

Sorting the Invisible: How the Periodic Table Was Built

Learning target: I can explain, with evidence from a passage, how scientists found patterns among the elements before anyone could observe an atom.

Reading with evidence

About 35 min

Individual

MS-PS1-1 · supports

reading

writing

Standards connections

MS-PS1-1 (supports): The periodic table is the tool students will use to name the atoms in every molecular model they build for this PE. This reading gives the history and logic behind that tool; it is background rather than evidence toward the PE.

Purpose: build · **Time:** about 35 minutes · **Format:** individual

Answers with reasoning

Sorting the Invisible

[1] Imagine organizing a closet full of objects you are not allowed to look at. You can weigh each one and test how it behaves, but you can never see its shape. That was the situation of chemists in the 1800s. They knew dozens of elements and could measure how much mass a typical atom of each one had compared with hydrogen. But no instrument could show them an atom. Any order they found would have to come from patterns in behavior and mass alone.

[2] The first clear pattern was spotted by a German chemist, Johann Döbereiner. In 1829 he described several sets of three elements that behaved alike: chlorine, bromine and iodine formed similar salts with metals; lithium, sodium and potassium were all soft metals that reacted with water. In each trio, the atomic mass of the middle element was close to the average of the other two: sodium's 23 Da sits almost exactly between lithium's 7 Da and potassium's 39 Da. The middle element's behavior was usually in between as well. Döbereiner's triads hinted that mass and behavior were linked, but they covered only a few elements.

[3] In 1864 and 1865 an English chemist, John Newlands, tried a bolder move. He lined up every known element in order of increasing atomic mass and noticed that properties seemed to repeat every eighth element, the way a musical note repeats every eighth key on a piano. He called this the law of octaves. The pattern worked for the lighter elements but broke down for the heavier ones, and when Newlands presented the idea to the Chemical Society in London in 1866, members laughed. One asked whether he had tried arranging the elements alphabetically.

[4] The breakthrough came in 1869 from a Russian chemist, Dmitri Mendeleev, who was writing a textbook and wanted a sensible order for the elements. He also listed them by increasing atomic mass, but he made two decisions that Newlands had not. First, he let the rows be different lengths, so that elements with similar behavior always landed in the same column. Second, when the next element in

the mass order did not fit the column it would have landed in, he left the space empty. An empty space, he argued, was not a flaw in the table but a sign of an element nobody had found yet.

[5] Mendeleev then did something that turned his table from a filing system into a scientific model: he predicted the properties of the missing elements. Using the averages of the elements above, below and beside each gap, he estimated their atomic masses and described how they would look and react. In 1875 a French chemist, Paul-Émile Lecoq de Boisbaudran, discovered gallium, and its properties matched the prediction for the element below aluminum. When the first measurement of gallium's density came in lower than predicted, Mendeleev suggested re-measuring; the corrected value agreed with his table. Scandium followed in 1879 and germanium in 1886. Germanium's measured atomic mass, about 72.6 Da, was within one dalton of the 72 Da Mendeleev had predicted.

[6] A model that correctly predicts things before they are discovered earns trust, and chemists adopted Mendeleev's table. It was not perfect. A few pairs, such as tellurium and iodine, had to be swapped out of mass order so that their properties would fit their columns, and Mendeleev could not explain why. The reason was found in 1913, when the English physicist Henry Moseley showed that the true ordering number of an element is not its mass but the number of protons in each of its atoms, now called the atomic number. Ordered by atomic number, the swapped pairs fall into place.

[7] The table also grew. When argon was discovered in 1894, it fit no existing column, so a new column of unreactive gases was added. By 2016 the table held 118 elements, many made in laboratories. Through all of these changes, the core idea from 1869 has survived: arrange the elements in order, line up the ones that behave alike, and an element's position will tell you how it is likely to behave. That is why a chart first sketched for a textbook still hangs in nearly every science classroom in the world.

Questions: cite the passage

1. According to paragraph 1, what two kinds of information could chemists in the 1800s collect about an element, and what one thing could they **not** do?

Answer: They could measure how much mass a typical atom had (compared with hydrogen) and test how the element behaved. They could not see an atom.

Why: Paragraph 1 lists mass and behavior as the available information and states that no instrument could show them an atom.

Also acceptable: Accept 'weigh it and test it' for the two kinds of information.

- Names mass (or atomic mass)
- Names behavior (or how it reacts)
- States they could not see atoms

2. Paragraph 2 says sodium's mass is close to the average of lithium's and potassium's. Calculate that average and compare it with sodium's 23 Da. Show your work.

Answer: $(7 \text{ Da} + 39 \text{ Da}) \div 2 = 46 \div 2 = 23 \text{ Da}$. Sodium's atomic mass is 23 Da, so the average matches exactly with these rounded values.

Why: The rounded masses give an exact match; with precise values (6.94, 39.10) the average is 23.02 versus 22.99, still within a tenth of a dalton.

Also acceptable: Accept 'the same' or 'a difference of 0 Da'.

3. What was the strength of Newlands's law of octaves, and what was its weakness? Quote the words from paragraph 3 that describe the weakness.

Answer: Strength: it put all the known elements in one mass order and showed properties repeating every eighth element. Weakness (quote): 'The pattern worked for the lighter elements but broke down for the heavier ones.'

