

Count or Ratio? Building Molecules and a Salt Block

Investigation question: What does a chemical formula actually count, and why does the answer change when you build table salt instead of water?

Physical model

Groups of 3

1 session

Setup 5 · Activity 40 · Cleanup 5 min

MS-PS1-1 · assesses

Scientific purpose

Students build gumdrop-and-toothpick models of six small molecules and the butane/isobutane pair, then build a table-salt block that they keep enlarging. By counting atoms in every build they discover that a molecule's count never changes no matter how many times it is rebuilt, while the salt block's totals grow and only its 1:1 ratio stays fixed. The formula stops being a label to memorize and becomes a claim about counts or ratios that students have checked with their own hands.

Why this helps students with this chapter

Students can recite that H_2O has three atoms and still believe NaCl is a two-atom molecule, because every formula looks the same on paper. Building both makes the difference physical: a water molecule is finished after three gumdrops, while the salt block never finishes and can be made any size. Rebuilding C_4H_{10} two different ways also shows that structure, not just count, decides the substance.

Standards connections

MS-PS1-1 (assesses, developing ball-and-stick models of simple molecules and of an extended structure, and describing their atomic composition): Students develop physical models of water, oxygen, carbon dioxide, methane, ammonia, hydrogen peroxide, butane, isobutane and a sodium chloride block, record each model's composition, and explain the count-versus-ratio difference. This is direct evidence toward the PE within its boundary: no electrons, bond energies or ionic charges are involved.

Roles (rotate each session)

- **Builder:** Assembles each model following the color key and the bond rule, and keeps finished models on the tray until they have been counted.
- **Checker:** Counts every sphere by color and every stick before a model is recorded, checks that each gumdrop has the right number of toothpicks, and calls out the counts.
- **Recorder:** Writes the counts, formula and shape in the build record, sketches the butane and isobutane skeletons, and fills the salt-block table.

Materials

Item	Quantity	Per	Note
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White gumdrops or mini marshmallows (hydrogen)	14	group	Foam craft balls in white work for a reusable, allergy-safe kit.
Red gumdrops (oxygen)	8	group	Seven are in use at once before the mid-lab take-apart step.
Black or dark gumdrops (carbon)	6	group	Any dark color; post it on the key.
Blue gumdrop (nitrogen)	1	group	
Purple gumdrops (sodium particles)	12	group	Any two colors not already on the key work for the salt block.
Green gumdrops (chlorine particles)	12	group	
Round toothpicks	70	group	Some will be broken in half for the salt block so it stays compact.
Printed color key and bond-rule card	1	group	
Paper plate or tray to hold finished models	1	group	
Recording sheet	1	student	
Paper cup for used toothpicks	1	group	

Estimated cost: 10 to 14 per class (an estimate; Two 1-pound bags of assorted gumdrops (about \$4 each) and a bag of mini marshmallows (\$2) cover eight groups; a box of 500 toothpicks is about \$2. A reusable foam-ball kit costs about \$12 once and avoids food entirely.)

Safety

- Toothpick points can puncture skin and eyes. Hold models at desk level, never wave them, and drop used toothpicks into the cup, not on the floor.
- No eating any material. Candy that has been handled and pierced is not food; some students have gelatin, dye or sugar restrictions, and shared candy spreads germs.
- Wash hands after the lab; gumdrop sugar on hands transfers to keyboards and door handles.
- Broken toothpick halves are sharp; snap them inside the cup or under a paper towel.

Teacher preparation and setup

1. Sort gumdrops by color into one zip bag per group with the counts above; sorting in advance saves ten minutes of class time.
2. Print the color key and bond rule on one card per group: white H (1 bond), red O (2 bonds), black C (4 bonds), blue N (3 bonds), purple Na and green Cl (salt block only, connect only to the other color).
3. Build one of each molecule yourself so you know the shapes: water bent, carbon dioxide straight, methane a pyramid with the carbon in the middle, ammonia a shallow pyramid, hydrogen peroxide a four-atom chain.

