

Atoms and Elements

Chapter 1 of 29 • The Composition of Matter

Lesson 1: What are the smallest pieces of matter, and how do we keep track of them?

Angela's Wand • Bring Science Alive! 7th Grade Integrated

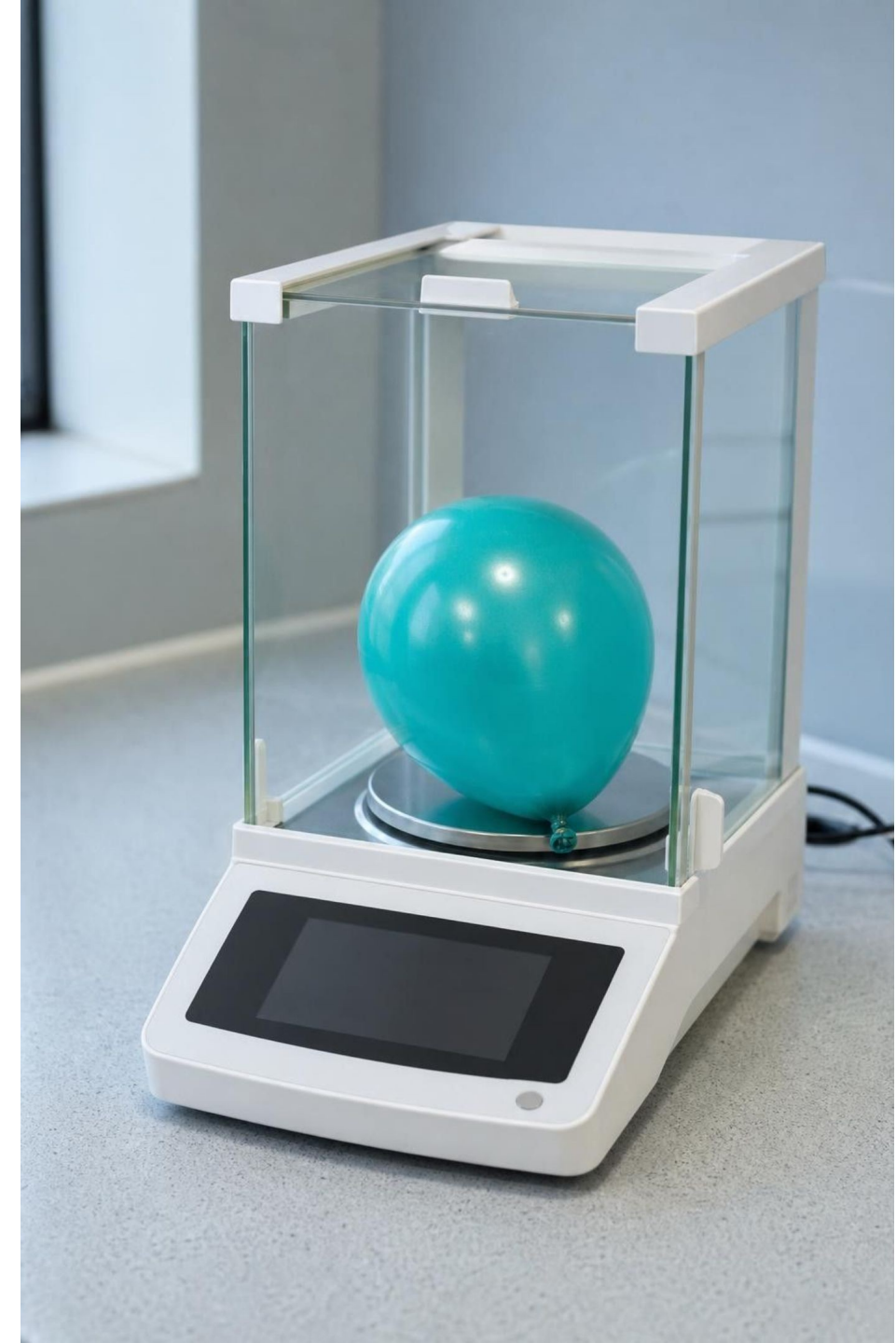


PHENOMENON

A balloon gets heavier from nothing you can see

A limp balloon on a sensitive balance reads 1.85 g. A student pumps it full of air, ties it, dries the outside and puts it back. The balance now reads 1.89 g. Nothing visible went in. Where did the extra mass come from, and what is it made of?

