

# The Mystery Element Cards: Build a Table That Predicts

**Investigation question:** Given only the properties and atomic masses of fourteen unnamed elements, can your group arrange them into a table that reveals a pattern, and can that table predict elements you were never given?

Evidence-based mystery

Groups of 4

1 session

Setup 5 · Activity 40 · Cleanup 5 min

MS-PS1-1 · practice

## Scientific purpose

Students re-create the reasoning of Döbereiner, Newlands and Mendeleev without being told the answer. Each card describes one element under an invented name: its atomic mass, state, how it reacts with water, how it combines with other elements, and one extra clue. Groups must decide what to sort by, discover that properties and mass together give a two-way pattern, leave gaps where the pattern demands them, and predict the mass and behavior of the missing elements. The teacher then reveals the real identities.

## Why this helps students with this chapter

Students usually meet the periodic table as a finished poster, so it looks like a list to memorize. Rebuilding a slice of it from evidence shows why it is shaped the way it is, why columns matter more than mass order when the two disagree, and why a blank space is a scientific claim rather than a hole in someone's knowledge.

## Standards connections

**MS-PS1-1** (practice, the periodic table as a model of the kinds of atoms): Students build and use the periodic arrangement as a model that organizes the kinds of atoms by properties and mass and makes testable predictions, the organizing idea they rely on when modeling molecules and extended structures in Lesson 2.

## Roles (rotate each session)

- **Card reader:** Reads each card aloud in full before it is placed; keeps the deck in order and makes sure no card is placed on a single clue.
- **Sorter:** Moves the cards on the desk according to the group's agreed rule, and announces when a card does not fit the rule.
- **Recorder:** Copies the final arrangement into the grid on the recording sheet and writes the gap predictions with the group's reasoning.
- **Challenger:** Tests the arrangement: picks any two cards in a column and asks what they share, picks any row and asks whether mass rises along it, and argues for a gap whenever the pattern breaks.

## Materials

| Item                                                                     | Quantity | Per     | Note                                                                   |
|--------------------------------------------------------------------------|----------|---------|------------------------------------------------------------------------|
| Mystery element card set (14 cards), printed on card stock and cut apart | 1 set    | group   | Card text is given in the recording sheet; print without the key.      |
| Blank index cards for gap predictions                                    | 4        | group   |                                                                        |
| Large sheet of paper or a desk-sized whiteboard for laying out the grid  | 1        | group   |                                                                        |
| Recording sheet                                                          | 1        | student |                                                                        |
| Calculator                                                               | 1        | group   |                                                                        |
| Sealed envelope with the identity key, opened only at the reveal         | 1        | group   | Lists each invented name beside its real element and real atomic mass. |

**Estimated cost:** 3 to 5 per class (an estimate; Estimate. Card stock for eight to ten sets and a few index cards; reuse sets each year by laminating.)

## Safety

- No materials beyond paper cards; no chemicals are handled. The water reactions on the cards are described, never demonstrated.
- Do not attempt any of the reactions described on the cards. Sodium, potassium and cesium react dangerously with water and must never be handled by students; this lab uses only their descriptions.

## Teacher preparation and setup

1. Print and cut the 14 cards for each group from the card text in the recording sheet. Shuffle each set so no group receives them in mass order.
2. Prepare one sealed identity envelope per group: Vex = lithium 6.9 Da; Rue = sodium 23.0; Pim = potassium 39.1; Zan = cesium 132.9; Hel = helium 4.0; Tam = neon 20.2; Nol = argon 39.9; Kesh = krypton 83.8; Xon = xenon 131.3; Flor = fluorine 19.0; Clo = chlorine 35.5; Iod = iodine 126.9; Cal = calcium 40.1; Bar = barium 137.3. Missing elements the pattern should predict: rubidium (85.5, soft reactive metal), strontium (87.6, metal that reacts with water, combines 1 to 2), bromine (79.9, red-brown liquid, combines 1 to 1 with the soft metals).
3. Remove or cover any periodic table posters in the room for the session; the point is to build the pattern, not to look it up.
4. Decide whether groups will do the first sort by mass only (recommended) so they feel the problem before adding properties.

