log[H^+]	Lemon juice [H^+] = 0.01 M → pH = 2
Strong acids fully dissociate ([H^+] = [acid])	HCl in pool acid: 0.01 M → pH = 2
Weak acids partially dissociate	Vinegar: 0.01 M → pH ≈ 3.4 (less acidic)

You learned…	Household Example
Titration: M_acid × V_acid = M_base × V_base (for 1:1 ratio)	Find vinegar concentration (about 0.83 M = 5%)
Buffer resists pH changes	Blood (pH 7.4), baking soda, pool water
Bicarbonate buffer system	$H_2CO_3 \rightleftharpoons H^+ + HCO_3^-$ (in your blood)
Antacids neutralize stomach acid	Tums ($CaCO_3$) + HCl → $CaCl_2$ + H_2O + CO_2

Final line (preview of L2-8): "Next session: Thermodynamics (Advanced) — calculating heat ($q = mc\Delta T$), enthalpy, and why your hand warmer gets hot. See you then."

SUPPLEMENTARY MATERIALS FOR L2-7 (No Grade)

Resource	Household Connection	Description	How to Find It
PhET "pH Scale" simulation	Interactive pH measurement	Drag items into water, see pH	Search "PhET pH scale"
PhET "Acid-Base Solutions" simulation	Strong vs. weak acids	See dissociation at particle level	Search "PhET acid-base solutions"
Titration virtual lab	Vinegar analysis	Interactive titration	Search "PhET titration"
Blood buffer article	Why pH 7.4 matters	Medical chemistry	Search "bicarbonate buffer system blood"

"*This week, test the pH of some household liquids using red cabbage indicator (boil red cabbage, use the purple water). Test lemon juice, vinegar, baking soda dissolved in water, and soap. Compare the colors. Next time, tell us what you observed.*"