

# Which Structure Is It, and Which Job Can It Do?

**Investigation question:** Using what a hand lens and a simple test show, plus what counting atoms in fragments reveals, which type of structure is each everyday solid, and which one should you choose for a job?

Data-driven decision

Groups of 4

1 session

Setup 8 · Activity 40 · Cleanup 5 min

MS-PS1-1 · practice

## Scientific purpose

Students rotate through five stations with real everyday solids (table salt, granulated sugar, pencil graphite, a polyethylene bag and quartz sand) and collect two kinds of evidence: what they can see and do with the material, and a teaching data card that reports atom counts in fragments of different sizes and how many neighbors each atom is bonded to. They use a decision matrix to match each substance, plus diamond from a data card only, to one of seven structure-type cards, then choose the best material for three jobs and defend each choice with structure. The product is a decision backed by evidence, not a guess at identity.

## Why this helps students with this chapter

The chapter's hardest idea is abstract: some formulas count, others give ratios, and the difference shows up in things you can see. Handling real salt, sugar, graphite, plastic and sand while reading what their atoms are doing turns the molecule-versus-extended-structure distinction into something students can point to. Choosing a material for a job forces them to use structure as a reason, which is the Structure and Function crosscutting concept in action.

## Standards connections

**MS-PS1-1** (practice, using models of molecules and extended structures to describe atomic composition and explain observable properties): Students do not build models here; they use written structure models and fragment-count data to describe each solid's composition (fixed count or fixed ratio) and connect structure to what they observe. That builds the modeling practice and the PS1.A idea that solids may be molecules or extended structures, without producing a full model of their own.

## Roles (rotate each session)

- **Observer:** Uses the hand lens at each station, describes grain shape and surface in words, and runs the crush, rub or stretch test exactly as the station card says.
- **Data reader:** Reads the fragment-count data card aloud, states whether the counts grow or stay the same, and works out the ratio or the fixed count.
- **Recorder:** Fills the station table and the data-card table for the group, and makes sure each row has evidence from both sources before moving on.
- **Decision lead:** Runs the decision matrix at the end: proposes a structure-type card for each substance, asks the group for two pieces of evidence, and manages the job choices.

## Materials

| Item                                                                                      | Quantity             | Per     | Note                                                             |
|-------------------------------------------------------------------------------------------|----------------------|---------|------------------------------------------------------------------|
| Hand lens (5x to 10x)                                                                     | 1 per station, 5     | class   | Phone cameras on zoom also work for the salt and sugar stations. |
| Black construction paper squares                                                          | 2 per station, 10    | class   |                                                                  |
| Table salt (coarse kosher salt shows cubes best)                                          | 1 tablespoon         | class   |                                                                  |
| Granulated sugar                                                                          | 1 tablespoon         | class   |                                                                  |
| Pencils (standard graphite) and white paper                                               | 2 pencils, 10 sheets | class   |                                                                  |
| Polyethylene grocery bag, cut into strips about 2 cm by 15 cm                             | 10 strips            | class   | Thin bags stretch and whiten most clearly.                       |
| Clean quartz-rich sand (play sand or craft sand), rinsed and dried                        | 1 tablespoon         | class   |                                                                  |
| Metal spoons for the crush test                                                           | 3                    | class   |                                                                  |
| Printed station cards (what to do at each station)                                        | 1 set of 5           | class   |                                                                  |
| Printed fragment-count data cards (six substances) and structure-type cards (seven types) | 1 set                | group   |                                                                  |
| Recording sheet                                                                           | 1                    | student |                                                                  |

**Estimated cost:** 6 to 10 per class (an estimate; Salt, sugar and a bag are pantry items; a small bag of play sand is about \$5; hand lenses are usually classroom stock (about \$1 each if bought). Printing the cards on card stock is the only recurring cost.)

