CHEMDU · COMMUNITY CHEMISTRY · LEVEL 2 ADVANCED

LECTURE L2-1

Atomic Structure

Isotopes, Atomic Mass, and Why Bananas Are Slightly Radioactive

Duration: 60 minutes

Advanced lecture script — pre-requisite: Level 1

HOOK (3 minutes)

Teacher holds up (or shows photos of):

A banana (contains potassium-40 — radioactive)

A smoke detector (contains americium-241 — also radioactive)

A box of table salt (sodium chloride — contains two isotopes of chlorine)

Teacher says: "A banana is slightly radioactive. So is a smoke detector. So is a granite countertop. But table salt is safe enough to eat.

Why are some things radioactive and others not? And how do scientists calculate the atomic mass you see on the periodic table — like chlorine's 35.45?

- Today's question: What are isotopes — and how do they affect the world around you? *

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

Explain what an isotope is using household examples

Calculate the average atomic mass of an element (like chlorine in table salt)

Understand why some isotopes are radioactive and some are stable"

SEGMENT 1: Review from Level 1 (5 minutes)

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

Level 1 Concept	Definition	Household Example
Atom	The smallest piece of an element	A single atom of gold is still gold
Proton	Positively charged particle in the nucleus	Determines which element (6 protons = carbon)
Neutron	Neutral particle in the nucleus	Adds weight; can make atoms radioactive
Electron	Negatively charged particle outside nucleus	Creates electricity, bonding, light
Nucleus	Tiny, dense center of an atom	Contains protons + neutrons
Atomic number	Number of protons	Carbon has atomic number 6
Radioactive decay	Unstable atom shoots out particles to become stable	Radon gas from uranium in soil
Alpha particle	Heavy, slow — stopped by paper	Smoke detector (safe when sealed)

Level 1 Concept	Definition	Household Example
Beta particle	Fast electron — stopped by aluminum foil	Carbon-14 dating
Gamma ray	High-energy wave — stopped by lead or concrete	Medical X-rays

Quick check (show of hands / chat): "What subatomic particle determines which element an atom is?" (Proton) "What is the atomic number of carbon?" (6) "What is the atomic number of oxygen?" (8)

Teacher: "Good. Now let's add one more detail: neutrons. Atoms of the same element always have the same number of protons. But they can have different numbers of neutrons. That's where isotopes come in."

SEGMENT 2: What Are Isotopes? (10 minutes)

Teacher says: "An isotope (EYE-soh-tope) is a version of an element with a different number of neutrons.

Isotope: Atoms of the same element (same number of protons) but different number of neutrons.

Show this table:

Element	Protons	Neutrons	Mass Number (P + N)	Isotope Name
Carbon	6	6	12	Carbon-12
Carbon	6	7	13	Carbon-13
Carbon	6	8	14	Carbon-14 (radioactive)

Teacher: *"Carbon-12 is stable — it never changes. Carbon-14 is radioactive — it slowly decays into nitrogen over thousands of years. That's how scientists date ancient bones and artifacts."*

Household Example 1: Chlorine in Table Salt

Teacher says: "Table salt is sodium chloride (NaCl). The chlorine in table salt is a mixture of two stable isotopes:

Isotope	Protons	Neutrons	Mass Number	% in Nature
Chlorine-35	17	18	35	About 76%
Chlorine-37	17	20	37	About 24%

> *"Both are stable — not radioactive. They behave the same way chemically because they have the same number of protons and electrons."*

Household Example 2: Potassium in Bananas

> Teacher says: *"Bananas contain potassium. Most potassium is stable — but about 0.0117% is potassium-40, which is radioactive.*

Isotope	Protons	Neutrons	Mass Number	% in Nature	Radioactive ?
Potassium-39	19	20	39	93.26%	No
Potassium-40	19	21	40	0.0117%	Yes (beta + gamma)
Potassium-41	19	22	41	6.73%	No

Teacher: "The radiation from a banana is extremely small — you'd have to eat millions of bananas at once to get sick. But it's real. A geiger counter can detect it."