## Investigation design

**Independent variable** The sorting rule the group applies (mass only; behavior first, then mass)

|                           |                                                                                                                                                      |
|---------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Dependent variable</b> | How well the arrangement predicts: number of cards that fit their column without conflict, and how close the gap predictions come to the real masses |
| <b>Controlled</b>         | Same 14 cards and masses for every group; No outside periodic table during the sort; Same time limit for the sort                                    |
| <b>Trials</b>             | Each group builds the arrangement twice, first by mass alone and then by behavior and mass together, and compares how many cards fit each time.      |
| <b>Comparison</b>         | Gap predictions versus the real masses and properties revealed in the envelope.                                                                      |

## Student procedure

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1. Spread the 14 cards face up. The card reader reads every card aloud once before anyone sorts. Write down two properties that you think will matter most.
2. First sort: put all 14 cards in a single line in order of increasing atomic mass. Look along the line. Record in q1 any properties that seem to come back again and again.
3. Second sort: now group cards that share the same kind of behavior (how they react with water, what state they are in, how they combine with other elements). Record the sorting rule you used.
4. Build a table: each behavior group becomes a column. Within every column, place cards from lowest mass at the top to highest at the bottom. Then slide the columns so that each row runs from lower mass on the left to higher mass on the right as far as possible.
5. The challenger tests the table: do the cards in each column truly share behavior? Does mass rise along each row? Wherever a row has a card whose mass jumps far above its neighbor in the row above, or where a column has a large mass gap between two cards, leave an empty space.
6. For every empty space, write a prediction card: estimate the missing element's atomic mass by averaging the cards above and below it in the column, and predict two of its properties from its column. Place the prediction card in the gap.
7. Copy the finished arrangement, gaps included, into the grid on your recording sheet and complete the gap-prediction table.
8. Find the one place where mass order and property order disagree (two neighbors whose masses are reversed). Decide which rule wins and write why in q2.
9. Only when the recorder has finished, open the identity envelope. Compare the real elements and masses with your predictions and complete the analysis questions.

## Expected observations

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- Four columns emerge: soft water-reactive metals (Vex, Rue, Pim, gap, Zan), harder metals that combine one to two (Cal, gap, Bar), reactive gas-or-solid elements that combine one to one with the metals (Flor, Clo, gap, Iod), and unreactive gases (Hel, Tam, Nol, Kesh, Xon).
- The three gaps fall in two neighboring rows: bromine's gap sits in the row of Pim and Kesh (predicted about 81 Da), and the rubidium and strontium gaps sit together in the row of Iod and Xon (predicted about 86 and 89 Da). Students often notice that all three predicted masses cluster between 80 and 89 Da.

- The Pim/Nol pair (39.1 and 39.9) is the one spot where mass order and behavior order disagree; most groups let behavior win after the challenger tests the column.

## Likely difficulties

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- Groups try to put HEL with the soft metals because it is 'light' or with FLOR because both are gases; the challenger role and the 'two cards in a column must share behavior' rule fix this.
- Students leave no gaps because a gap feels like failure. Ask whether a column that jumps from 35.5 straight to 126.9 is as orderly as one that goes 35.5, then about 81, then 126.9, and whether a row that reads 39.1, 40.1, 126.9, 83.8 can be said to rise from left to right.
- CAL and BAR form a column of only two cards, so students are unsure a column of two counts. Remind them Döbereiner worked with trios and that the gap makes it three.
- The reveal tempts students to erase their predictions; insist the predicted and real values both stay on the sheet, since the comparison is the evidence.