4. Decide the no-eating policy and announce it before bags are opened; set out foam balls for any student who needs a non-food kit.
5. Draw a 4-by-4 checkerboard on the board labeled Na and Cl for reference during the salt-block steps.

Investigation design

Independent variable	The structure built: which molecule, or the size of the salt block
Dependent variable	The number of atoms of each element in the build, the total, and the ratio between elements
Controlled	The color key (same color always means the same element); The bond rule (H 1, O 2, N 3, C 4 toothpicks); One toothpick per single bond, two for a double bond; Salt block rule: a gumdrop connects only to the other color; The same two people count every build
Trials	Each build is counted independently by the checker and the recorder before it is written down; the class pools salt-block counts for all sizes on the board.
Comparison	Molecule builds (count fixed) versus salt blocks of increasing size (totals grow, ratio fixed).

Student procedure

1. Read the color key and the bond rule: hydrogen takes 1 toothpick, oxygen 2, nitrogen 3, carbon 4. One toothpick between two gumdrops is one bond. For oxygen gas and carbon dioxide, use two toothpicks side by side between the same pair to stand for a double bond.
2. Build water: one red, two white, each white joined to the red by one toothpick. Make the two toothpicks meet at the red in a wide V, not a straight line. Count spheres by color, count bonds, write the formula and shape in the build record.
3. Build oxygen gas (two red joined by two side-by-side toothpicks) and carbon dioxide (one black in the middle, a red on each side joined by double toothpicks, all in a straight line). Record both.
4. Build methane (one black with four whites, pointing to the corners of a pyramid, not flat) and ammonia (one blue with three whites, a shallow pyramid). Record both. Keep every model on the tray for now.
5. Build hydrogen peroxide: white-red-red-white in a chain, one toothpick per bond. Set it next to water, compare the two, and record. Then take water, oxygen gas, carbon dioxide, methane and ammonia apart, returning toothpicks to the cup; keep only hydrogen peroxide on the tray. You will need the freed black and white gumdrops for butane.
6. Build butane: four blacks in a row joined by single toothpicks. Add whites until every black has exactly four toothpicks. Count the whites. Record. Now take it apart and build isobutane: one black in the center joined to three other blacks, then add whites until every black has four toothpicks. Count the whites. Record both, and draw both carbon skeletons in the drawing box.
7. Start the salt block. Lay out a 2-by-2 square: purple, green on the first row, green, purple on the second, so every neighbor is the other color. Join neighbors with half toothpicks. Count each color and record the row for the 2-by-2 layer.

8. Build a second 2-by-2 layer with the colors swapped and set it on top so every purple sits above a green. Join the layers with half toothpicks. You now have a 2-by-2-by-2 cube. Count each color, record, and write the ratio in simplest form.
9. Enlarge the block: add a column to make 3-by-2-by-2, then another row to make 3-by-3-by-2, always keeping every neighbor the other color. Count and record after each size. If time allows, build one more size of your choice.
10. Look at your two tables. Decide for each build whether the formula is a count (the same every time) or a ratio (the totals change but the proportion does not). Answer q1 and q2 on the sheet, then the analysis questions on your own.

Expected observations

- Every molecule build gives one fixed count: water 2 H, 1 O (3 atoms, 2 bonds); oxygen gas 2 O (1 double bond); carbon dioxide 1 C, 2 O (2 double bonds, straight); methane 1 C, 4 H (4 bonds, pyramid); ammonia 1 N, 3 H (3 bonds, shallow pyramid); hydrogen peroxide 2 H, 2 O (3 bonds, chain).
- Butane and isobutane both end with 4 C and 10 H and 13 bonds, but the drawing shows a chain of four carbons (hydrogens 3, 2, 2, 3) versus a central carbon with three arms (hydrogens 1 on the center, 3 on each arm).
- Salt blocks: 2-by-2 layer 2 and 2; 2-by-2-by-2 cube 4 and 4; 3-by-2-by-2 6 and 6; 3-by-3-by-2 9 and 9. Totals climb from 4 to 18 while the ratio stays 1:1.
- Groups notice that the salt block has no natural stopping point and that a bigger block just repeats the same checkerboard.

