45-minute lesson script with props

The 45-minute core lesson, minute by minute (no IR instrument needed)

For students aged about 14–18 or first-year undergraduates.

- Each stage lists the props, what is on the screen, what to say, what students do, the answers to expect and the answer to give.
- It works with the single-colour engraved model and with colour + engraved.
- This lesson is for everyday teaching: it is *not* one of the controlled studies in our research article, although we would love to hear how it went.

00:00–02:00 The case opens

Props
2–3 coffee cups and the energy-drink can on the front of the desk. Models stay hidden.

Screen
Slide 2: “What do all of these have in common?”

Say
“Before we open a book: look at the desk. What do all of these have in common?”

Students
Call out ideas; you collect them without judging.

Expect
“Drinks”, “they wake you up”, “caffeine”, brand names (keep brands covered).

Your move
“Keep those answers. In 40 minutes we will know which of them is chemistry.”

02:00–04:00 First guess

Props
Board and marker; worksheet box 1.

Screen
Slide 3.

Say
“Which chemical do you link with coffee and energy drinks?”

Students
Write their guess in box 1, then share.

Expect
Caffeine; sometimes sugar or taurine for the energy drink.

Your move
Write **caffeine** on the board and circle it. “Good. Now let’s test what you think you know about it.”

04:00–07:00 Exhibit A: the blind smell test

Props
Jars 1–4, closed, in the teacher's hands only. Smelling is voluntary: anyone may decline without giving a reason and record the results instead.

Screen
Slide 4: four numbered jars.

Say

- "Two of these jars hold things you know, ground coffee and an energy drink, and both contain caffeine. One holds pure caffeine dissolved in water, about as much per litre as the energy drink. One holds only water. Which two jars will smell exactly alike? Predict first, then write what you smell for each number."
- Then: "Coffee and the energy drink both contain caffeine. So why do they smell so different?"

Students
Predict first, then smell from a distance and write a word for each jar in box 2. Last question: "Which jar holds only caffeine dissolved in water?"
Lecture hall: three to five volunteers at the desk smell and call out; the hall records the predictions and the volunteers' words.

Expect
Jars 3 and 4 both marked "nothing"; guesses between them split roughly by chance. Some students expect caffeine to smell like coffee.

Your move
Collect hypotheses on the board. Do not give the answer yet.

The teacher holds each numbered jar in turn, lifts the lid briefly about 20 cm from the students and wafts the air towards them; nobody sniffs from the jar or touches its contents.

07:00–10:00 Exhibit A: the reveal

Props
Turn the jars over to show the labels; hold up the sealed vial of white solid.

Screen
Slide 5: the four jars revealed one by one; jar 3 smells the same as jar 4.

Say
"This white powder is pure caffeine. It is what I dissolved in jar 3, about as much as in the energy drink. Who could tell jar 3 from the water in jar 4?"

Students
Compare their notes for jars 3 and 4.

Expect
Surprise: "then what makes coffee smell?"

Your move
"Caffeine is one substance, and it has no smell. Coffee is a mixture of many compounds, and some of them carry the aroma. Same molecule in two drinks, completely different smells." Write **substance** and **mixture** on the board.

Jar 2 · energy drink

About 0.3 g of caffeine per litre, plus everything else in the can.

Smells strongly.

Jar 3 · caffeine solution

About the same caffeine per litre, and nothing else.

Should smell of nothing, like the water in jar 4.

- The science: pure caffeine is odourless (PubChem, citing the Merck Index).
- The water jar is what makes it evidence rather than an impression, a small lesson in why scientists use controls.
- The aroma of coffee comes from a complex mixture of many other compounds (Sunarharum, Williams & Smyth, 2014).



Roasted coffee beans: their smell comes from a mixture of many other compounds, not from caffeine. Photo: Robert Knapp, Wikimedia Commons, CC BY-SA 3.0.

10:00–14:00 Exhibit B: read the label

Props
The can, passed round (closed); the coffee cups.

Screen
Slides 6 and 7: the EU rule, then the sum revealed step by step; then the label calculator with the numbers from the can.

Say
“Find the words ‘high caffeine content’ and the number next to them. How much caffeine is in the whole can?” Then: “Now find the same number on the coffee cup.”

Students
Read mg per 100 ml, calculate mg per can in box 3, look for a number on the cup.

Expect
About 75–80 mg for a 250 ml can; “the cup doesn’t say”.

Your move
“So which contains more caffeine, the can or the cup? The can declares its amount; the cup may not tell you how much caffeine your serving contains. In one study a single coffee-shop serving held anywhere from 58 to

259 mg: less than the can, or more than three times as much, and usually more than the can.”

- The science: in the EU, drinks other than coffee and tea with more than **150 mg of caffeine per litre** must carry the words “High caffeine content. Not recommended for children or pregnant or breast-feeding women”, followed by the caffeine content in mg per 100 ml (Regulation (EU) No 1169/2011, Annex III, point 4.1).
- Typical energy drinks contain about 300–320 mg per litre (EFSA Panel on Dietetic Products, Nutrition and Allergies, 2015).
- In one study of coffee-shop coffee, caffeine ranged from 58 to 259 mg per serving, and the same drink bought from the same shop on six consecutive days ranged from 259 to 564 mg (McCusker, Goldberger & Cone, 2003).