## Safety

- Nothing at the stations may be tasted, even salt and sugar; they have been handled by many people.
- Do the crush test inside the folded paper pocket so grains of sand or salt cannot fly toward eyes. Press, do not strike.
- Do not blow on the sand or salt; fine dust is a breathing irritant. Wipe the station with a damp towel at the end.
- Keep hand lenses away from direct sunlight; a lens can focus the sun into a hot spot on paper or skin.
- Plastic bag strips are small, but whole bags stay in the supply box; no bags over heads or faces.
- Wash hands after the lab, especially after the graphite station.

## Teacher preparation and setup

1. Set up five stations around the room, each with its station card, black paper, a hand lens and a pinch of material. Put the spoon and a folded paper 'crush pocket' only at the salt, sugar and sand stations.

2. Print one set of six data cards and seven structure-type cards per group on card stock; the cards are reproduced in the recording sheet below so you can copy them directly.
3. Rinse and dry the sand the day before so dust does not fly; check it under a lens yourself to confirm the grains are glassy and hard.
4. Try the bag strip: pull slowly from both ends and confirm it necks, whitens and stays stretched. Trim strips so every group gets a fresh one.
5. Rub a pencil on paper and smear it with a fingertip so you can describe the gray, slippery streak students should expect.

## Investigation design

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|                             |                                                                                                                                                                                                                                            |
|-----------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Independent variable</b> | The substance at each station (salt, sugar, graphite, polyethylene bag, quartz sand, plus diamond by card)                                                                                                                                 |
| <b>Dependent variable</b>   | What is observed: grain or surface shape, the result of the crush, rub or stretch test, and the pattern in the fragment counts (fixed count or fixed ratio)                                                                                |
| <b>Controlled</b>           | The same hand lens and black paper at every station; The same test procedure for every crushable solid (press with a spoon inside a paper pocket); A fresh bag strip of the same size for every group; The same data cards for every group |
| <b>Trials</b>               | Every member looks at every station; the class pools station observations on the board before the decision matrix is finalized.                                                                                                            |
| <b>Comparison</b>           | Substances whose fragment counts stay fixed (molecules) versus substances whose counts grow with a fixed ratio (extended structures), set against what each one does under the lens and the test.                                          |

## Student procedure

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1. Read all seven structure-type cards as a group before visiting any station, so you know what you are looking for. Note that one card may not match any substance.
2. At each station, the observer looks at a pinch of material through the hand lens on black paper and describes the shape of the grains (or the surface) in words, then runs the station's test: press with the spoon inside the paper pocket (salt, sugar, sand), rub on paper and smear with a finger (graphite), or pull slowly from both ends (bag strip).
3. The recorder writes the shape, the test result and one word for how the material behaved in the station table. Everyone looks before the group moves on; take about five minutes per station.
4. At each station the data reader reads the substance's fragment-count card. Decide together: do the counts stay the same from fragment to fragment, or do they grow? If they grow, work out the ratio in simplest form; if they stay the same, write the fixed count. Note the number of bonds per atom reported on the card.
5. Record the data-card reading in the data table. Then rotate to the next station until all five are done.
6. Back at your seats, read the sixth data card, diamond, which has no station. Fill its data row from the card alone.

7. Run the decision matrix: for each of the six substances, choose the structure-type card that fits and write two pieces of evidence, one from the station (or the card's described behavior, for diamond) and one from the fragment counts. Mark which type card was left unmatched.
8. Choose a material for each of the three jobs in the job table. For each job, name the material and write one sentence that uses its structure as the reason.
9. Answer q1 and q2 on the sheet, then complete the analysis questions individually.