Likely difficulties

- Students build methane flat like a plus sign. Ask them to hold it up and check whether all four hydrogens could be equally far from each other; push them toward the pyramid shape, and accept a rough pyramid.
- Hydrogen counts on butane come out at 8 or 12 because a carbon has three or five toothpicks. The checker must count toothpicks on every black gumdrop before the whites are counted.
- Salt blocks with two purples touching. Have groups say the rule aloud ('only the other color') before each new row, and compare with the checkerboard on the board.
- Students write the ratio as 9:9 instead of simplest form. Ask what 9:9 reduces to and why the simplest form is what the formula shows.
- Groups rush the double bonds and use one toothpick for oxygen gas. It does not change the count, so do not stall on it; note that double bonds are shown but not assessed.

Structured debrief

1. Pool the salt-block counts from every group on the board as a table of size, Na, Cl, ratio. Ask what every row has in common (1:1) and what no two rows share (totals). Then ask the same question about the water rows across groups: every group has 2 H, 1 O, and no group could have anything else.
2. Hold up a water model and a salt block. Ask: which one is finished? The water model is complete; the salt block could keep growing until the gumdrops run out. Name this difference: molecule (definite

count) versus extended structure (repeating subunit, definite ratio).

- Put butane and isobutane side by side and ask the class for one sentence that uses composition and structure. Land on: same composition, different structure, different substance. Mention that the counts alone could never tell you which was which.
- Close on the model's limits (q8): real atoms are not colored balls, bonds are not sticks, and the salt block's particles actually carry electric charges that hold the pattern together, a detail for later grades. The model is right about counts, connections and rough shape, which is exactly what MS-PS1-1 asks for.

Recording sheet: what students fill in

Lab 1 recording sheet: Count or ratio?

Record every build after the checker has counted it. Count spheres by color for the composition and toothpicks between pairs for the bonds (a side-by-side pair of toothpicks is one double bond). Write the formula from your count, not from memory.

Color key and bond rule — White = hydrogen (1 toothpick). Red = oxygen (2). Blue = nitrogen (3). Black = carbon (4). Purple = sodium particle and green = chlorine particle, salt block only, each connects only to the other color. Colors are a labeling habit, not the real color of atoms.

Molecule builds

Molecule	Atoms of each element (from your model)	Total atoms	Number of bonds	Formula	Shape (bent, straight, pyramid, chain, branch)
Water					
Oxygen gas					
Carbon dioxide					
Methane					
Ammonia					
Hydrogen peroxide					
Butane					
Isobutane					

- ✎ Draw the carbon skeletons of butane and isobutane side by side as circles and lines (carbons only). Next to each carbon write how many hydrogens it holds, and check that the hydrogens add to 10 in both.

Answer: Two carbon skeletons. Butane: four circles in a row joined by three lines, labeled 3, 2, 2, 3 hydrogens (sum 10). Isobutane: one central circle joined by three lines to three outer circles, labeled 1 hydrogen on the center and 3 on each outer carbon (sum 10). No line joins the three outer carbons to one another.

Why: The drawing is the evidence that structure, not count, differs. Every carbon must end with four bonds: the label plus the number of lines on each circle should total 4.

- Butane drawn as a chain of four with hydrogens 3, 2, 2, 3
- Isobutane drawn as a center with three arms with hydrogens 1, 3, 3, 3
- Hydrogens sum to 10 in both
- No bond drawn between isobutane's outer carbons

Salt block builds

Block size	Purple (Na) count	Green (Cl) count	Total particles	Ratio Na : Cl in simplest form
2 by 2 layer				
2 by 2 by 2 cube				
3 by 2 by 2				
3 by 3 by 2				
Your choice: ____				

1. Which builds gave the same count every time, and which build could you have kept making bigger? Name them.

Answer: Same count every time: water, oxygen gas, carbon dioxide, methane, ammonia, hydrogen peroxide, butane and isobutane (the molecules). Could keep growing: the salt block.