## Structured debrief

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1. Have each group post its arrangement. Nearly every group finds four columns; compare where groups disagreed and why. Groups that sorted by mass alone will have a line, not a table, which is the Newlands step; groups that used behavior first will have columns, which is the Mendeleev step.
2. Reveal the real elements together. Walk the three gaps: rubidium (predicted about 86 from 39.1 and 132.9, real 85.5), strontium (predicted about 88.7 from 40.1 and 137.3, real 87.6) and bromine (predicted about 81 from 35.5 and 126.9, real 79.9). Ask why averaging works so well for these columns.
3. Point to the PIM and NOL cards, 39.1 and 39.9: by mass NOL should sit before PIM, but their behaviors put PIM with the soft metals and NOL with the unreactive gases. This is the real argon/potassium reversal. Mendeleev faced the same choice with tellurium and iodine and let properties win. The modern table fixes it with atomic number, which students will meet later.
4. Close on the big idea: a table that only lists is a catalog; a table whose gaps predict real elements is a model. The periodic table works as a model, and its gaps were the first successful tests of it.

## Recording sheet: what students fill in

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### Lab 2 recording sheet: The mystery element cards

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**Teaching dataset** — The element names on these cards are invented. The masses and behaviors are rounded versions of real elements, which your teacher will reveal at the end. Do not look anything up until the reveal.

## Card set (teacher prints and cuts apart; 14 cards)

### Card 1

VEX. Atomic mass 6.9 Da. Soft, silvery metal you could cut with a butter knife. In water it fizzes steadily and does not catch fire. Combines with the gases FLOR, CLO and IOD one atom to one atom. Lightest metal known.

### Card 2

RUE. Atomic mass 23.0 Da. Soft, silvery metal. In water it skids about and reacts fast enough to catch fire. Must be stored under oil. Combines with FLOR, CLO and IOD one atom to one atom.

### Card 3

PIM. Atomic mass 39.1 Da. Soft, silvery metal. In water it bursts into flame at once. Stored under oil. Combines with FLOR, CLO and IOD one atom to one atom.

### Card 4

ZAN. Atomic mass 132.9 Da. Soft, gold-tinted metal that melts in a warm hand. Explodes on contact with water. Stored sealed away from air. Combines with FLOR, CLO and IOD one atom to one atom.

### Card 5

HEL. Atomic mass 4.0 Da. Colorless gas, lighter than air. Does not react with water or with anything else known. Glows pale orange-pink in a lit tube. Used to lift balloons.

### Card 6

TAM. Atomic mass 20.2 Da. Colorless gas. No known compounds. Glows bright red-orange in a lit tube.

### Card 7

NOL. Atomic mass 39.9 Da. Colorless gas. No known compounds. Glows violet in a lit tube. Makes up about one percent of air.

### Card 8

KESH. Atomic mass 83.8 Da. Colorless gas. Forms a few compounds only under special laboratory conditions. Used in some bright white lamps.

### Card 9

XON. Atomic mass 131.3 Da. Colorless gas, dense. Forms a few compounds with FLOR under special conditions. Used in some car headlights.

### Card 10

FLOR. Atomic mass 19.0 Da. Pale yellow gas. The most reactive element known; attacks glass. Combines with VEX, RUE, PIM and ZAN one atom to one atom, and with CAL and BAR two atoms to one.

### Card 11

CLO. Atomic mass 35.5 Da. Yellow-green gas with a sharp smell. Very reactive. Combines with VEX, RUE, PIM and ZAN one atom to one atom, and with CAL and BAR two atoms to one.

### Card 12

IOD. Atomic mass 126.9 Da. Gray-black shiny solid that turns straight into a purple vapor when gently warmed. Reactive, but less so than CLO. Combines with the soft metals one atom to one atom, and with CAL and BAR two atoms to one.

### Card 13

CAL. Atomic mass 40.1 Da. Silvery metal, harder than VEX or RUE. Reacts slowly with water, releasing bubbles. Combines with FLOR, CLO and IOD one atom to two atoms.

### Card 14

BAR. Atomic mass 137.3 Da. Silvery metal. Reacts quickly with water. Combines with FLOR, CLO and IOD one atom to two atoms. Its compounds burn with a green flame.