- Notice: what changed and what stayed the same?
- Wonder: what is inside the balloon now that was not there before?
- Predict: would a helium-filled balloon read heavier or lighter than this one?





LEARNING TARGETS

What you will be able to do

- 1 Explain that all matter is made of atoms, and tell an atom from an element.
- 2 Compare the atomic scale to everyday scales and use the picometer.
- 3 Describe how a scanning tunneling microscope maps a surface, and name its criteria and constraints.
- 4 Explain how patterns in properties and mass grew into the periodic table.
- 5 Use an element's symbol, mass and position to predict how it behaves.

What counts as matter?

- 1 Matter is anything that has mass and takes up space.
- 2 Solids, liquids and gases are all matter, including the air in the balloon.
- 3 Light, sound and heat are not matter: they carry energy but are not made of stuff.
- 4 The balance proved it: air has mass, so air is matter.





Keep cutting: is there a smallest piece?

Imagine sawing an iron nail in half, then halving one piece, then halving again. Every cut so far has given you a smaller piece of iron. Could that go on forever? Matter turns out to be grainy at the bottom. After about 30 halvings of a 10 cm nail you would be holding a single iron atom, and cutting that would no longer give you iron.

Three words that must stay separate

matter: Anything that has mass and takes up space. *The air in a bike tire is matter; the hiss when it leaks is not.*

atom: One single particle of an element, the smallest piece that still counts as that element. *One iron atom is about 250 picometers across, far too small to see.*

element: A substance made of only one kind of atom. *A copper wire is the element copper; it holds an enormous number of copper atoms.*



One element, many faces: carbon

Model: The element carbon

Center: Carbon (C), atomic mass about 12 Da

One carbon atom: A single particle, roughly 150 pm across. Not visible with any light microscope.

A diamond: Carbon atoms locked in a rigid 3-D pattern. Hard, clear, sparkling.

Pencil graphite: The same carbon atoms stacked in flat sheets that slide. Soft, gray, slippery.

Soot from a candle: Carbon atoms in tiny, jumbled clusters. Black powder.

Symbol C: The one-letter shorthand chemists everywhere use for this element.

Different arrangements of the same kind of atom give very different materials, but the element is the same.



Check for understanding

Quick check: atom or element?

Which of these is an element?

A. Air

B. Water

C. Neon

D. Table salt





How small is small? A ladder of scales

MODEL

Model: From a meter stick down to one atom

Meter stick, 1 m: Human scale. Rooms, people, desks.

Millimeter, 1 mm: A grain of sand is about 1 mm across and holds on the order of 10^{19} atoms.

Hair width, about 0.1 mm: 100 micrometers. The limit of what a sharp eye can resolve.

Bacterium, about 1 micrometer: A thousandth of a millimeter. Light microscopes show these.

Virus, about 100 nanometers: A ten-thousandth of a millimeter. Too small for light; needs an electron microscope.

Atom, about 100 to 300 picometers: A trillionth of a meter is 1 pm. A hair is roughly half a million to a million atoms wide.

Most steps down this ladder are a factor of 10 to 1,000. An atom is roughly ten million times smaller than the millimeter sand grain.



VOCABULARY IN CONTEXT

Talking about size the way scientists do

scale: A size range where things are roughly the same size and the same units make sense. *Cities are on the kilometer scale; fingernails grow on the millimeter scale.*

atomic scale: The size range of atoms, roughly 100 to 300 picometers across. *At the atomic scale a flat-looking metal surface is a bumpy field of atoms.*

picometer (pm): One trillionth of a meter, 10^{-12} m. *A hydrogen atom, the smallest, is roughly 100 pm across; its edge is fuzzy, so estimates vary.*

CHECK FOR UNDERSTANDING

Quick check: choose the unit

A strip of paper is 1 mm wide. About how many picometers is that, and how many 200 pm atoms could line up across it?

A. 1,000 pm; 5 atoms

B. 1,000,000 pm; 5,000 atoms

C. 1,000,000,000 pm; 5,000,000 atoms

D. 1,000,000,000,000 pm; 5 billion atoms





The engineering problem: how do you map atoms?

