

Atoms, Molecules, Ions & the Periodic Table

Preparation for General Chemistry · Dr. Karmach

By the end of this unit, you can...

- Locate protons, neutrons, and electrons in the atom and state what each count determines
- Read and write isotope symbols, converting between mass number, atomic number, and particle counts
- Calculate the average atomic mass of an element from isotope masses and abundances
- Give an element's period, group, family, and metal/nonmetal/metalloid class
- Predict the charge an atom takes when it forms an ion, and count the particles in that ion

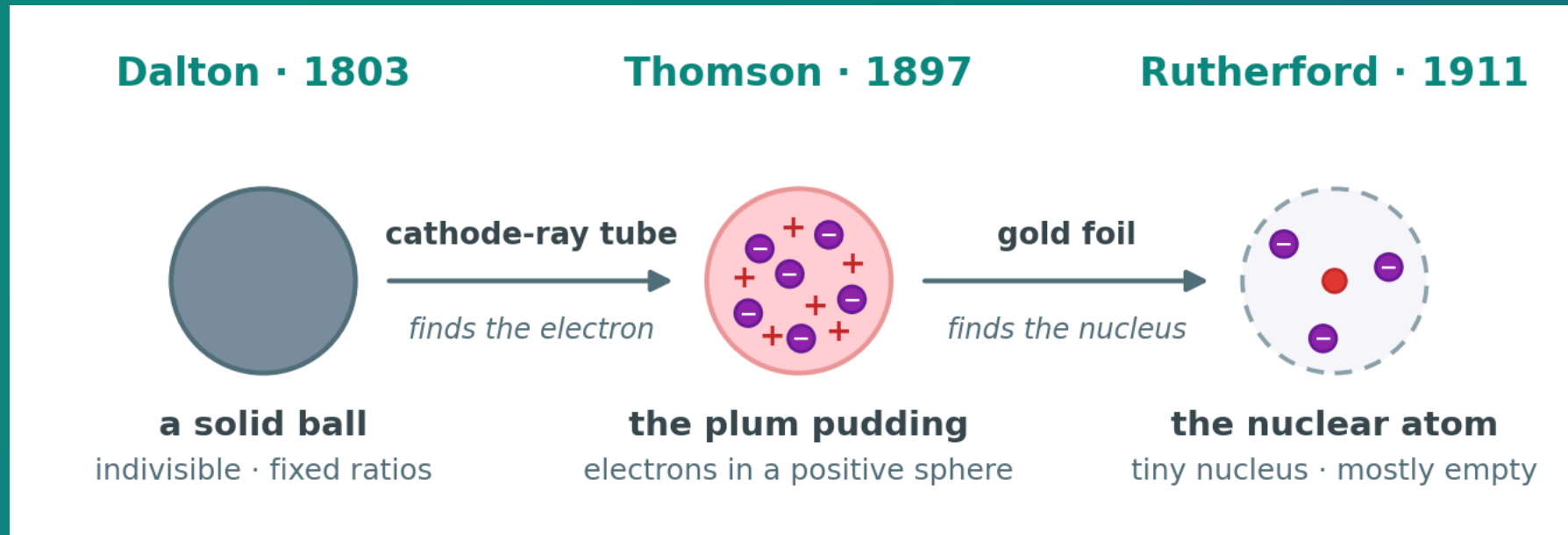
Today's route

1. How We Found the Atom
2. Element Symbols
3. Atomic Structure
4. Isotope Notation
5. Average Atomic Mass
6. Periodic Table Organization
7. Ions

1 • How We Found the Atom

Name the two mass laws the balance measured first, trace how the atomic model was redrawn twice, Dalton's atoms to Thomson's electron to Rutherford's nucleus, and state the experiment that forced each redraw.

Nobody has ever seen an atom



Yet you know what one looks like. That picture was redrawn twice in about a century, each time because an experiment said no. Here is the evidence trail.

A model earns its keep

solid ball → plum pudding → nuclear atom
each arrow: one experiment the old picture could not explain

A model is not a guess: it is the simplest picture that explains every experiment. A result the picture cannot explain forces a redraw, and each redraw keeps the parts that still work.

The law of conservation of mass

total mass before a reaction = total mass after

Lavoisier, 1789: reactions run in sealed flasks, weighed before and after

Two measured laws came before any atom. The first is Lavoisier's: weigh everything in, weigh everything out, and the totals match. Matter changes form; it never appears or disappears.



Worked example: heating limestone



given: 15.9 g CaCO_3 heated · 8.3 g CaO remains · wanted: mass of CO_2 released

Heating 15.9 g of limestone leaves 8.3 g of solid calcium oxide; the carbon dioxide escapes into the air. Find the mass of that gas without catching it.

✓ Worked example: solution



given: 15.9 g CaCO_3 · 8.3 g CaO remains · wanted: mass of CO_2

Apply the law

Subtract

$$\text{mass of CO}_2 = 15.9 \text{ g} - 8.3 \text{ g} = 7.6 \text{ g}$$

$$8.3 + 7.6 = 15.9 \checkmark \cdot \text{the totals match}$$

 **Sense check:** The gas escaped unseen, yet its mass is known: conservation turns one subtraction into a measurement. ✓

The law of definite proportions

100 g of water = 11.2 g hydrogen + 88.8 g oxygen

rain, seawater, or lab-made: the same split in every sample

The second law is Proust's: a compound's elements always combine in the same proportions by mass. And when two elements form two compounds, those proportions shift by whole-number steps: multiple proportions.

Dalton: matter comes in atoms

element = one kind of atom · compound = a fixed ratio of atoms

water: 2 H for every 1 O, in every sample ever measured

a reaction rearranges atoms

none created, none destroyed, none split

In 1803 Dalton explained both laws with one idea: matter comes in tiny indivisible pieces, atoms. Indestructible atoms keep mass conserved; atoms combining only in whole numbers keep proportions definite.