Why: Molecules are finished particles with a definite count; the salt block repeats a subunit and has no natural stopping point.

- Names the molecule builds as fixed
- Names the salt block as the one that could keep growing

2. Look at the ratio column of the salt table. What stayed the same as the block grew, and what changed?

Answer: The ratio of purple to green stayed 1:1 for every size. The counts of each color and the total changed (2 and 2, then 4 and 4, 6 and 6, 9 and 9).

Why: This is the observation that defines an extended structure: the proportion is fixed, the size is not.

- States the ratio stayed 1:1
- States that totals or individual counts grew

Analysis questions: answer key

3. Water and hydrogen peroxide use the same two colors of gumdrops. Using your build record, explain what makes them different substances.

Answer: They have different compositions. Water is 2 H and 1 O; hydrogen peroxide is 2 H and 2 O. One extra oxygen atom in every molecule makes a different substance with different properties (you drink one and would never drink the other).

Why: Same elements, different count: composition differs. Full credit requires the counts from the record.

- Gives both counts
- Attributes the difference to composition (number of atoms)

4. Butane and isobutane used exactly the same gumdrops: four black and ten white. Using your drawing, explain what makes them different substances.

Answer: They have the same composition (4 C, 10 H) but different structures. In butane the four carbons form a chain; in isobutane one carbon in the middle is bonded to the other three. The way the atoms are connected is different, so they are different substances.

Why: Same count, different connections: structure differs. Watch for 'triangle' descriptions; the three outer carbons are not bonded to each other.

- States the composition is identical
- Describes chain versus branch
- Concludes structure makes them different substances

5. Suppose you built a 4-by-4-by-4 salt block with every neighbor the other color. How many purple, how many green, what total, and what ratio? Show your reasoning.

Answer: 32 purple, 32 green, 64 total, ratio 1:1. A 4-by-4-by-4 block has $4 \times 4 \times 4 = 64$ positions; with every neighbor the other color, each layer is a checkerboard with 8 and 8, and four layers give 32 and 32. Ratio $32:32 = 1:1$.

Why: Students may count by layers (8 + 8 per layer, 4 layers) or halve the total. Either route earns full credit with the arithmetic shown.

Also acceptable: Accept 'half of 64 each' with the 1:1 ratio stated.

6. The formula H_2O and the formula NaCl look alike, but they mean different things. Using numbers from both of your tables, explain what each formula counts and why the salt formula has no small numbers.

Answer: H_2O counts the atoms in one water molecule: every water build had exactly 2 hydrogen and 1 oxygen, 3 atoms, and could not be anything else. NaCl gives a ratio, 1 sodium for every 1 chlorine: the salt table showed 4 and 4, 6 and 6, 9 and 9, so the number of particles depends on the size of the block, but the proportion is always 1:1. The salt formula has no small numbers because the simplest form of 1:1 is just one symbol of each; the formula is not saying 'one of each' in a molecule, it is saying 'equal numbers' in a structure of any size.

Why: This is the lab's central idea. The answer must use data from both tables and distinguish count from ratio explicitly.

- States H_2O is a count of one molecule, with the numbers
- States NaCl is a ratio, with at least two sizes from the salt table
- Explains why the salt formula has no subscripts (simplest form of 1:1)

7. A classmate looks at your 3-by-3-by-2 block and says, 'That is a bigger molecule of salt.' Write a reply that uses the words molecule, extended structure and ratio correctly.

Answer: It is not a molecule at all. A molecule has a definite number of atoms, like the three in water; our block has 18 particles now but could have had 8 or 64, so it has no set size, and that makes it an extended structure: a repeating pattern of sodium and chlorine particles in a 1:1 ratio. A bigger block is just the same pattern repeated more times, not a bigger molecule.

Why: Checks that students can reject the 'bigger molecule' idea with the right vocabulary and the ratio argument.