- Light microscopes show bacteria but blur anything below about 200 nm; atoms are 1,000 times smaller still.
- Electron microscopes reach further, but in the 1970s could not map single atoms on an ordinary flat surface.
- Heinrich Rohrer and Gerd Binnig (IBM, Zurich) decided a new approach was needed, not a better lens.
- First step: state exactly what success means and what limits the work.

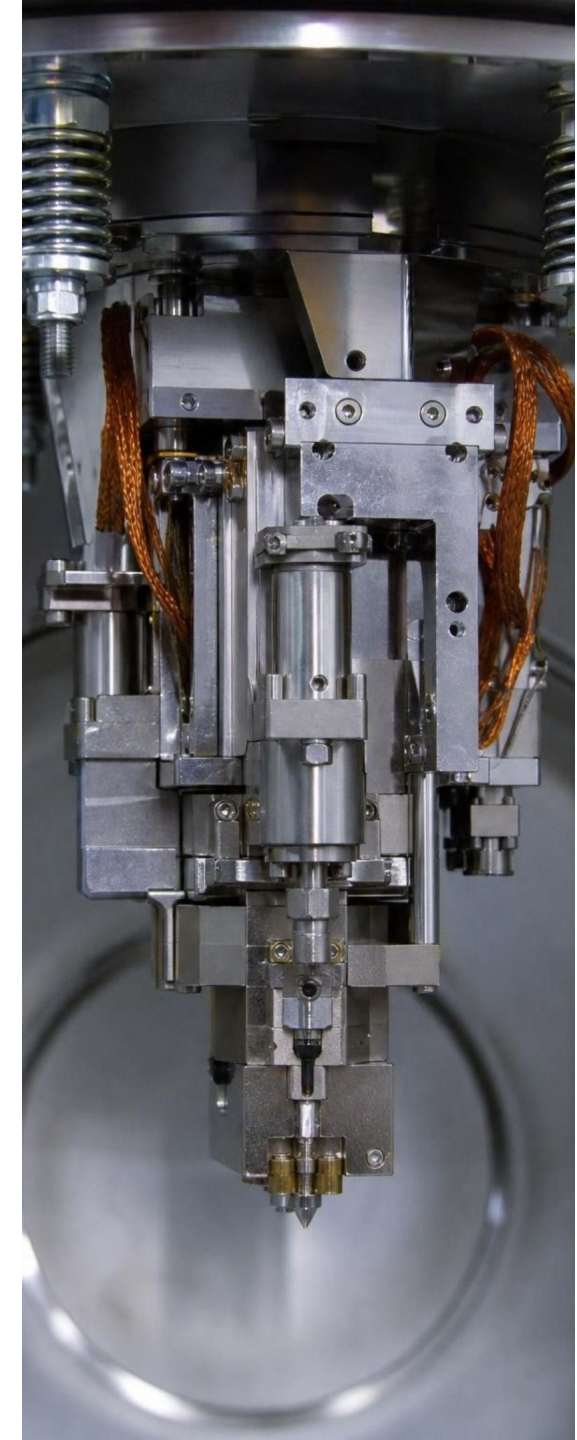
MODEL

Criteria versus constraints for the STM team

Model: What the microscope had to do, and what limited the team

A criterion is a target you aim for; a constraint is a wall you work within.

Criteria (what success requires)	Constraints (limits on the solution)
Show the positions of single atoms on a surface	Existing tools could not do the job, so parts had to be invented
Tell apart features about 100 pm apart	Footsteps and traffic shook the instrument, so data came at night
Measure surface features, not just show them	The probe must come within about a nanometer without touching
Eventually move individual atoms on purpose	Progress had to be shown regularly to keep the lab's support



How the STM builds a map without light

Model: One scan line of a scanning tunneling microscope

1 A metal probe sharpened to a tip a few atoms wide

2 → **(position)**
Tip lowered to within about 1 nm of the surface

3 → **(approach)**
A small voltage lets a tiny current cross the gap

4 → **(measure)**
Current grows sharply when the tip is nearer the surface

5 → **(respond)**
Tip sweeps side to side, line after line, recording current

6 → **(scan)**
Computer turns the readings into a bumpy map of the atoms

Over the top of an atom the gap is smaller and the current rises; over the space between atoms it falls.