Thomson: the atom has parts

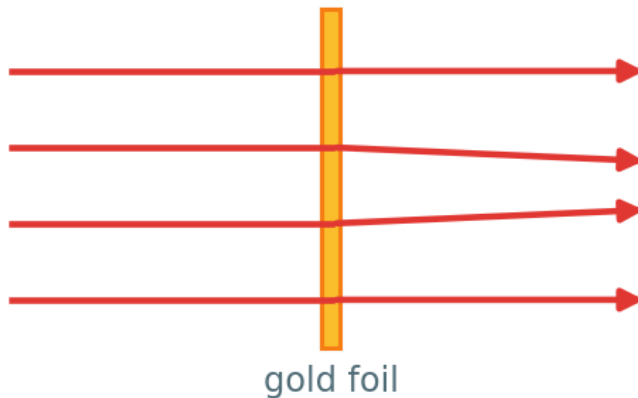
every metal tested → the same negative particle
the electron: about 1,800 times lighter than a hydrogen atom

In 1897 Thomson pulled identical negative particles from every metal he tried: the electron. Atoms have parts. To keep the atom neutral, he dotted the electrons through a diffuse positive sphere: the plum pudding model.

Rutherford: a tiny, dense nucleus

expected: pudding atom

charge spread thin, nothing to bounce off



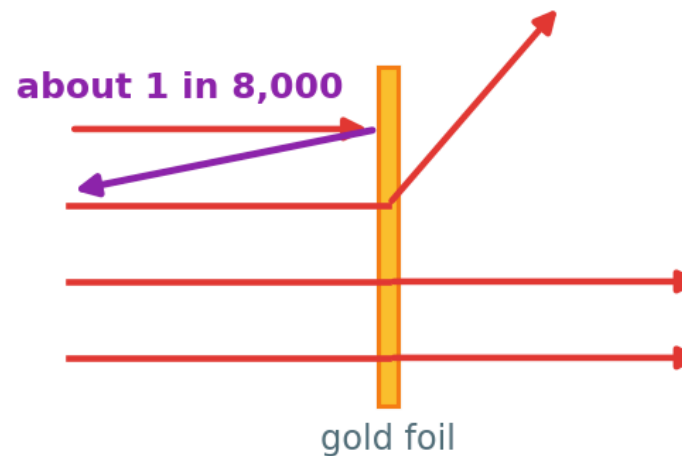
all pass, barely nudged

a nudge of a degree or two at most

alpha particles: small, fast, positive projectiles fired at foil a few thousand atoms thick

observed: 1909

counted flash by flash, all the way around



a few bounce straight back

some deflected past 90°, some nearly 180°

Left: what the pudding atom predicts. Right: what Rutherford's team observed in 1909. A bounce that hard needs a center holding the atom's positive charge and nearly all its mass.

2 · Element Symbols

Read and write element symbols, one capital letter or a capital plus a lowercase letter, and recognize the nine common metals whose symbols come from Latin names.

The labels already use them



A saline bag reads NaCl. A supplement lists Fe and Zn. A gold ring is stamped Au 750. Element symbols are chemistry's alphabet, and everyday labels already speak it.

A symbol abbreviates an element's name

the first letter

H hydrogen	C carbon	N nitrogen	O oxygen	F fluorine	S sulfur	I iodine
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the first two letters

He helium	Al aluminum	Br bromine	Ca calcium	Co cobalt	Si silicon
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the first letter + a later one

Cl chlorine	Cr chromium	Mg magnesium	Zn zinc
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A symbol is shorthand for an element or one atom of it. Most take letters from the English name. The first letter leads; a second is the next letter or a later one.

One or two letters name an element

H · C · N · O · S · K

one letter, always capital

Ca · Cl · Ne · Fe · Zn

two letters: capital first, lowercase second

Every element has a symbol of one or two letters. The first letter is always capitalized; a second letter, when present, is always lowercase. No symbol has two capitals.

The lowercase letter carries meaning

Co = cobalt, one element
a blue metal, atomic number 27

CO = carbon + oxygen
two capitals, two elements: the compound carbon monoxide

Capitalization is chemistry, not typography. Co names one metal; CO names a poisonous gas built from two elements. Read the case before reading the letters.

Nine symbols come from Latin

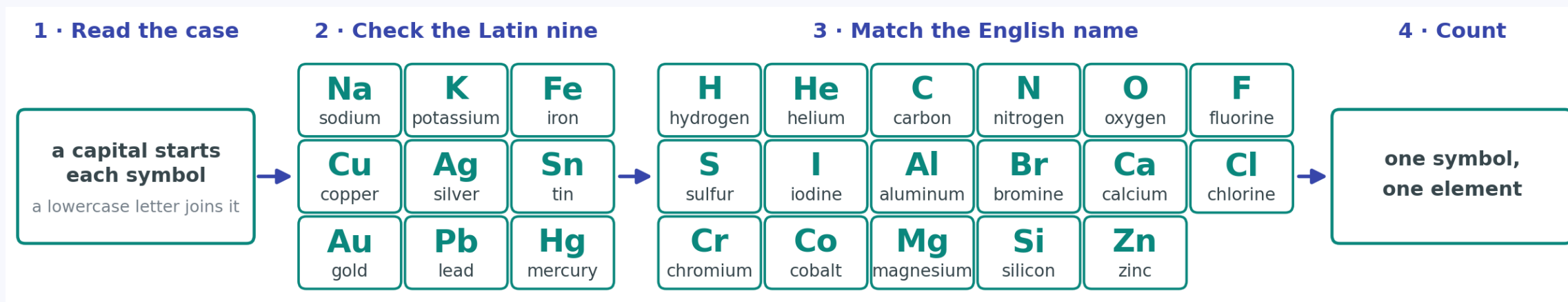
Na sodium <i>natrium</i>	K potassium <i>kalium</i>	Fe iron <i>ferrum</i>
Cu copper <i>cuprum</i>	Ag silver <i>argentum</i>	Sn tin <i>stannum</i>
Au gold <i>aurum</i>	Pb lead <i>plumbum</i>	Hg mercury <i>hydrargyrum</i>

hydrargyrum means water-silver: the one metal that pours

The oldest known metals carry symbols from their Latin names: Fe fits iron once ferrum is known. These nine appear on labels, batteries, and plumbing; memorize them as pairs.