- Says the block is not a molecule and why (no definite count)
- Uses extended structure correctly
- Uses ratio correctly (1:1 at any size)

8. Name two ways the gumdrop model does not match real atoms and bonds, and one thing the model shows well.

Answer: Limits (any two): atoms are not colored and have no sharp edges; bonds are not sticks and are not rigid; sizes are not to scale; the angles are only rough; the salt particles really carry electric charges that hold them together, which the model cannot show; a real salt crystal gives each particle six neighbors, more than our toothpicks allowed. Shows well (any one): which atoms are present and how many; which atom is bonded to which; the rough shape (bent water, straight carbon dioxide); the repeating pattern of salt.

Why: Model evaluation is part of the modeling practice. Students should see the model as a tool with a purpose, not a picture.

- Two accurate limitations
- One accurate strength

9. Quartz is silicon and oxygen in a 1:2 ratio. If you built a quartz model with 24 silicon gumdrops, how many oxygen gumdrops would it need? If your bag held only 40 oxygen gumdrops, what is the largest number of silicon gumdrops you could use? Show the arithmetic.

Answer: 48 oxygen gumdrops: $24 \text{ silicon} \times 2 = 48$. With only 40 oxygen, the most silicon is $40 \div 2 = 20$, because every silicon needs two oxygens to keep the 1:2 ratio.

Why: Applies the ratio in both directions. The second part checks that students divide rather than multiply.

Also acceptable: Accept 20 with ' $40 \div 2$ ' or 'half of 40' shown.

Individual evidence of learning

Each student submits their own completed build record, the butane/isobutane drawing, the salt-block table and written answers to q1 through q9. The build record and q6 are the primary evidence for the composition-modeling target; q7 is the evidence for distinguishing a molecule from an extended structure.

Assessment criteria

Criterion	Proficient looks like
Model composition	All eight molecule rows have correct counts, totals, bond numbers and formulas written from the model, with shapes named.

Count versus ratio	Salt-block table complete with totals and simplest-form ratio; q6 explains that H ₂ O counts the atoms in one molecule while NaCl gives the ratio in a structure of any size, citing numbers from both tables.
Composition and structure	q3 and q4 correctly attribute the water/peroxide difference to composition and the butane/isobutane difference to structure, with the drawing showing chain versus branch and hydrogens summing to 10.
Model evaluation	q8 names two real limits of the model (for example, atoms are not colored, bonds are not sticks, salt's particles are charged, sizes are not to scale) and one thing it shows well (counts, connections or shape).

Accessibility adaptations

- Provide a build record with the water and oxygen rows filled in as worked examples, and a laminated checkerboard template for the salt layers.
- Use foam balls and pre-cut half toothpicks (or pipe-cleaner pieces) for students with limited fine-motor control; allow the builder and checker roles to swap at any time.
- Offer a large-print color key with the element name in students' home languages, and accept spoken answers for q6 and q7 recorded on a device.
- For low vision, use foam balls in high-contrast colors and wrap one salt color with textured tape so the checkerboard can be checked by touch.

Low-cost alternative

Use modeling clay balls in two or three colors (make the key from whatever colors you have) and cut drinking straws for bonds. If gumdrops are scarce, have groups build the molecules in sequence, taking each apart before the next, and build the salt block only to the 2-by-2-by-2 cube plus one enlargement.

Model limitations

Gumdrops and toothpicks model counts, connections and rough shape only. Real atoms are not colored, hard or sticky; bonds are not rigid rods, and real bond angles are only roughly captured. The salt block shows the 1:1 alternation but not that its particles carry electric charges, and in a real salt crystal every particle has six neighbors, while in a small gumdrop block most pieces sit on the surface with only two to four. Sizes are not to scale: a hydrogen atom is not nearly as large relative to carbon as a marshmallow is to a gumdrop. This activity has not been physically tested by the authors; the counts in expectedObservations follow from the build rules.

Teacher notes

Check the butane and isobutane rows against the drawing: if the hydrogens on the skeleton do not add to 10, the model was built with the wrong number of toothpicks on a carbon. Keep one salt block and one water model for the misconception slide; placing them side by side when asking 'which is finished?' is the most effective moment of the lesson. If groups run short, the 3-by-3-by-2 block can be skipped; two sizes are enough to see the ratio hold.