## Expected observations

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- Salt: cube-shaped grains with square faces; crushing yields smaller blocks with flat faces. Sugar: slanted, angular grains, never square; crushing yields powder. Sand: glassy, hard, rounded or angular grains that do not crush under a spoon.
- Graphite: a gray, shiny streak that smears into a slippery film with a fingertip; under the lens the mark is made of flakes. Bag strip: stretches several times its length, narrows (necks), turns whitish in the stretched zone, and stays stretched.
- Data-card readings: salt grows with 1:1 (extended); sugar fixed at 12, 22, 11 (molecule, 45 atoms); graphite grows, one element, 3 bonds (extended, layered); polyethylene grows with 1 C : 2 H, chains (extended, polymer); quartz grows with 1:2 (extended, network); diamond grows, one element, 4 bonds (extended, network).
- Decision matrix: salt C, sugar B, graphite D, polyethylene G, quartz F, diamond E; Type A unmatched. Jobs: graphite, polyethylene (or any polymer), diamond.

## Likely difficulties

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- Students want to match sugar to Type A because its counts are fixed. Point them to the station: sugar grains are crystals with a repeating pattern, so the molecules are stacked, which is Type B.
- Graphite and diamond get swapped because the counts are identical. Send students back to the bonds-per-atom column and the described behavior (writes versus hardest material).
- The bag strip is pulled too fast and tears. Demonstrate a slow, steady pull; the necking and whitening appear in the first few centimeters of stretch.
- Fine salt looks like dust rather than cubes under a weak lens. Coarse kosher salt, or a phone camera on zoom, shows the cubes clearly.
- Groups write 'because it is hard' as a job reason. Push for the structure behind the property: bonds in all directions with nothing to slide.

## Structured debrief

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1. Pool the decision matrix on the board and resolve disagreements with evidence, not votes. The usual split is graphite versus diamond (same counts, different bonds per atom) and sugar (fixed count but a crystal). Both splits are the lesson's main ideas, so let the class argue them out.
2. Ask: which evidence could the fragment counts give that the hand lens could not, and the reverse? Counts settle molecule-versus-extended-structure; the lens and tests show the consequences of structure (cubes, flakes, stretch, hardness).

- Put the job choices on the board and ask for the structure word behind each: sheets that slide (graphite), chains that straighten (polyethylene), a network bonded in all directions (diamond). Then ask what each material would be terrible at, to show that structure explains weaknesses as well as strengths.
- Close on q8: real chemists use X-rays and other tools to find the repeating pattern inside a solid and measure properties such as melting point; the invented counts stand in for that evidence. The unmatched card, Type A, is the reminder that most molecules we meet are gases and liquids, not grains on a table.

## Recording sheet: what students fill in

### Lab 2 recording sheet: Which structure, which job?

You will collect two kinds of evidence for each substance: what you can see and test at the station, and what a teaching data card says about the atoms in fragments of different sizes. Both kinds go into your decision.

#### Station observations

| Station | Substance              | Grain or surface shape under the lens | Test (crush, rub or stretch) and what happened | One word for how it behaved |
|---------|------------------------|---------------------------------------|------------------------------------------------|-----------------------------|
| 1       | Table salt             |                                       |                                                |                             |
| 2       | Granulated sugar       |                                       |                                                |                             |
| 3       | Pencil graphite        |                                       |                                                |                             |
| 4       | Polyethylene bag strip |                                       |                                                |                             |
| 5       | Quartz sand            |                                       |                                                |                             |

## Fragment-count data cards (teaching dataset)

Simulated teaching dataset: the numbers are invented to be realistic, not measured.

| Substance           | Fragment 1       | Fragment 2       | Fragment 3        | Bonds per atom reported                   | Other note on the card                                                                   |
|---------------------|------------------|------------------|-------------------|-------------------------------------------|------------------------------------------------------------------------------------------|
| Table salt          | 6 Na, 6 Cl       | 20 Na, 20 Cl     | 150 Na, 150 Cl    | each particle touches 6 of the other kind | pattern repeats at right angles in all directions                                        |
| Granulated sugar    | 12 C, 22 H, 11 O | 12 C, 22 H, 11 O | 12 C, 22 H, 11 O  | C 4, O 2, H 1 within the particle         | a grain holds billions of these 45-atom particles stacked in a slanted repeating pattern |
| Pencil graphite     | 50 C             | 400 C            | 9,000 C           | 3, all in one flat sheet                  | sheets stack with only weak attraction between them                                      |
| Polyethylene bag    | 30 C, 60 H       | 200 C, 400 H     | 5,000 C, 10,000 H | C 4 (2 to carbons, 2 to hydrogens), H 1   | atoms form long chains that can slide past and line up with each other                   |
| Quartz sand         | 10 Si, 20 O      | 48 Si, 96 O      | 300 Si, 600 O     | Si 4, O 2                                 | every silicon joins 4 oxygens and every oxygen joins 2 silicons, in all directions       |
| Diamond (card only) | 50 C             | 400 C            | 9,000 C           | 4, pointing in different directions       | one rigid network in all directions; the hardest natural material                        |