The method

1. **Read the case:** each capital starts a symbol.
2. **Check the Latin nine:** Na, K, Fe, Cu, Ag, Sn, Au, Pb, Hg.
3. **Match the English name:** first letter first.
4. **Count:** one symbol, one element; a repeat is the same element.





Guided example: a pond treatment



the formula printed on the label

Garden stores sell a blue crystal that clears algae from ponds. Its label gives the formula CuSO_4 .

Name every element in it.

✓ Guided example: solution

Step 1 • Read the case



three capitals: three symbols · the lowercase u joins the C before it

Step 2 • Check the Latin nine

$\text{Cu} \rightarrow \text{cuprum} \rightarrow \text{copper}$

one of the Latin nine

Step 3 • Match the English name

$\text{S} \rightarrow \text{sulfur} \cdot \text{O} \rightarrow \text{oxygen}$

the subscript ₄ counts oxygen atoms; it names no element

🧠 **Sense check:** Every capital is matched to a name. ✓

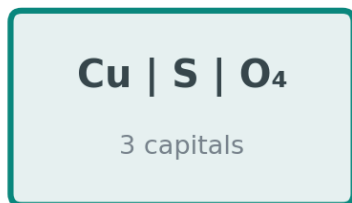
✓ Guided example: the route on the map

Step 4 · Count



three symbols $\rightarrow$ three elements: copper, sulfur, oxygen

1 · Read the case



2 · Check the Latin nine

Na sodium	K potassium	Fe iron
Cu copper	Ag silver	Sn tin
Au gold	Pb lead	Hg mercury

3 · Match the English name

H hydrogen	He helium	C carbon	N nitrogen	O oxygen	F fluorine
S sulfur	I iodine	Al aluminum	Br bromine	Ca calcium	Cl chlorine
Cr chromium	Co cobalt	Mg magnesium	Si silicon	Zn zinc	

4 · Count

3 elements
copper · sulfur · oxygen

 **Sense check:** One symbol came from the Latin nine and two from English names. Each capital is one element. ✓



Practice 1

Fe · CO · Na · Sn

four symbol-and-name pairings: exactly one is wrong

One pairing below is wrong. Which one?

- A. Fe, iron
- B. CO, cobalt
- C. Na, sodium
- D. Sn, tin

✓ Practice 1 · answer: B

cobalt = Co · CO = carbon monoxide (answer B)
a capital O is a second element, not part of cobalt's symbol

B is the wrong pairing: two capitals mean two elements, so CO is a compound of carbon and oxygen. A, C, and D are correct Latin pairs: ferrum gives Fe, natrium gives Na, stannum gives Sn.

🧠 **Sense check:** Case first, letters second: a capital plus a lowercase letter is one element; two capitals are two. ✓

✓ Practice 1: the route on the map

Fe · CO · Na · Sn

found: CO is carbon + oxygen, not cobalt (answer B)

1 · Read the case

Fe · C | O · Na · Sn
CO: two capitals

2 · Check the Latin nine

Na sodium	K potassium	Fe iron
Cu copper	Ag silver	Sn tin
Au gold	Pb lead	Hg mercury

3 · Match the English name

H hydrogen	He helium	C carbon	N nitrogen	O oxygen	F fluorine
S sulfur	I iodine	Al aluminum	Br bromine	Ca calcium	Cl chlorine
Cr chromium	Co cobalt	Mg magnesium	Si silicon	Zn zinc	

4 · Count

CO = 2 elements
carbon + oxygen

 **Sense check:** Fe, Na, and Sn sit in the Latin nine. CO splits at its second capital into C and O, two English-name symbols. Cobalt, Co, was never used. ✓

 Practice 2

the light-sensitive crystals in photographic film

Black-and-white film is coated with tiny crystals of AgBr . Which elements does AgBr contain?

- A. silver and bromine
- B. gold and bromine
- C. argon and bromine
- D. silver and boron

✓ Practice 2 · answer: A

$\text{AgBr} \rightarrow \text{Ag} \mid \text{Br}$

Ag: argentum → silver · Br: bromine (answer A)

B swapped the two precious metals: gold is Au, from aurum. C matched Ag to an English name that starts with A: argon is Ar. D dropped the lowercase r: boron is B alone, and the r joins B in Br, bromine.

🧠 **Sense check:** Check the Latin nine first: Ag is on it. Only then match the rest to English names. ✓

✓ Practice 2: the route on the map



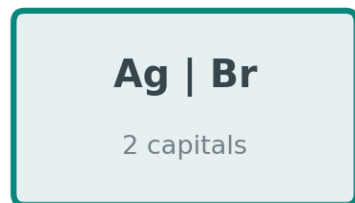
found: silver and bromine

1 · Read the case

2 · Check the Latin nine

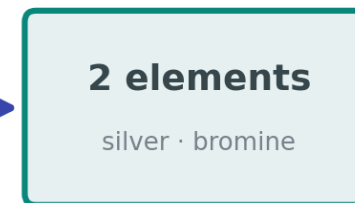
3 · Match the English name

4 · Count



Na sodium	K potassium	Fe iron
Cu copper	Ag silver	Sn tin
Au gold	Pb lead	Hg mercury

H hydrogen	He helium	C carbon	N nitrogen	O oxygen	F fluorine
S sulfur	I iodine	Al aluminum	Br bromine	Ca calcium	Cl chlorine
Cr chromium	Co cobalt	Mg magnesium	Si silicon	Zn zinc	



🧠 **Sense check:** Two capitals, two symbols: one from the Latin nine and one from an English name. ✓



Practice 3

one potassium atom for each chlorine atom
wanted: the formula, both symbols written correctly

A salt substitute for low-sodium diets pairs one potassium with each chlorine. Which formula writes both symbols correctly?