THINK, PAIR, SHARE

Discuss: is the STM like reading braille?

Fair: both build a picture of bumps by moving across a surface in a pattern.

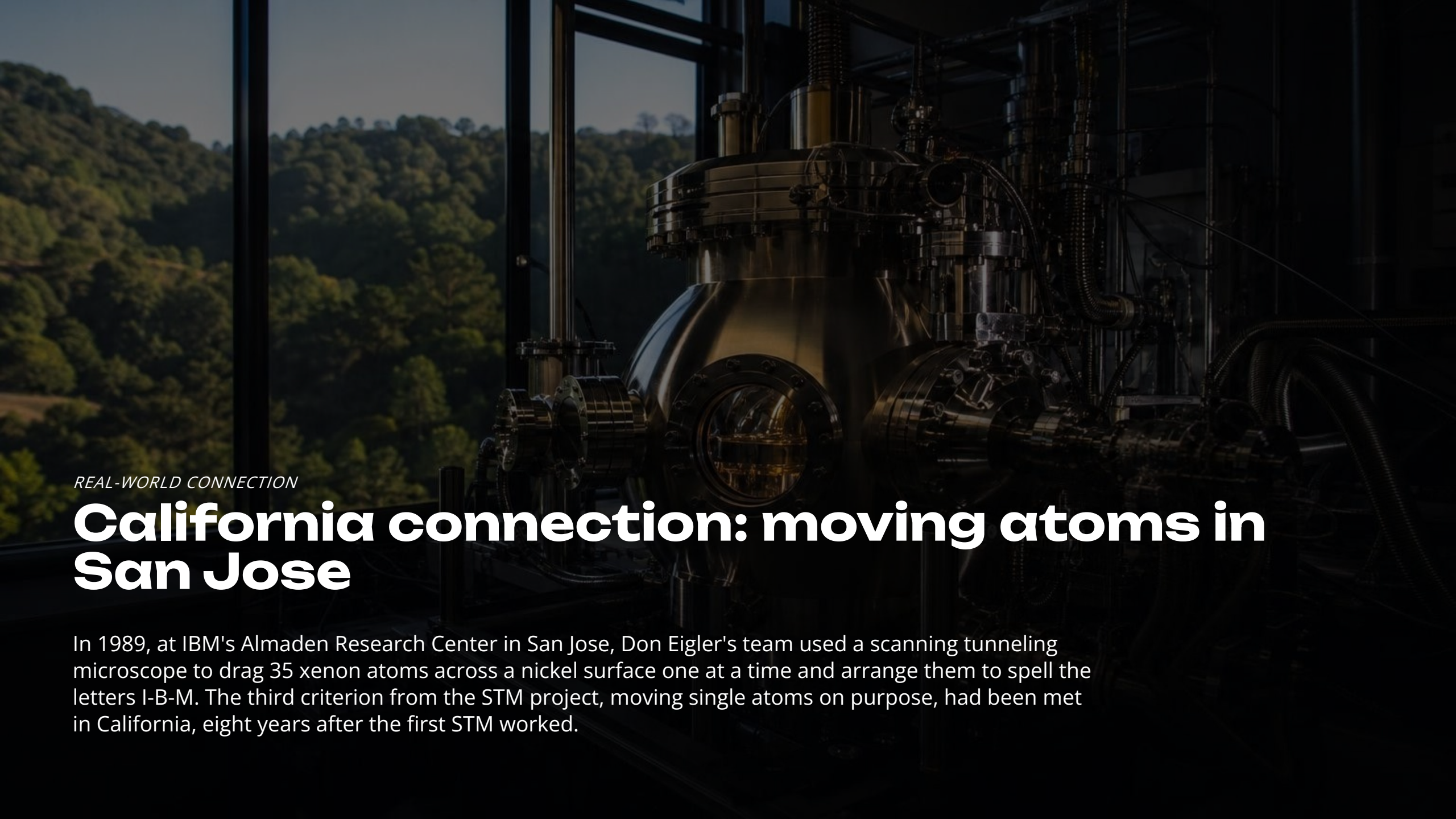
Fair: both work in the dark; neither needs light.

Breaks: a finger presses on the dots; the STM tip never touches.