14:00–18:00 Exhibit C: the molecule in your hands

Props
One engraved model per pair, handed out now.

Screen
Slide 8: the numbers after C, H, N and O appear one press at a time.

Say
“This is one caffeine molecule, many millions of times bigger than the real one. Read the letters, count the atoms and write the formula.”

Students
Count by element in box 4 and check each other.

Expect
Hydrogens miscounted (some sit behind other atoms); $C_8H_{10}N_4O_2$ after checking.

Your move
Reveal the last line of slide 8: 24 atoms. “Which hydrogens did you miss? Turn the model to find them.”



What each pair gets: an engraved caffeine model, here our single-colour print seen from above.

18:00–23:00 Exhibit C: rotate to reveal

Props
The models; worksheet box 5.

Screen
Slide 9: the same model from the front and from behind.

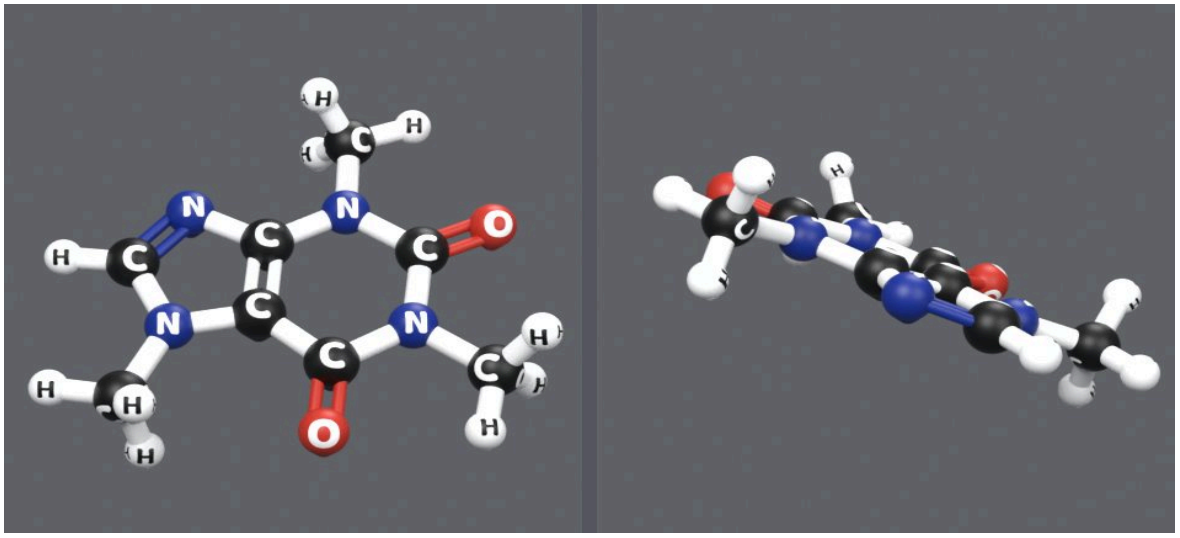
Say
Three levels. “

- **1. Recall:** partner A holds the model with its plain back towards partner B; B names every atom possible from its position and bonds.
- **2. Turn and search:** turn it round. About 18 of the 24 letters face you from the front; turn and tilt the model to find the other six.
- **3. Verify:** read every letter and score yourself.
- Then swap.”

Students
Name, turn, check, score themselves in box 5, swap roles.

Expect
Carbons and oxygens named well, nitrogens confused with carbons, hydrogens easy.

Your move
“What helped you name a nitrogen without its letter? Count its bonds.”



Why it works on our models: from the front 18 of 24 symbols are readable, turned round none are (turn it yourself). Rendered from the print design.

23:00–26:00 Exhibit C: 3D meets 2D

Props
2D structure printouts, one per pair; models.

Screen
Slide 10: the 2D structure. For a bigger picture, switch to the viewer in *Flat 2D*.