- A. PCl
- B. KCL
- C. PoCl
- D. KCl

✓ Practice 3 · answer: D

potassium → K · chlorine → Cl · KCl

K from kalium, one of the Latin nine · Cl: capital C, lowercase l (answer D)

A took potassium's first letter: P is phosphorus. B capitalized chlorine's second letter: CL reads as two symbols, C and L, and no element is L. C took the first two letters: Po is polonium.

🧠 **Sense check:** Writing runs the method in reverse: check the Latin nine before the English name, then write one capital per element. ✓

✓ Practice 3: the route on the map

potassium → K · chlorine → Cl
found: KCl

1 · Read the case

K | Cl
capital, then lowercase

2 · Check the Latin nine

Na sodium	K potassium	Fe iron
Cu copper	Ag silver	Sn tin
Au gold	Pb lead	Hg mercury

3 · Match the English name

H hydrogen	He helium	C carbon	N nitrogen	O oxygen	F fluorine
S sulfur	I iodine	Al aluminum	Br bromine	Ca calcium	Cl chlorine
Cr chromium	Co cobalt	Mg magnesium	Si silicon	Zn zinc	

4 · Count

2 elements
potassium · chlorine

🧠 **Sense check:** Potassium is a Latin-name metal, so its symbol is K. Chlorine takes its first letter and a later one, l. ✓



Practice 4



acetic acid, the sour part of vinegar

Vinegar tastes sour because of acetic acid, CH_3COOH . How many different elements does it contain?

- A. 4
- B. 8
- C. 3
- D. 6

✓ Practice 4 · answer: C



six symbols written · three different elements: carbon, hydrogen, oxygen (answer C)

A read CO as Co, cobalt: C, H, Co, O makes 4. B counted atoms, not elements: $2 \text{ C} + 4 \text{ H} + 2 \text{ O} = 8$. D counted every symbol as written, repeats included: 6.

 **Sense check:** Two capitals side by side, C then O, are two symbols. A symbol written twice names the same element twice. ✓

✓ Practice 4: the route on the map



1 · Read the case

C | H₃ | C | O | O | H
6 capitals

2 · Check the Latin nine

Na sodium	K potassium	Fe iron
Cu copper	Ag silver	Sn tin
Au gold	Pb lead	Hg mercury

3 · Match the English name

H hydrogen	He helium	C carbon	N nitrogen	O oxygen	F fluorine
S sulfur	I iodine	Al aluminum	Br bromine	Ca calcium	Cl chlorine
Cr chromium	Co cobalt	Mg magnesium	Si silicon	Zn zinc	

4 · Count

3 elements
C, H, O each repeat

 **Sense check:** No Latin symbol appears. Six capitals collapse to three English-name elements once the repeats are merged. ✓

 Practice 5

a powder potters add to glazes to fire a deep blue

Potters fire a deep blue into glazes with a pinch of CoCO_3 . Which list names every element in it?

- A. carbon, oxygen
- B. cobalt
- C. copper, carbon, oxygen
- D. cobalt, carbon, oxygen

✓ Practice 5 · answer: D

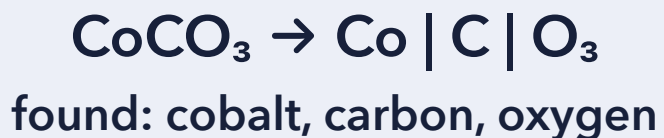


Co: cobalt · C: carbon · O: oxygen (answer D)

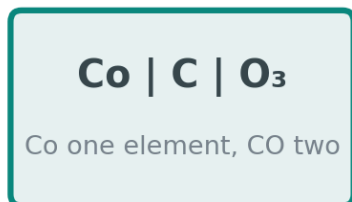
A read Co as two symbols, C and O: a lowercase o never starts a symbol, so Co is one element, cobalt. B read CO as Co too: two capitals are two symbols, carbon and oxygen. C matched Co to copper: copper is Cu, from cuprum.

 **Sense check:** The same two letters appear twice in two cases: Co is one element, CO is two. The ₃ counts oxygen atoms. ✓

✓ Practice 5: the route on the map



1 · Read the case



2 · Check the Latin nine

Na sodium	K potassium	Fe iron
Cu copper	Ag silver	Sn tin
Au gold	Pb lead	Hg mercury

3 · Match the English name

H hydrogen	He helium	C carbon	N nitrogen	O oxygen	F fluorine
S sulfur	I iodine	Al aluminum	Br bromine	Ca calcium	Cl chlorine
Cr chromium	Co cobalt	Mg magnesium	Si silicon	Zn zinc	

4 · Count

3 elements
cobalt · carbon · oxygen

 **Sense check:** The case split did the work: three capitals, three elements. Cu sits in the Latin nine, but the symbol here is Co, an English name. ✓

3 · Atomic Structure

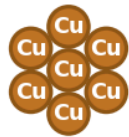
Count the protons, neutrons, and electrons in any neutral atom, and name the element from its proton count.