Breaks: a finger feels height directly; the STM measures a current and infers height.

Reading braille with a fingertip is a common comparison for the STM. In what ways is the comparison fair, and where does it break down?





REAL-WORLD CONNECTION

California connection: moving atoms in San Jose

In 1989, at IBM's Almaden Research Center in San Jose, Don Eigler's team used a scanning tunneling microscope to drag 35 xenon atoms across a nickel surface one at a time and arrange them to spell the letters I-B-M. The third criterion from the STM project, moving single atoms on purpose, had been met in California, eight years after the first STM worked.



CHECK FOR UNDERSTANDING

Quick check: criterion or constraint?

- 1 The tool must tell apart two bumps that are 100 pm apart.
- 2 The building vibrates whenever people walk down the hall.
- 3 The tool should be able to push one atom to a new spot.
- 4 Only parts the lab already owns can be used in the first version.
- 5 The finished map must be readable by someone who did not make it.

Sort each statement about a surface-mapping tool. Hold up C for criterion, K for constraint.

Classifying elements before anyone could map them

- In 1829 Johann Döbereiner noticed trios of elements with matching properties.
- Lithium, sodium and potassium: all soft, silvery metals, all react with water.
- Their atomic masses: about 7, 23 and 39 daltons. The middle one is close to the average of the other two.
- Same pattern in chlorine, bromine, iodine and in calcium, strontium, barium.
- The middle element's behavior sits between its two partners as well.



A timeline of sorting the elements

Model: From trios to the modern table

1829: Döbereiner's trios: Groups of three elements with alike properties; middle mass near the average.

1869: Mendeleev's first table: Rows by rising mass, columns by shared properties. Lothar Meyer built a similar table independently.

1875-1886: predictions confirmed: Gallium (1875), scandium (1879) and germanium (1886) matched the predicted gaps.

1864-65: Newlands' eights: Listed elements by mass; properties seemed to repeat every eighth element. Mocked at the time.

1871: blanks with predictions: Mendeleev left gaps and predicted the mass and behavior of three missing elements.

1913: atomic number: Henry Moseley showed the true order is by atomic number, fixing the few mass exceptions.

Each step kept the useful part of the last one and fixed what did not work.

Why leaving a blank space was the brave move

Mendeleev refused to force an element into a column where its properties did not fit. Instead he left a gap and claimed an undiscovered element belonged there. He predicted its atomic mass by averaging its neighbors and predicted its behavior from its column. When gallium turned up in 1875 with almost exactly the predicted properties, the table stopped being a list and became a scientific model.





THINK, PAIR, SHARE

Discuss: would you trust a chart with holes in it?

A classmate says a table with blank spaces proves the scientist did not know what they were doing. Argue for and against, using what Mendeleev did with his blanks.

Reading the neighborhoods of the periodic table

Model: Where things are on the table and what position tells you

Period (row): Atomic mass generally rises from left to right along a row, with a few exceptions.

Group (column): Elements in one column tend to share properties and react in similar ways.