Household Example 3: Americium in Smoke Detectors

> Teacher says: *"Some smoke detectors contain americium-241. This isotope is radioactive (alpha emitter). It's sealed inside a small metal chamber. The alpha particles ionize the air, creating a small electric current. Smoke disrupts the current — and the alarm sounds."*

Isotope	Protons	Neutrons	Mass Number	Radioactive ?	Use
Americium-241	95	146	241	Yes (alpha)	Smoke detectors

Safety note: "The americium is sealed inside. Never take apart a smoke detector. Dispose of old smoke detectors at hazardous waste facilities."

Notation for Isotopes

> Teacher says: "Chemists use a special notation to write isotopes quickly."

AZX notation:

A = mass number (protons + neutrons)

Z = atomic number (protons)

X = element symbol

Example — Carbon-14:

text

C

or written as ^{14}C or C-14

Practice (teacher demonstrates, students follow): *"Write the AZX notation for Chlorine-35."*

Answer: ^{35}Cl with a subscript 17 (or simply Cl-35)

> Partner talk (1 minute): *"Tell your partner: What is the difference between Carbon-12 and Carbon-14?"*

Answer: Same number of protons (6), different number of neutrons (6 vs. 8). Carbon-14 is radioactive; Carbon-12 is stable.

SEGMENT 3: Atomic Mass — Why It's Not a Whole Number (12 minutes)

> Teacher says: "Look at the periodic table. The atomic mass of chlorine is 35.45 — not 35, not 37. Why?

Atomic mass is the weighted average of all the isotopes of an element, based on how common each isotope is in nature.

The formula:

Average atomic mass = $(mass_1 \times fraction_1) + (mass_2 \times fraction_2) + ...$

Teacher: "The 'fraction' is the percent abundance divided by 100."

Worked Example 1: Chlorine (Household — Table Salt)

> Teacher says: "Chlorine has two stable isotopes:

Isotope	Mass (amu)	Percent Abundance
Chlorine-35	34.97 amu	75.78% (0.7578)
Chlorine-37	36.97 amu	24.22% (0.2422)

Step-by-step calculation:

Step	Calculation
Step 1	Convert percent to fraction: 75.78% = 0.7578; 24.22% = 0.2422
Step 2	Multiply each mass by its fraction: 34.97 × 0.7578 = 26.50
Step 3	36.97 × 0.2422 = 8.95
Step 4	Add them together: 26.50 + 8.95 = 35.45

Answer: The average atomic mass of chlorine is 35.45 amu — exactly what the periodic table shows.

Teacher: *"That's why chlorine isn't 35 or 37. It's a weighted average — closer to 35 because Chlorine-35 is more common."*

Worked Example 2: Potassium (Household — Bananas)

Teacher says: "Potassium has three isotopes. Let's calculate its average atomic mass.

Isotope	Mass (amu)	Percent Abundance
Potassium-39	38.96 amu	93.26% (0.9326)
Potassium-40	39.96 amu	0.0117% (0.000117)
Potassium-41	40.96 amu	6.73% (0.0673)

Step-by-step calculation:

Step	Calculation
Step 1	K-39: 38.96 × 0.9326 = 36.33
Step 2	K-40: 39.96 × 0.000117 = 0.00468
Step 3	K-41: 40.96 × 0.0673 = 2.76
Step 4	Add: 36.33 + 0.00468 + 2.76 = 39.09 amu

Answer: The average atomic mass of potassium is about 39.1 amu — matches the periodic table.

Teacher: *"Notice that potassium-40 is only 0.0117% of natural potassium — a tiny fraction. But it's enough to make bananas detectable with a geiger counter."*

Worked Example 3: Carbon (Used in Radiocarbon Dating)

Teacher says: "Carbon has three isotopes. Calculate its average atomic mass.

Isotope	Mass (amu)	Percent Abundance
Carbon-12	12.00 amu	98.93% (0.9893)
Carbon-13	13.00 amu	1.07% (0.0107)
Carbon-14	14.00 amu	Trace (0.0000000001%) — negligible

Step-by-step calculation:

Step	Calculation
Step 1	C-12: 12.00 × 0.9893 = 11.87
Step 2	C-13: 13.00 × 0.0107 = 0.139
Step 3	Add: 11.87 + 0.139 = 12.01 amu

Answer: The average atomic mass of carbon is 12.01 amu.