Our arrangement (write the card name in each cell; write GAP where you left a space)

| Row | Column A | Column B | Column C | Column D |
|-----|----------|----------|----------|----------|
| 1   |          |          |          |          |
| 2   |          |          |          |          |
| 3   |          |          |          |          |
| 4   |          |          |          |          |
| 5   |          |          |          |          |
| 6   |          |          |          |          |

### Gap predictions

| Gap location<br>(row, column) | Card above<br>(mass) | Card below<br>(mass) | Predicted mass<br>(average) | Two predicted<br>properties | Real element and<br>mass (after reveal) |
|-------------------------------|----------------------|----------------------|-----------------------------|-----------------------------|-----------------------------------------|
|                               |                      |                      |                             |                             |                                         |
|                               |                      |                      |                             |                             |                                         |
|                               |                      |                      |                             |                             |                                         |

- After the mass-only sort, which behaviors seemed to come back again and again along the line? Name at least two.

**Answer:** Behaviors that recur along the mass line: a soft metal that reacts with water appears at 6.9, 23.0, 39.1 and 132.9; an unreactive gas appears at 4.0, 20.2, 39.9, 83.8 and 131.3; a very reactive element that combines one to one with the metals appears at 19.0, 35.5 and 126.9.

**Why:** This is the Newlands observation: properties repeat at intervals along the mass line. Any two recurring behaviors earn credit.

- Names at least two behaviors that recur
- Links each to more than one card

- Where did mass order and behavior order disagree? Which rule did your group let win, and why?

**Answer:** PIM (39.1) and NOL (39.9). By mass NOL comes first, but NOL behaves like the unreactive gases and PIM like the soft metals, so behavior won and PIM sits in the metal column while NOL sits with the gases.

**Why:** Mirrors the real potassium/argon reversal. The group must choose behavior to keep columns consistent.

- Identifies the Pim/Nol pair
- Chooses behavior and gives the column-consistency reason

## Analysis questions: answer key

3. What rule did your group use to decide which cards share a column? Give one example of two cards and the behaviors they share.

**Answer:** Cards share a column when they react with water in the same way, are in the same state, and combine with other elements in the same ratio. Example: RUE and PIM are both soft metals stored under oil that react with water and combine one to one with CLO.

**Why:** Combining ratio is the most reliable clue on the cards and is the one chemists of the 1800s actually used.

- States a behavior-based rule
- Gives a concrete pair with shared behaviors

4. Pick one of your gaps. Show the calculation for its predicted mass and compare it with the real element's mass from the envelope. How close were you, and why does averaging work here?

**Answer:** Example for the metal column gap:  $(39.1 + 132.9) \div 2 = 86.0$  Da; real rubidium is 85.5 Da, a difference of 0.5 Da. Other gaps:  $(40.1 + 137.3) \div 2 = 88.7$  vs. strontium 87.6;  $(35.5 + 126.9) \div 2 = 81.2$  vs. bromine 79.9. Averaging works because in these columns the mass steps between neighbors are roughly even, so the middle element sits near the midpoint, the pattern Döbereiner noticed in his trios.

**Why:** Full credit needs the calculation, the comparison and the explanation that mass steps are roughly even in the column.

*Also acceptable: Any of the three gaps with correct arithmetic.*

5. The cards for RUE and PIM say they combine with CLO one atom to one atom, while CAL combines one atom to two. How did combining ratios help you decide columns even without seeing any atoms?

**Answer:** The ratio tells you how an element behaves when it joins with others, which is a property of the kind of atom, not of its appearance. RUE and PIM both pair one to one with CLO, so they belong together; CAL takes two CLO per atom, so it is a different kind even though it is also a silvery metal. Chemists measured these ratios by weighing what combined with what, long before any microscope could show atoms.

**Why:** Students should see that combining ratios are evidence about atoms that does not require seeing atoms. No valence language is expected.

- Explains that ratio is behavior, not appearance
- Uses the Rue/Pim versus Cal contrast
- Notes that ratios were measurable without seeing atoms

6. Mendeleev left blank spaces in his 1871 table and predicted three elements that were later found. Explain what makes a blank space a scientific prediction rather than a gap in knowledge, using one of your own gaps as the example.