About 90 kinds of atoms

three objects · each a single element



gold ring
every atom Au



copper wire
every atom Cu

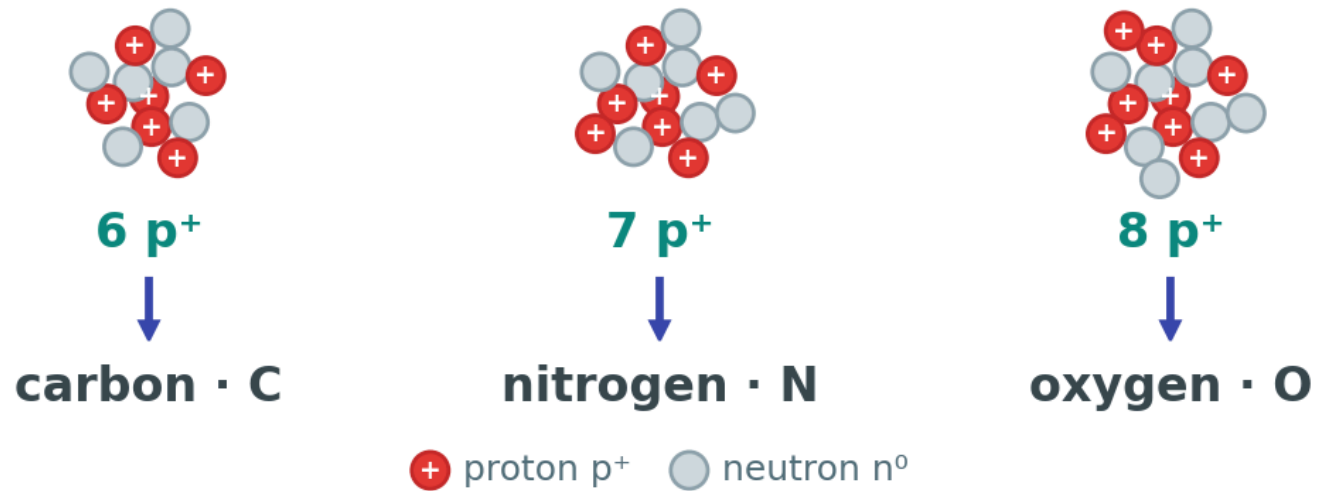


diamond
every atom C

A gold ring, a copper wire, a diamond: each one kind of atom. Nature supplies about 90 of 118 known kinds, the naturally occurring elements; labs make the rest.

Protons name the element

the proton count names the element



An atom with six protons is carbon, every time. Electrons come and go in ordinary chemistry; neutron counts vary among atoms of one element. Change the proton count and the atom is a different element.

Three particles build every atom

proton p^+ · charge $1+$ · relative mass 1
in the nucleus

neutron n^0 · charge 0 · relative mass ≈ 1
in the nucleus

electron e^- · charge $1-$ · relative mass $\approx 1/1840$
outside the nucleus

The nucleus is the dense center; electrons fill the space around it. The names carry the charges: Proton Positive, Neutron Neutral.

Particle masses in atomic mass units

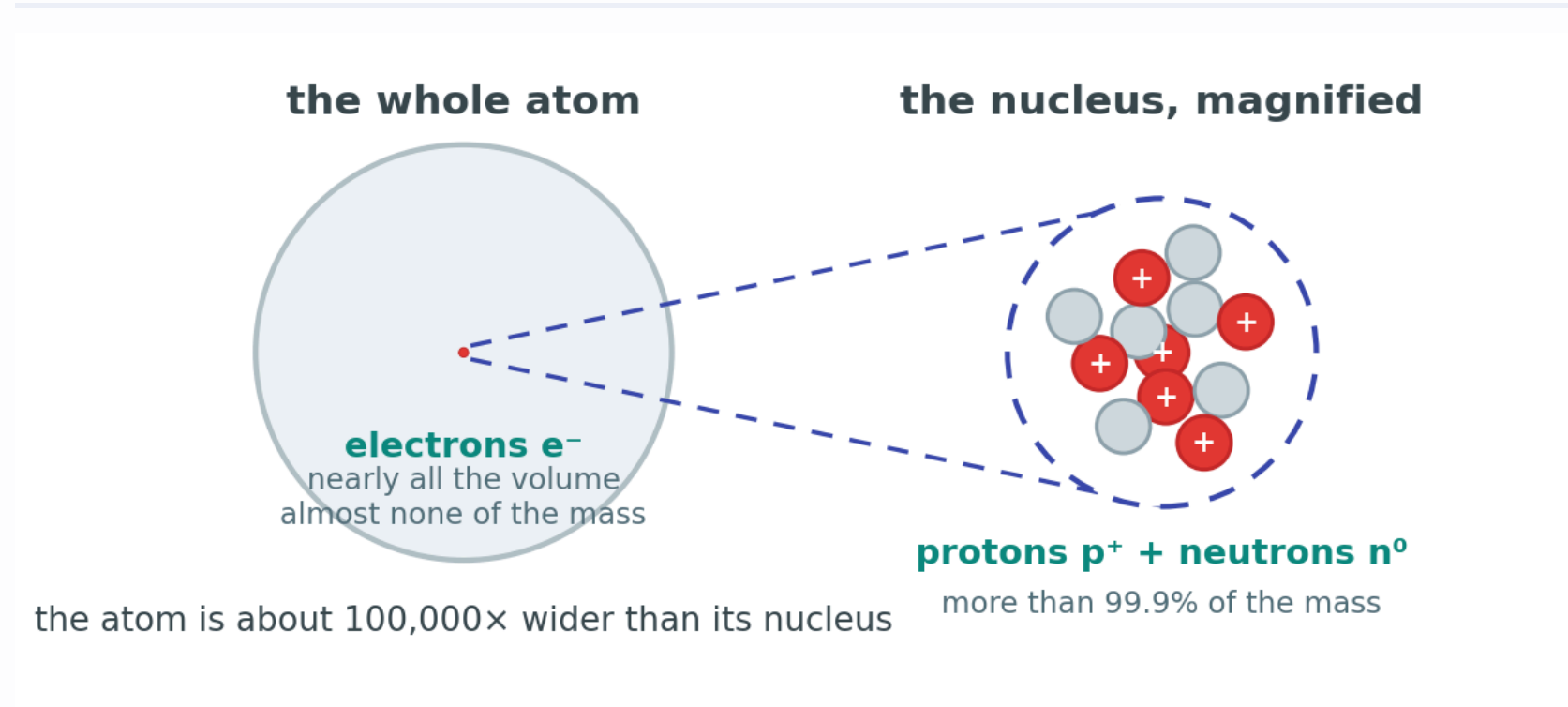
proton 1.0073 amu · neutron 1.0087 amu · electron 0.00055 amu
1 amu = 1/12 the mass of one carbon-12 atom · a proton or a neutron $\approx$ 1840 electrons