This is a teaching dataset: the fragment counts are invented to mirror real substances. The bonds-per-atom and pattern notes match the real structures.

## Structure-type cards

### Card 1

Type A. Small molecule, loose: particles with a definite count of atoms (for example 3 or 5) that move freely as a liquid or gas at room temperature; no repeating pattern.

### Card 2

Type B. Molecular crystal: molecules with a definite count of atoms, stacked in a repeating pattern; strong bonds inside each molecule, weak attraction between molecules.

### Card 3

Type C. Two-element crystal, right-angle pattern: two kinds of particles alternating in a fixed 1:1 ratio, repeating in all directions; no molecules.

### Card 4

Type D. Layered crystal of one element: each atom bonded to 3 neighbors in a flat sheet; sheets stacked with only weak attraction between them.

### Card 5

Type E. Network crystal of one element: each atom bonded to 4 neighbors pointing in different directions; one rigid structure in all directions.

### Card 6

Type F. Two-element network crystal, 1:2 ratio: every atom of one element bonded to 4 of the other, every atom of the other bonded to 2 of the first; rigid in all directions.

Card 7

Type G. Polymer: one small unit repeated thousands of times in a long chain; chains can slide past and line up with each other.

### Data-card reading

| Substance        | Do the counts stay the same or grow? | Fixed count or ratio (simplest form) | Molecule or extended structure? | Bonds per atom |
|------------------|--------------------------------------|--------------------------------------|---------------------------------|----------------|
| Table salt       |                                      |                                      |                                 |                |
| Granulated sugar |                                      |                                      |                                 |                |
| Pencil graphite  |                                      |                                      |                                 |                |
| Polyethylene bag |                                      |                                      |                                 |                |
| Quartz sand      |                                      |                                      |                                 |                |
| Diamond          |                                      |                                      |                                 |                |

### Decision matrix

| Substance            | Structure-type card (letter) | Evidence from the station or described behavior | Evidence from the fragment counts |
|----------------------|------------------------------|-------------------------------------------------|-----------------------------------|
| Table salt           |                              |                                                 |                                   |
| Granulated sugar     |                              |                                                 |                                   |
| Pencil graphite      |                              |                                                 |                                   |
| Polyethylene bag     |                              |                                                 |                                   |
| Quartz sand          |                              |                                                 |                                   |
| Diamond              |                              |                                                 |                                   |
| Unmatched type card: |                              |                                                 |                                   |

## Choose a material for the job

| Job                                                               | Material chosen | Reason that uses its structure |
|-------------------------------------------------------------------|-----------------|--------------------------------|
| Job 1: leaves a mark on paper that can be rubbed off              |                 |                                |
| Job 2: a light strap that stretches a little and does not shatter |                 |                                |
| Job 3: the tip of a drill for cutting stone and concrete          |                 |                                |

1. Which structure-type card did not match any substance? What kind of substance would match it, and why could it not be at a station like the others?

**Answer:** Type A, the loose small molecule. A substance such as water, carbon dioxide or ammonia would match it: a definite count of atoms with no repeating pattern. It could not sit at a station as grains because at room temperature these substances are liquids or gases, not solids with a shape to look at.