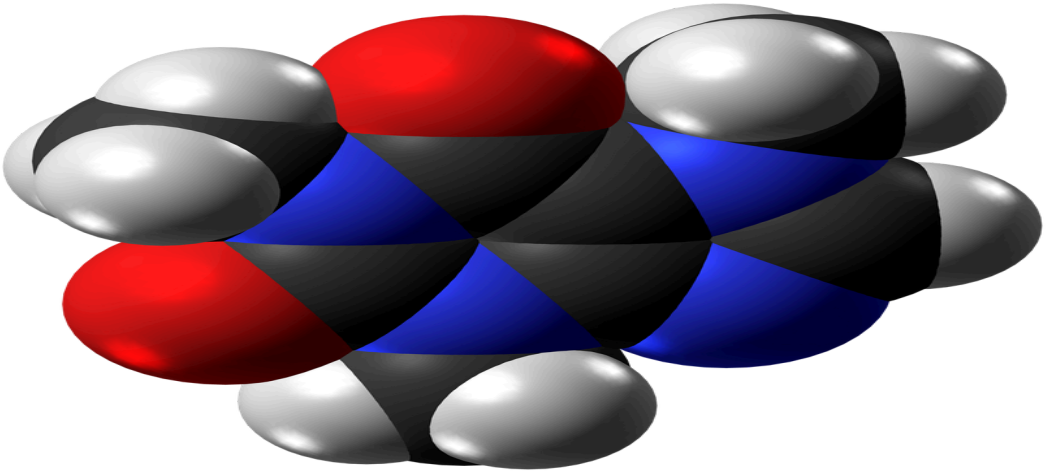
Say
“Put the model next to the drawing. Find the four nitrogens, the two C=O double bonds and the two rings. Which ring has five atoms, which has six?”

Students
Point on both, mark on the printout, answer in box 6.

Expect

Hydrogens missing on the drawing confuse some students.

Your move
“Chemists leave the hydrogens on carbon out of drawings. Where are they on your model?”



A third picture of the same molecule: a space-filling model, each atom drawn as a sphere with its approximate van der Waals radius, a standard way to show how much space a molecule fills (not a photograph of atoms). Ask: which atoms of your model are hidden inside this one? Image: Jynto, Wikimedia Commons, CC0.

26:00–34:00 Exhibit D: the spectra, on the big screen

Props
The models stay on the desks; the viewer in full screen on the projector, *Flat 2D*, *Atom Labels* on.

Screen
Slide 11 for the three questions; for each answer press its *Show it live* button. The slides close, the live viewer opens in full screen on that spectrum, lying flat. Click the bands and atoms there; press `Esc` and return to the slides.

Say
If time is short, do IR and ^{1}H NMR live and leave the mass spectrum for box 7 of the worksheet. “Chemists do not identify a molecule by looking at it. They measure it. Three challenges: answer first, then we look.” After each vote, open the spectrum: IR and click the band at 1686 cm^{-1}; ^{1}H NMR in DMSO-d_6; the mass spectrum.

Students
Vote and write each answer in box 7, then find the same groups on the model in their hands: the two C=O groups, the three methyl groups and the lone ring hydrogen.

Expect
“One peak for each bond” for IR; “ten signals” for NMR.

Ages 14–16
Show only the mass spectrum: the peak at *m/z* 194 is the whole molecule, and its mass matches the formula students counted on the model. Keep IR and NMR for older students or for the infrared extension.

Your move

- “A band belongs to a vibration of the whole molecule, so read it as where the C=O groups contribute most.

- Equivalent hydrogens share one signal.
- The peak at *m/z* 194 is the molecular ion, $M^{+\cdot}$: the whole molecule with one electron removed. Its nominal mass, 194, is consistent with the molar mass of $C_8H_{10}N_4O_2$, 194.19 g/mol."
- Questions for every spectrum are in the spectra gallery.

34:00–37:00 The evidence board

Screen
Best live: press *Show it live* on slide 12 to open the viewer in *All in one* mode, all ten caffeine spectra on one screen, and click through them. If the network fails, slide 12 itself reveals the three spectrum pictures one by one.

Say
"Would one peak be enough to identify caffeine?"

Expect
"Yes, the 194." Many molecules share a mass, a group or a signal.

Your move
"IR tells you which groups are there, NMR in what surroundings the atoms sit, mass spectrometry how heavy the molecule is. None of them alone is proof; together they point to one molecule."

37:00–41:00 Models away

Props
Collect the models into the box.

Screen
Slide 13: four questions.

Say
"Models away. Answer from memory, on your own."

Students
Answer the four questions in box 8, then sketch caffeine from memory: the two rings, where the nitrogens and the oxygens sit. Not a perfect drawing, just the layout.

Expect
See the answer key.

Your move
Go through the answers together; ask a student who skipped the smell test to explain jar 3.

41:00–45:00 The verdict

Props
Back to the cups and the can.

Screen
Slide 14: the verdict, revealed line by line.

Say
"Case 58-08-2: what is in your cup, one chemical or a whole world of molecules? Look at your first guess and how sure you were. Has it changed? Write your verdict: our conclusion is… because… one limitation is…"

Students
Write the verdict in box 9; two or three read theirs out.

Expect
“Caffeine doesn’t smell”, “coffee is a mixture”, “the can has to tell you”.

Your move
Point back to the answers from minute one: “Which of these turned out to be chemistry?” Set the homework: press End to jump to the last slide, skipping the extension slides.

Stretch task for older students

The molar mass of caffeine is about 194.19 g/mol. How many caffeine molecules are in 80 mg? (About 4.1×10^{-4} mol, or roughly 2.5×10^{20} molecules: a quarter of a thousand billion billion copies of the object in their hand.) The label calculator does the same sum for any can.