**Answer:** A blank is a prediction when it says something specific that could be wrong: this spot should hold an element with a mass near 86 that is a soft metal, reacts violently with water and combines one to one with CLO. If an element is found there with those properties, the model is supported; if one is found with different properties, the model is in trouble. A gap in knowledge just says 'we do not know.' Our gap for rubidium made a claim, and the envelope confirmed it.

**Why:** Key idea: predictions are testable claims. Credit any of the three gaps used correctly.

- Defines a prediction as a specific, testable claim
- Gives the predicted mass and properties for one gap
- Says what would count as confirming or refuting it

7. Your table was built from behavior and mass alone. A later discovery, atomic number, gave the real table its order. Based on the place where mass order failed, why might scientists have wanted something better than mass?

**Answer:** Because mass sometimes puts an element in the wrong column (PIM and NOL), scientists wanted a property that always matched the column pattern. Atomic number does that: it rises by exactly one from each element to the next with no reversals.

**Why:** Students only need to recognize that a rule with exceptions invites a search for a better rule. Atomic number is named, not explained.

- Refers to the mass reversal
- Says a rule without exceptions was wanted

8. A new card arrives: a colorless gas, 222 Da, no compounds known. Place it in your table and predict two more of its properties.

**Answer:** Below XON in the unreactive gas column, as the sixth row of that column. Predictions: colorless, no known compounds or very few, glows a color in a lit tube, denser than XON, and it will sit at the right-hand end of its row.

**Why:** This is radon (222 Da). Position predicts behavior; any two column-based properties earn credit.

*Also acceptable: Accept 'forms a few compounds under special conditions' by analogy with Kesh and Xon.*

## Individual evidence of learning

Each student submits a completed arrangement grid, the gap-prediction table with predicted and real masses side by side, and individual answers to q1 through q8. The gap table and q6 are the main evidence for understanding why blank spaces are predictions.

## Assessment criteria

| Criterion                       | Proficient looks like                                                                                                                                                               |
|---------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Arrangement</b>              | Four behavior columns with mass rising down each column and across each row as far as the cards allow; the Pim/Nol reversal is noted and resolved by behavior.                      |
| <b>Gap prediction</b>           | At least two gaps identified, masses predicted by averaging with the calculation shown, two properties predicted from the column, and the comparison with the real values recorded. |
| <b>Reasoning about evidence</b> | Explains how combining ratios and water reactions, not appearance alone, decide columns, and why a confirmed prediction counts as evidence for the model.                           |
| <b>Transfer</b>                 | Places the 222 Da gas card correctly below Xon and predicts it is unreactive and glows in a tube.                                                                                   |

## Accessibility adaptations

- Print large-format cards with a colored stripe for state (gas, solid, metal) so sorting by state is a visual step for students who need support.
- Provide a partly filled grid (first column done) as a scaffold, and let the recorder role be shared with a scribe for students who write slowly.

- Offer a multilingual glossary card for reactive, combines, ratio and gap, and allow q5 and q6 to be answered orally and recorded.
- For students ready for extension, add two blank cards with 85.5 Da and 87.6 Da and no properties, and ask them to write the properties the table predicts.

## Low-cost alternative

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Hand-write the 14 cards on index cards. If card stock is unavailable, groups can work from a single printed sheet and sort by writing names on sticky notes.

## Model limitations

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The card set is a tiny slice of the periodic table chosen so that the pattern is visible: four columns and no transition metals. Averaging masses to predict a missing element works for these columns but fails in parts of the real table, and the modern table is ordered by atomic number, not mass. Property descriptions are simplified (for example, helium's 'no compounds' is true in practice but xenon and krypton do form a few). The activity has not been physically run by the authors; timing is an estimate.

## Teacher notes

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Keep the identity envelopes sealed until every recorder has finished; the comparison between predicted and real values is the evidence. If a group has only three columns, they have usually merged CAL and BAR into the soft-metal column; ask them to compare combining ratios. The 222 Da card in q8 is radon; do not discuss radioactivity unless asked, and if asked, say only that it is a radioactive gas found in some basements and that its placement in the table is still predicted by its behavior.