**Why:** The distractor card checks that students understand that most small molecules are not solids at room temperature and that a molecule need not form a crystal.

- Identifies Type A as unmatched
- Names a small molecule that would fit
- Explains it is a liquid or gas at room temperature

2. Which substance was hardest to place, and which piece of evidence finally decided it?

**Answer:** Group-specific. Common answers: sugar (fixed counts but crystal grains; decided by the data card's note that the particles stack in a repeating pattern) or graphite versus diamond (identical counts; decided by bonds per atom and the described behavior).

**Why:** Any substance is acceptable if the deciding evidence named is real and relevant.

- Names a substance
- Names a specific piece of evidence that decided it

## Analysis questions: answer key

3. Graphite and diamond have identical fragment counts on their data cards. What evidence told you they are different structures, and what would happen if someone used a diamond chip as a pencil?

**Answer:** The counts only show that both are pure carbon extended structures. The difference is on the bonds-per-atom line: graphite has 3 bonds per atom in flat sheets with weak attraction between sheets, while diamond has 4 bonds per atom pointing in different directions in one rigid network. The station confirmed graphite's sheets: the pencil left a flaky, slippery streak because sheets peeled off onto the paper. A diamond would leave no mark: there are no sheets to peel, and scraping would have to break bonds, which it cannot do, so the diamond would scratch the paper instead of writing on it.

**Why:** Students must separate composition (identical) from structure (different) and use the structure to predict a behavior they did not observe.

- States the counts cannot distinguish them
- Uses bonds per atom or sheets versus network
- Predicts that diamond leaves no mark and explains why

4. Sugar is the only substance whose fragment counts never changed and whose grains are still crystals. Explain how a sugar grain can be made of molecules and still be an extended structure.

**Answer:** Each sugar particle is a molecule with a fixed count of 45 atoms (12 C, 22 H, 11 O), which is why every fragment card shows the same count. But a grain is billions of these molecules stacked in a repeating slanted pattern, held by weak attraction between molecules. So the molecule is the subunit, and the grain is an extended structure built by repeating that subunit, which is why the grains have a regular crystal shape.

**Why:** This is the molecular-crystal case (Type B): both descriptions are true at different scales.

- States the molecule has a fixed count
- States the grain is a repeating stack of molecules
- Connects the stacking to the crystal shape or to Type B

5. A quartz fragment is found to contain 720 oxygen atoms. How many silicon atoms does it hold? Show the ratio you used.

**Answer:** 360 silicon atoms. The ratio is 1 Si : 2 O, so silicon = oxygen  $\div$  2 =  $720 \div 2 = 360$ .

**Why:** Checks that students apply the ratio in the inverse direction (dividing rather than multiplying).

*Also acceptable: Accept 'half of 720' with the ratio stated.*

6. When you pulled the bag strip, it narrowed and turned whitish but did not snap back. Use the polymer structure card to explain what the chains inside were doing.

**Answer:** Polyethylene is made of long chains of a repeating unit. Before stretching, the chains are tangled and folded. Pulling straightens them and lines them up along the direction of the pull, so the strip gets longer and narrower. The lined-up region scatters light differently, which is the whitish look. The chains stayed lined up when I let go, so the strip did not return to its original length.

**Why:** A qualitative chain-alignment explanation is the target; students do not need the vocabulary of crystallinity.

- Describes chains straightening or lining up
- Links alignment to the narrowing and whitening
- Explains why it stays stretched

7. Explain your choice for Job 3 (the drill tip). Then say why salt, which also has a rigid repeating pattern, would be a poor choice for the same job.

**Answer:** Diamond: every carbon atom is bonded to four neighbors in different directions, making one rigid network with nothing that can slide or peel, so it is hard enough to grind through stone and concrete. Salt also has a rigid repeating pattern, but its particles are held by attractions between oppositely charged particles rather than by a network of strong bonds in all directions; it breaks easily along flat planes (crushing gave smaller blocks), and it dissolves in water, so a salt drill tip would shatter and wash away.