Teacher: *"Carbon-14 is so rare that it doesn't affect the average atomic mass. But it's extremely useful for dating old objects."*

SEGMENT 4: Stable vs. Radioactive Isotopes (10 minutes)

Teacher says: "Not all isotopes are radioactive. The stability of an isotope depends on the ratio of neutrons to protons."

The Neutron-to-Proton Ratio (n/p)

Show this table:

Element	Stable Isotopes	Unstable (Radioactive) Isotopes	n/p Ratio for Stable
Hydrogen (1 proton)	H-1 (0 neutrons)	H-2 (deuterium — stable), H-3 (tritium — radioactive)	0 to 1
Carbon (6 protons)	C-12 (6 n), C-13 (7 n)	C-14 (8 n — radioactive)	1.0 to 1.17
Chlorine (17 protons)	Cl-35 (18 n), Cl-37 (20 n)	Cl-36 (radioactive)	1.06 to 1.18
Uranium (92 protons)	None (all isotopes are radioactive)	U-235, U-238	> 1.5

Teacher: *"For small elements, stable isotopes have about the same number of neutrons as protons ($n/p \approx 1$). As elements get larger, they need more neutrons to stay stable — up to about 1.5 neutrons per proton.*"

Why Some Isotopes Are Radioactive

Teacher: "If an isotope has too many or too few neutrons, it's unstable. It will decay (release particles or energy) to become more stable."

Household example — Carbon-14:

Protons: 6

Neutrons: 8

n/p ratio = 8/6 = 1.33 (too high for carbon)

Decays into nitrogen-14 (stable) with a half-life of 5,730 years

Household example — Potassium-40 (in bananas):

Protons: 19

Neutrons: 21

n/p ratio = 21/19 = 1.11 (slightly high for potassium)

Decays into argon-40 or calcium-40 (stable) with a half-life of 1.25 billion years

> Partner talk (1 minute): *"Tell your partner: Why is Carbon-14 radioactive but Carbon-12 is stable?"*

Answer: Carbon-14 has too many neutrons (8) for its 6 protons (n/p = 1.33). Carbon-12 has the right number (6 neutrons, n/p = 1.0).

SEGMENT 5: Household Radioactive Isotopes — Where They Are (10 minutes)

> Teacher says: "Let's look at where isotopes show up in everyday life — and whether they're dangerous."

Show this table:

Household Item	Isotope	Type of Radiation	Radioactive ?	Dangerous?	What to Do
Banana	Potassium-40	Beta, gamma	Yes (0.0117% of K)	No	Eat normally
Smoke detector	Americium-241	Alpha	Yes (sealed)	No (if sealed)	Don't take apart
Old radium watch (pre-1970s)	Radium-226	Alpha, beta, gamma	Yes	Maybe (if opened)	Don't open; store in box
Granite countertop	Uranium, radium, radon	Alpha, gamma	Yes (very low)	No (unless you sleep on it)	Ventilate kitchen
Cat litter (clay-based)	Uranium, thorium	Alpha	Yes (very low)	No	Use normally; wash hands
Brazil nuts	Radium	Alpha, gamma	Yes (very low)	No	Eat in moderation
Tap water	Various (radon, uranium)	Alpha	Yes (trace)	No (unless well water is high)	Test well water for radon
Radon gas (in basements)	Radon-222	Alpha	Yes	YES (if high levels)	Test home for radon

Radon — The Most Important Household Isotope

> Teacher says: *"Radon is the #1 cause of lung cancer in people who have never smoked. It comes from uranium in the soil. Uranium decays into radium, which decays

into radon-222 (an alpha emitter).*

Radon is a gas. It seeps into basements through cracks. You breathe it in. The alpha particles damage your lung cells.

What to do:

- Test your home for radon (kit costs $15-30 at hardware store)*
- If levels are above 4 pCi/L, install a radon mitigation system (pipe + fan, about $800-1,500)*

Partner talk (1 minute): "Tell your partner: Why is radon more dangerous than a smoke detector?"

Answer: Radon is a gas you breathe in (alpha particles inside your lungs). Smoke detector radiation is sealed inside plastic — you don't inhale it.