Protons and neutrons each weigh about 1 amu. Electrons add almost nothing.

Estimate the mass, in amu, of an atom with 6 protons, 6 neutrons, and 6 electrons.

$6 p^+ + 6 n^0 \approx 12 \text{ amu} \cdot 6 e^- = 6 \times 0.00055 = 0.0033 \text{ amu}$
the nucleus carries the mass · this atom is carbon-12, the atom that defines the amu

Where the mass sits



Protons and neutrons give the atom nearly all its mass, packed into the tiny nucleus. If the nucleus were a marble, the atom would be a stadium.

Two numbers describe an atom

atomic number Z = protons

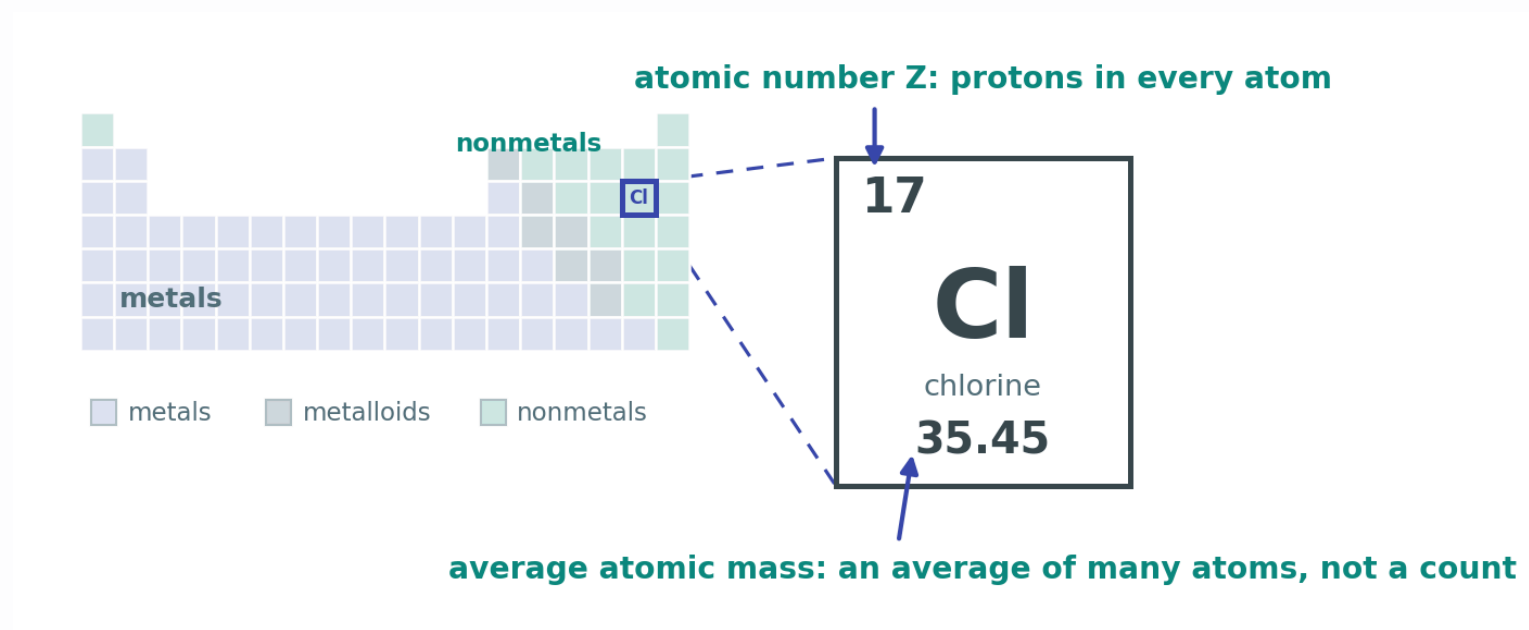
Z names the element: every carbon atom has $Z = 6$

mass number A = protons + neutrons

A counts the particles in the nucleus of one atom

Z is the same for every atom of an element. In a neutral atom, electrons match protons, so the charges cancel.