Why: Students must quote or closely paraphrase the weakness sentence from paragraph 3.

Also acceptable: A student who adds that the Chemical Society laughed at him is describing the reception, not the weakness, and should still name the breakdown for heavier elements.

- Names the repeating-every-eighth idea as the strength
- Quotes the breakdown for heavier elements

4. Paragraph 4 names two decisions Mendeleev made that Newlands had not. State both in your own words, then explain why the second one took courage.

Answer: Decision 1: he allowed rows of different lengths so that similar elements always ended up in the same column. Decision 2: when an element did not fit the column, he left the space empty instead of forcing it in. The second took courage because he was claiming that elements existed which nobody had ever found, and he could be proven wrong if they were never discovered.

Why: The courage explanation should connect the empty space to a risky, testable claim about undiscovered elements.

Also acceptable: Accept 'people might laugh at him like they laughed at Newlands' if it is linked to the gaps being a prediction.

- Both decisions stated in the student's own words
- Courage explained as a public, testable claim about undiscovered elements

5. Find the sentence in paragraph 5 that explains what turned the table 'from a filing system into a scientific model.' Write it down, then explain in your own words what the difference is.

Answer: The sentence: 'he predicted the properties of the missing elements.' A filing system only stores what is already known; a scientific model makes predictions about things not yet observed that can be checked.

Why: The distinction between organizing and predicting is the heart of the passage.

Also acceptable: Quoting the full sentence beginning 'Mendeleev then did something...' is acceptable.

- Identifies the prediction sentence
- Explains that a model predicts while a filing system only stores

6. Give two pieces of evidence from paragraph 5 that Mendeleev's predictions were accurate. Include a number in at least one.

Answer: Any two: gallium's properties matched the prediction for eka-aluminum closely; the re-measured density of gallium agreed with his table; germanium's measured atomic mass (about 72.6 Da) was within one dalton of the predicted 72 Da; scandium (1879) and germanium (1886) were found as predicted.

Why: At least one piece of evidence must contain a number (72 Da, 72.6 Da, 1875, 1879 or 1886).

Also acceptable: A date counts as a number.

- Two distinct pieces of evidence from paragraph 5
- At least one includes a number

7. Paragraph 6 says the table 'was not perfect.' What problem did it have, and what discovery in 1913 solved it?

Answer: Problem: a few pairs, such as tellurium and iodine, had to be placed out of mass order so their properties fit their columns, and Mendeleev could not explain why. Solution: in 1913 Henry Moseley showed the true ordering number is the number of protons in each atom (the atomic number), and in that order the swapped pairs fit without exceptions.

Why: This item is the accurate correction to the textbook's 'ordered by atomic mass' framing. Students need only the idea that a better ordering number was found.

Also acceptable: Accept 'number of protons' without the term atomic number.

- Names the out-of-order pair problem
- Names Moseley's 1913 atomic number (proton count)

8. The passage argues that a model which predicts correctly 'earns trust.' Using evidence from at least two paragraphs, explain whether you agree that Mendeleev's table deserved more trust than Newlands's octaves.

Answer: Agree, with evidence such as: Newlands's octaves broke down for heavier elements (paragraph 3), while Mendeleev's gaps led to correct predictions of gallium, scandium and germanium (paragraph 5), and the table survived later changes such as the new column for argon and the switch to atomic number (paragraphs 6 and 7). A model that keeps being confirmed deserves more trust.

Why: Full credit requires a position, evidence from at least two paragraphs, and reasoning that connects correct prediction to trust. A student may argue that Newlands deserved more credit than he got; that is acceptable if the evidence is accurate and the trust-through-prediction idea is addressed.

Also acceptable: A partial-agreement answer (Newlands found the pattern first, but Mendeleev's version earned trust by predicting) is a strong response.

- Clear position
- Evidence from at least two different paragraphs
- Reasoning links prediction or survival of the model to trust

Teacher notes

The passage is 700 words and is deliberately accurate where the textbook simplifies: the modern table is ordered by atomic number, not mass, and tellurium and iodine are the classic exception. All dates and names are historically established (Döbereiner 1829; Newlands 1864-66; Mendeleev 1869; gallium 1875, scandium 1879, germanium 1886; argon 1894; Moseley 1913; 118 elements by 2016). The anecdote about arranging elements alphabetically is documented from the 1866 Chemical Society meeting. If students ask what a proton is, say it is a particle inside the atom that later classes will study; the point here is only that a better ordering number exists.

Scaffold offered to students: Timeline first

Before answering the questions, draw a horizontal line across scrap paper and mark these dates from the passage: 1829, 1864, 1866, 1869, 1875, 1879, 1886, 1894, 1913, 2016. Above each date write the person or event in three words or fewer. Most questions can be answered by finding the right spot on your timeline and rereading that paragraph.

Extension: Predict like Mendeleev

Suppose the element between calcium (40 Da) and barium (137 Da) in their column had not yet been discovered. Use Döbereiner's halfway idea to predict its atomic mass, then look up strontium's real atomic mass and compute how far off the prediction is as a percentage. Write two sentences on why the halfway rule is a useful pattern but not an exact law.