**Why:** At this level, 'breaks along flat planes when pressed' and 'dissolves' are sufficient reasons; the charged-particle explanation is a bonus, not a requirement.

- Chooses diamond and cites 4 bonds in all directions or the rigid network
- Gives at least one structure-based or observed reason salt would fail (cleaves when crushed, dissolves)

8. The fragment-count cards were invented for teaching. What could a real laboratory measure to test whether a solid is a molecule or an extended structure, and what is one thing the hand-lens observations could not tell you?

**Answer:** A real lab could shine X-rays through the solid and read the repeating pattern from how they scatter, measure the melting point (molecular solids melt low, network and salt crystals melt very high), see whether it dissolves and whether the solution conducts, or weigh and analyze a known mass to find the ratio of elements. The hand lens could not tell you what the particles are, how many atoms they contain or how they are bonded; it only shows the shapes and behaviors that result from the structure.

**Why:** Students should recognize that the invented counts stand in for real measurements and that observation at the grain scale cannot reach the atomic scale.

- Names at least one realistic measurement (X-ray pattern, melting point, solubility, composition analysis)
- States one limit of the hand-lens evidence

## Individual evidence of learning

Each student submits their own station table, data-card table, decision matrix, job table and written answers to q1 through q8. The decision matrix with its two kinds of evidence is the primary product; q3 and q7 are the evidence for explaining properties from structure.

## Assessment criteria

| Criterion                                 | Proficient looks like                                                                                                                                                                                      |
|-------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Evidence collection</b>                | Station table has a shape description and a test result for all five stations; data-card table correctly marks fixed count or ratio for all six substances and reports bonds per atom.                     |
| <b>Decision matrix</b>                    | All six substances matched to the correct type card with one station-based and one count-based piece of evidence each; the unmatched card is identified.                                                   |
| <b>Structure explains the job</b>         | Each job choice names a suitable material and gives a reason that describes its atomic-level structure (sliding sheets, straightening chains, network bonded in all directions), not just a property word. |
| <b>Molecule versus extended structure</b> | q4 explains that sugar molecules have a fixed count and that the grain is a repeating stack of them, so both descriptions apply at different scales.                                                       |

## Accessibility adaptations

- Provide a station table with the salt row completed as a worked example, and a one-page version of the structure-type cards with icons for sheet, network, chain and stack.
- Allow a partner to read the data cards aloud and let the student with low vision use a phone camera at maximum zoom instead of a hand lens; textured sample cards (sandpaper for 'hard,' a strip of stretched bag for 'stretchy') support touch.
- Let students who need movement rotate stations individually rather than as a group, and accept the decision matrix as a spoken explanation recorded on a device.
- Post the key vocabulary (molecule, extended structure, ratio, crystal, polymer, chain, sheet, network) with home-language translations at every station.

## Low-cost alternative

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Skip the sand station and use the quartz data card alone, as with diamond; replace hand lenses with phone cameras on zoom; cut a single bag into strips for the whole class. Salt, sugar and a pencil are all the physical materials the lab truly needs.

## Model limitations

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The fragment counts are invented teaching data; no one counts atoms in a grain of sugar, and real identification uses tools such as X-ray patterns and property measurements. The structure-type cards simplify: salt's particles carry charges, polyethylene bags contain additives, pencil 'lead' is graphite mixed with clay, and play sand is mostly quartz but not pure. The hand-lens tests show consequences of structure, not structure itself, and crushing with a spoon is not a proper hardness test. This activity has not been physically tested by the authors; the expected station observations are those commonly reported for these household materials.

## Teacher notes

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Grade the decision matrix on the evidence columns, not just the letters; a correct letter with one piece of evidence is partial credit. If a group matches graphite to Type E and diamond to Type D, the counts were read correctly but the bonds line was ignored, which is a quick reteach. Keep a stretched bag strip and an unstretched one for the polymer slide; the contrast is more convincing than any diagram.