Reading the periodic table



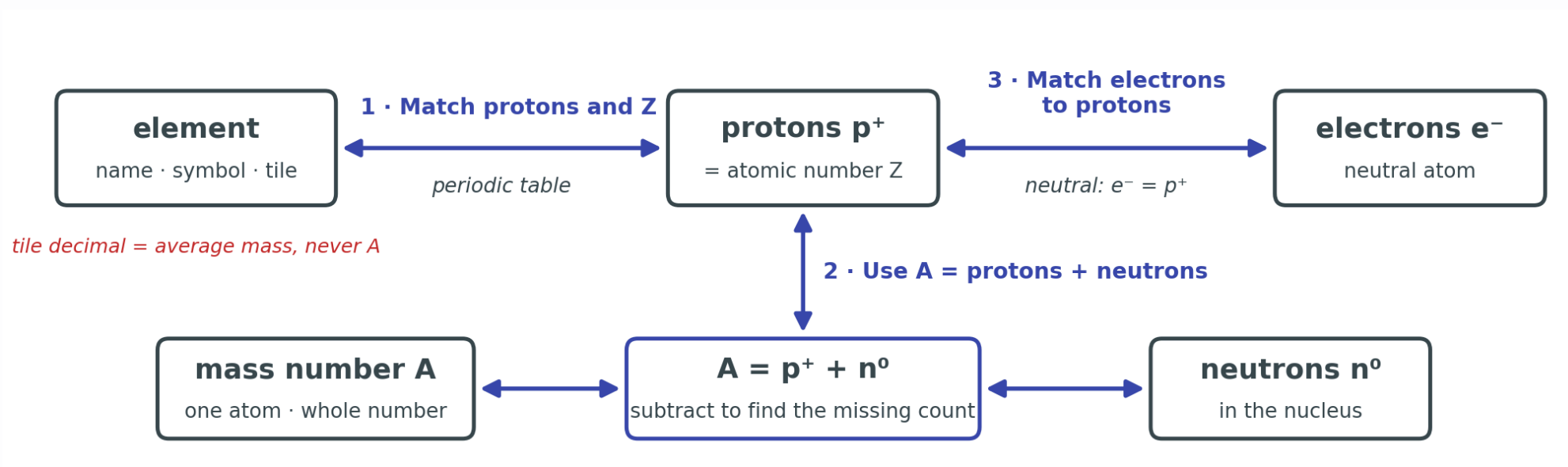
The table lists the elements in order of Z. A tile carries the atomic number and the average mass of the element's atoms. Metals fill the left and center; nonmetals sit to the upper right.



The method

1. **Match protons and Z.** The atomic number is the proton count; it names the element.
2. **Use $A = \text{protons} + \text{neutrons}$.** Subtract to find whichever count is missing.
3. **Match electrons to protons.** A neutral atom holds equal numbers.

One map for every count



Protons sit at the center. Each method step is one link out of them. Protons plus one nucleus count (A or neutrons) fill in the rest.



Guided example: a sodium atom

sodium: $Z = 11$ · mass number $A = 23$

given: one neutral atom · wanted: protons, neutrons, electrons

A neutral sodium atom has mass number 23. Count its protons, neutrons, and electrons.

✓ Guided example: solution

sodium: $Z = 11$ · mass number $A = 23$

given: one neutral atom · wanted: protons, neutrons, electrons

Step 1 · Match protons and Z

Step 2 · Use $A = \text{protons} + \text{neutrons}$

neutrons = $A - \text{protons} = 23 - 11 = 12$

23 particles in the nucleus · 11 of them protons · the other 12 neutrons

Step 3 · Match electrons to protons

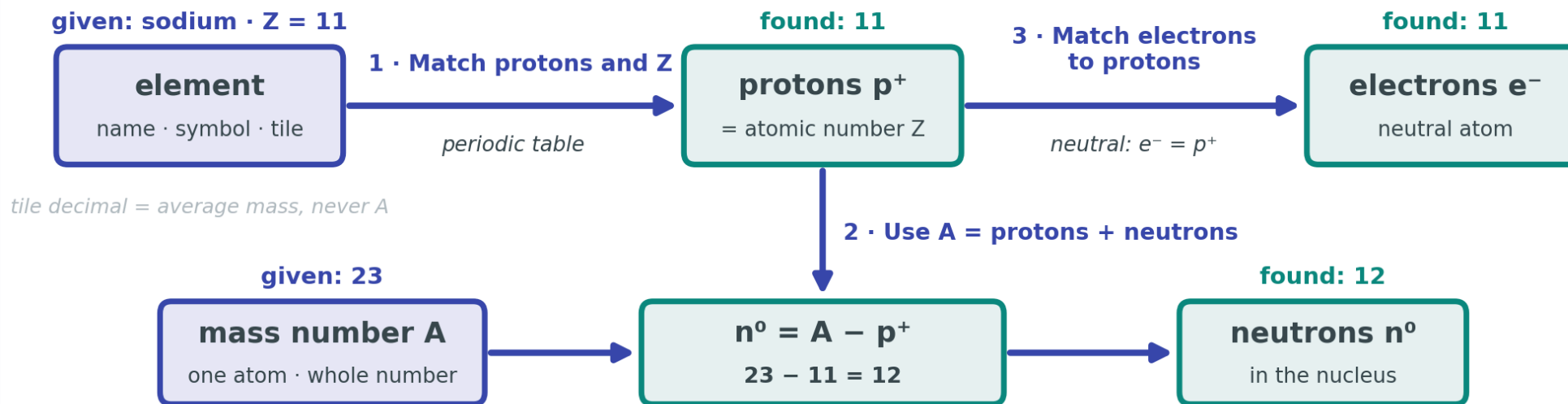
sodium $\rightarrow 11 \text{ p}^+ \cdot 12 \text{ n}^0 \cdot 11 \text{ e}^-$

neutral: 11 positive charges balance 11 negative charges

 **Sense check:** Rebuild the mass number: $11 + 12 = 23$, the given A . ✓

✓ Guided example: the route on the map

sodium: $Z = 11 \cdot A = 23 \rightarrow 11 \text{ p}^+ \cdot 12 \text{ n}^0 \cdot 11 \text{ e}^-$
 given: Z and A · found: protons, neutrons, electrons



🧠 **Sense check:** Z and A given: the protons come first, then one link out of them for each other count. ✓

 Practice 1

periodic-table tile: 47 · Ag · 107.87

silver · one neutral atom

Silver conducts electricity better than any other metal. How many protons are in one silver atom?