SEGMENT 6: Calculating Remaining Radioactivity — Half-Life (8 minutes)

Teacher says: "Radioactive isotopes decay at predictable rates. The half-life (HALF-lyfe) is the time it takes for half of a radioactive sample to decay.

Half-life: The time it takes for half of the radioactive atoms in a sample to decay into a different element.

Show this simple example:

Starting Amount	After 1 Half-Life	After 2 Half-Lives	After 3 Half-Lives
100 atoms	50 atoms	25 atoms	12.5 atoms

Worked Example 1: Carbon-14 (Radiocarbon Dating)

Teacher says: *"Carbon-14 has a half-life of 5,730 years. If you start with 100 grams of carbon-14, how much remains after 17,190 years?"*

Step	Calculation
Step 1	Determine how many half-lives have passed: 17,190 ÷ 5,730 = 3 half-lives
Step 2	After 1 half-life: 100 g → 50 g
Step 3	After 2 half-lives: 50 g → 25 g
Step 4	After 3 half-lives: 25 g → 12.5 g

Answer: 12.5 grams remain.

Worked Example 2: Potassium-40 (Bananas — Optional Math)

Teacher says: *"Potassium-40 has a half-life of 1.25 billion years. If you start with 100 atoms of potassium-40, how many remain after 2.5 billion years?"*

Step	Calculation
Step 1	Half-lives passed: 2.5 billion ÷ 1.25 billion = 2 half-lives
Step 2	After 1 half-life: 100 → 50 atoms
Step 3	After 2 half-lives: 50 → 25 atoms

Answer: 25 atoms remain.

Worked Example 3: Americium-241 (Smoke Detector — Optional)

Teacher says: *"Americium-241 has a half-life of 432 years. If a smoke detector contains 1 microgram of americium-241, how much remains after 864 years?"*

Step	Calculation
Step 1	Half-lives passed: 864 ÷ 432 = 2 half-lives
Step 2	After 1 half-life: 1 μg → 0.5 μg
Step 3	After 2 half-lives: 0.5 μg → 0.25 μg

Answer: 0.25 micrograms remain.

Teacher: *"This is why smoke detectors last so long — the half-life is 432 years, so they remain radioactive for many decades."*

CLOSING — The 60-Second Challenge (4 minutes)

Teacher says: "Pair up. Person A: 60 seconds — explain what an isotope is and give two household examples. Person B: 60 seconds — calculate the average atomic mass of an element with two isotopes: isotope A (mass 10, 20% abundance) and isotope B (mass 11, 80% abundance)."

Answer for Person B: (10 × 0.20) + (11 × 0.80) = 2 + 8.8 = 10.8 amu

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

You learned...	Household Example
Isotope = same protons, different neutrons	Carbon-12, Carbon-13, Carbon-14
Atomic mass = weighted average of isotopes	Chlorine in table salt is 35.45 amu
Radioactive isotopes have unstable n/p ratio	Carbon-14 (too many neutrons)
Half-life = time for half to decay	Carbon-14: 5,730 years
Radon = radioactive gas from soil	Test your home (kit $15-30)

You learned...	Household Example
Smoke detectors contain americium-241	Safe when sealed — don't take apart
Bananas contain potassium-40	Safe — but detectably radioactive

Final line (preview of L2-2): "Next session: Periodic Table (Advanced) — why potassium pills are safe but pure potassium metal explodes in water, and how to predict an element's behavior using periodic trends. See you then."

SUPPLEMENTARY MATERIALS FOR L2-1 (No Grade)

Resource	Household Connection	Description	How to Find It
PhET "Isotopes and Atomic Mass" simulation	Build isotopes of carbon, hydrogen	Interactive — see how neutrons change mass	Search "PhET isotopes and atomic mass"
Half-life simulation	Carbon-14 dating	Watch atoms decay over time	Search "PhET half-life"
Radon test kit information	Home safety	Where to buy, how to use	Search "EPA radon test kit"
Article: "Banana equivalent dose"	Radiation humor	Explains how bananas compare to other sources	Search "banana equivalent dose"

"This week, look at the smoke detector in your home. Find the radiation symbol or the word 'americium' on the label (usually on the back). Don't open it — just look. Next time, tell us what you found."