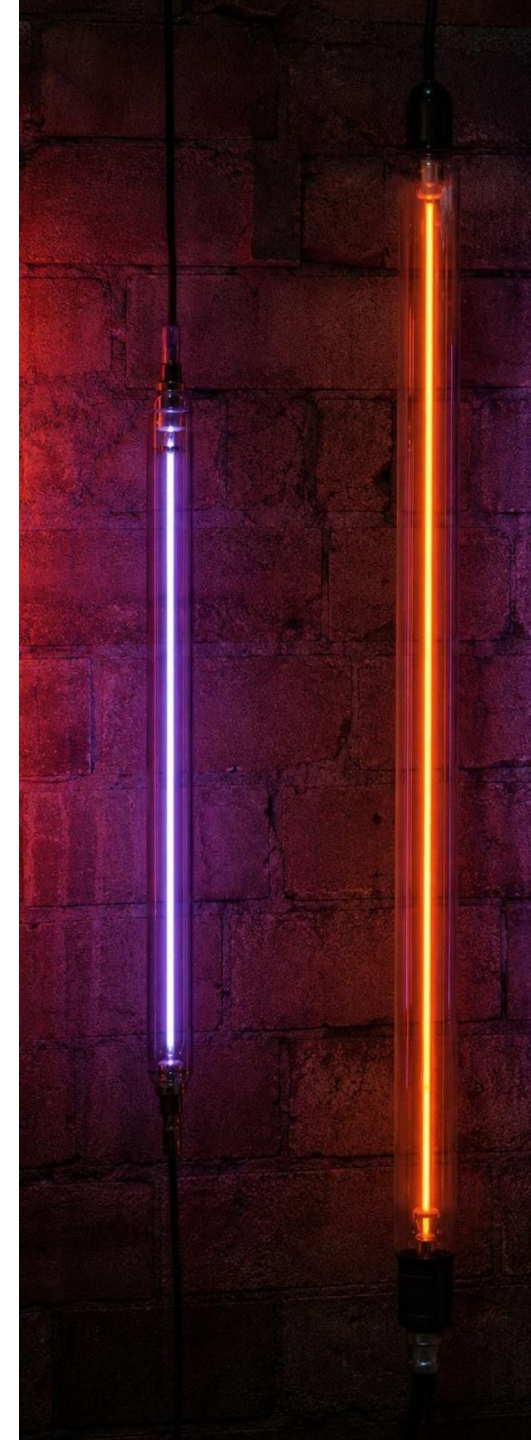
Far-left column: Li, Na, K, Rb: Soft, silvery metals that react with water, more violently going down the column.

Far-right column: He, Ne, Ar, Kr: Colorless gases at room temperature that form almost no compounds. Neon and argon glow in signs.

Element tile: Shows the symbol, the name and the average atomic mass in daltons.

The exceptions: Ar before K, Te before I: Properties decided the order, not mass. The reason, atomic number, comes later.

Position is a prediction: tell me the column and I can guess how the element behaves.





VOCABULARY IN CONTEXT

Reading one tile of the table

atomic mass: The mass of one atom in daltons. The printed value is an average for the element's atoms. *Sodium, about 23 Da, has an atom roughly 23 times as massive as a hydrogen atom.*

group: A column of the periodic table whose elements tend to behave alike. *Neon and argon share a group, and both are unreactive gases used in lights.*

chemical symbol: A one- or two-letter shorthand for an element, the same in every language. *Pb means lead, from the Latin plumbum; K means potassium, from the Latin kalium.*

Task: sort the mystery elements like Mendeleev

Simulated data for practice.

Using only the properties and masses below, decide which elements belong in the same column, order them, and predict a seventh element's mass and behavior.

Mystery element	Atomic mass (Da)	State at room temp.	Reaction with water	Other
Vex	7	soft silvery metal	fizzes steadily	lightest metal in the set
Tam	20	colorless gas	none	glows red-orange in a lit tube
Rue	23	soft silvery metal	fast; can ignite	stored under oil
Pim	39	soft silvery metal	ignites at once	stored under oil
Nol	40	colorless gas	none	glows violet in a lit tube
Kesh	84	colorless gas	none	used in some bright lamps





CHECK FOR UNDERSTANDING

Quick check: where does it live?

A newly found element is a colorless gas at room temperature that forms almost no compounds. Where do you expect it on the table, and which elements should it resemble?

A. Far-right column, like neon and argon

B. Far-left column, like sodium and potassium

C. Middle of the table, like iron and copper

D. Impossible to say from two properties

MISCONCEPTION CHECK

True or false? Air is nothing

"An inflated balloon weighs the same as an empty one, because air is invisible and invisible things are not made of anything."

True or false? Explain your reasoning.



PUTTING IT TOGETHER

Putting it together

- 1 All matter, including air, is made of atoms; an element is a substance of one kind of atom.
- 2 Atoms live on the picometer scale, about ten million times smaller than a sand grain.
- 3 Precise criteria and constraints let Rohrer and Binnig build a tool that maps surfaces atom by atom.
- 4 Patterns in properties and mass, plus bold predictions, grew into the periodic table.
- 5 An element's position on the table predicts how it behaves.





EXIT TICKET

Exit ticket

- Write one sentence that uses both 'atom' and 'element' correctly.
- Name one criterion and one constraint from your touch-microscope design, and label which is which.
- An element glows in a sign and never reacts. Which column of the table is it in, and name a neighbor.
- About how many times smaller than a millimeter is an atom: a thousand, a million, or ten million?