

The Salt That Had No Molecules: How X-rays Revealed Extended Structures

Learning target: I can use evidence from a passage to explain how scientists learned that diamond, graphite and table salt are extended structures, and to describe what each structure looks like at the atomic scale.

Reading with evidence

About 40 min

Individual

MS-PS1-1 · practice

reading

writing

Name _____

Date _____

Period _____

Directions

Read the passage once straight through. Then read it again with a pencil, numbering the paragraphs 1 to 7 and underlining each date, each name and each number with a unit. Answer the questions in complete sentences. When a question asks for evidence, quote or closely paraphrase the passage and give the paragraph number.

You will need: This worksheet, Pencil, Scrap paper, Grid paper for the extension

The Salt That Had No Molecules

[1] In 1772 the French chemist Antoine Lavoisier focused sunlight through a large lens onto a diamond sealed inside a glass jar. The diamond heated, glowed and slowly disappeared, leaving behind a gas that turned limewater cloudy, the same test that carbon dioxide passes. Twenty-five years later, in 1797, the English chemist Smithson Tennant burned a weighed amount of diamond and a weighed amount of charcoal and collected the gas from each. Equal masses gave equal amounts of carbon dioxide. The conclusion was hard to accept: diamond, the hardest material anyone knew, was made of the same thing as charcoal, which is nothing but carbon. One gram of carbon from either source produces about 3.7 grams of carbon dioxide.

[2] That left a puzzle that lasted more than a century. Chemists could measure what a substance was made of, its composition, by burning it or breaking it apart. They could not see how its atoms were arranged. If diamond and graphite, the soft gray form of carbon in a pencil core, had the same composition, then the difference between them had to lie in the arrangement, the structure. But no instrument of the 1800s could show an arrangement of atoms.

[3] The instrument arrived in 1912, when the German physicist Max von Laue showed that a beam of X-rays passing through a crystal comes out as a pattern of sharp spots. The spots meant that the atoms inside a crystal are lined up in neat, repeating rows that scatter the X-rays in an orderly way. In 1913 William Henry Bragg and his son William Lawrence Bragg worked out how to read a spot pattern backward to find where the atoms sit. Among the first structures they solved were table salt and diamond.

[4] The salt result surprised many chemists. The Braggs found that sodium and chlorine alternate in every direction, like the dark and light squares of a three-dimensional checkerboard. Each sodium has six chlorine neighbors, and each chlorine has six sodium neighbors, all at the same distance. No sodium belongs to any particular chlorine. There is no small, separate particle of salt, no 'molecule' of NaCl, only a pattern that continues to the edge of the grain. The formula NaCl describes a ratio of one to one, not the contents of a particle. Some chemists objected for years; as late as 1927 the English chemist Henry Armstrong complained in the journal *Nature* that a salt with no molecules went against common sense. But the checkerboard model predicted the X-ray spots exactly, and it explained why salt grains tend to grow as tiny cubes. The model won.

[5] Diamond's structure explained its hardness. Every carbon atom is bonded to four neighbors spread evenly around it, and each of those neighbors is bonded to four more. The result is a single rigid network that continues in every direction. To scratch a diamond you must break strong bonds, and there is no direction in which the bonds are weak or missing.

[6] Graphite's structure was solved in 1924 by the British scientist John Desmond Bernal. Each carbon atom is bonded to only three neighbors, and together they form flat sheets of six-sided rings, like chicken wire. The sheets stack one on top of another, but no bonds join one sheet to the next, only weak attractions. The distance between sheets is about 335 picometers, while the distance between bonded atoms inside a sheet is about 142 picometers. The sheets slide apart with a gentle push, which is why a pencil leaves a mark: the paper peels off thin stacks of carbon sheets.

[7] These discoveries settled the puzzle and gave scientists a new way of thinking. The kind of atom is only the beginning. How many atoms join, and how they are connected, decides whether a substance is a tiny separate molecule, a rigid network, a stack of sliding sheets or a long chain. And the arrangement at the atomic scale leaves fingerprints at the human scale: the cube shape of a salt grain, the hardness of a diamond, the gray streak of a pencil. When you build a model with plastic balls, you are doing what the Braggs did with X-rays: showing an arrangement nobody can see.

Questions: cite the passage

1. Paragraph 1 describes two experiments, 25 years apart. What did each one show, and what conclusion did the two together force?

2. Paragraph 1 says one gram of carbon produces about 3.7 grams of carbon dioxide. How much carbon dioxide should 2.5 grams of diamond produce? How much should 2.5 grams of charcoal produce? Show your work, then say in one sentence why getting the same two answers mattered to Tennant.

3. According to paragraph 2, what could chemists of the 1800s measure, and what could they not see? Write the two words the passage uses for these two things.

4. What evidence convinced scientists that the atoms inside a crystal are arranged in repeating rows? Quote or closely paraphrase paragraph 3.

5. Paragraph 4 says there is 'no molecule of NaCl.' Explain in your own words what the Braggs found inside salt, what the formula NaCl means if it is not a molecule, and why the passage says 'the model won' even though some chemists objected.

6. Using the two distances in paragraph 6, calculate how many times farther apart the graphite sheets are than the bonded atoms within a sheet. Round to one decimal place. Then say what this number suggests about the attraction between sheets compared with the bonds inside a sheet.

7. Compare diamond (paragraph 5) and graphite (paragraph 6): how many bonded neighbors does each carbon atom have, and in which directions do the bonds point? Which single feature of graphite explains why a pencil leaves a mark?

8. Paragraph 7 claims that the arrangement of atoms 'leaves fingerprints at the human scale.' Using evidence from at least two other paragraphs, explain what this means and whether the passage supports the claim.

Paragraph map

Before answering, write one phrase beside each paragraph number on scrap paper: 1 = burning diamond; 2 = the puzzle (composition versus structure); 3 = X-rays; 4 = salt; 5 = diamond; 6 = graphite; 7 = the big idea. Every question names its paragraph, so find the phrase, reread only that paragraph, and underline the sentence that answers the question before you write.

Model the salt checkerboard

Paragraph 4 says each sodium in salt has six chlorine neighbors at the same distance. Using grid paper, draw one flat layer of the checkerboard, 5 squares by 5, and label the squares Na and Cl so that they alternate. Count how many neighbors of the other kind each inside square touches edge to edge, then explain where the remaining neighbors (to make six) must be (hint: think about the layers above and below) and why a flat drawing can show only part of the pattern. Finally, count the Na and Cl squares in your 5 by 5 layer and explain why the counts are not exactly equal even though the ratio for a whole grain is 1:1.