- A. 108
- B. 61
- C. 47
- D. 155

✓ Practice 1 · answer: C

tile 47 · Ag · 107.87 → Z = 47 → 47 p⁺ (answer C)

the whole number on the tile is Z, the proton count · 47 protons is silver

A read the tile's average mass, rounded, as the proton count: 108. B subtracted Z from that rounded mass: $108 - 47 = 61$, a neutron estimate, not protons. D added the tile's two numbers: $47 + 108 = 155$.

🧠 **Sense check:** Every silver atom has 47 protons. The decimal 107.87 is an average mass and never enters a count.

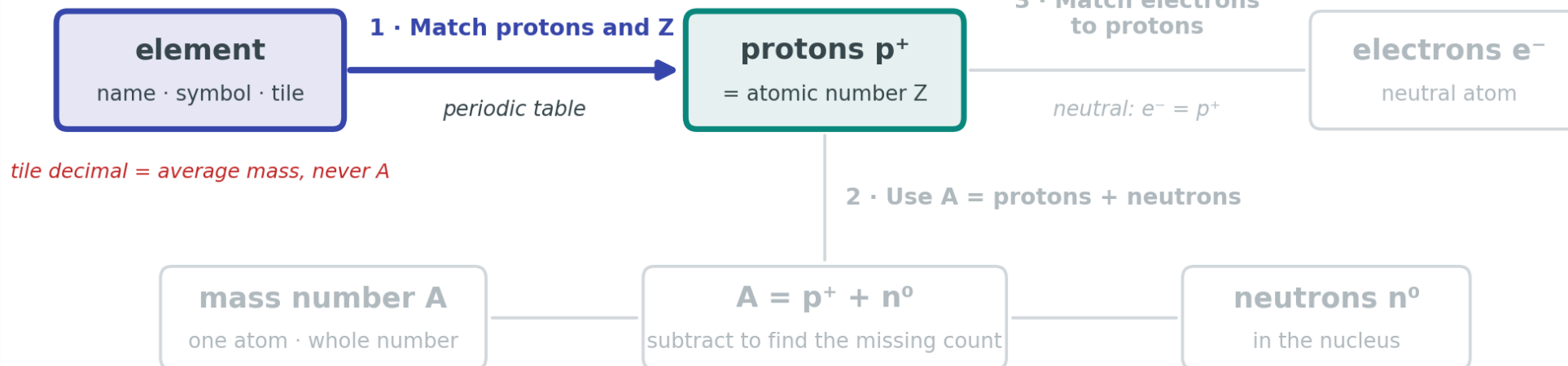
✓

✓ Practice 1: the route on the map

tile 47 · Ag · 107.87 → 47 p⁺
given: the tile · found: the proton count

given: tile: 47 · Ag · 107.87

found: 47



🧠 **Sense check:** One link only: the tile gives Z, and Z is the proton count. ✓



Worked example 1: silicon

silicon: $Z = 14$ · mass number $A = 29$

given: one neutral atom · wanted: protons, neutrons, electrons

A neutral silicon atom has mass number 29. Count its protons, neutrons, and electrons.

✓ Worked example 1: solution

silicon: $Z = 14$ · mass number $A = 29$

given: one neutral atom · wanted: protons, neutrons, electrons

Step 1 · Match protons and Z

Step 2 · Use $A = \text{protons} + \text{neutrons}$

Step 3 · Match electrons to protons

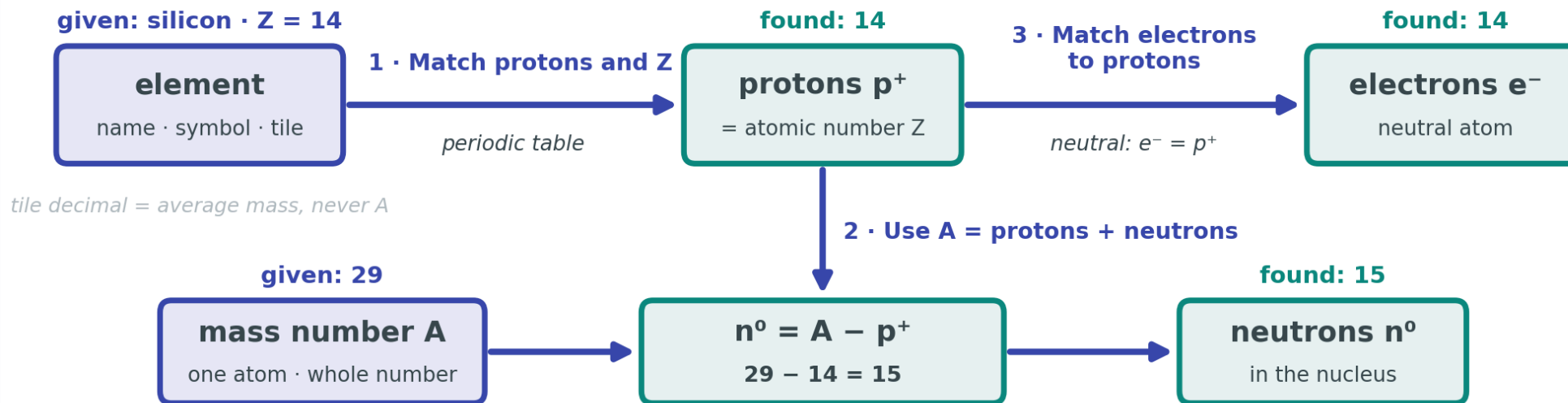
silicon $\rightarrow 14 \text{ p}^+ \cdot 15 \text{ n}^0 \cdot 14 \text{ e}^-$

protons = $Z = 14$ · neutrons = $29 - 14 = 15$ · electrons = 14 $\rightarrow$ neutral

🧠 **Sense check:** Rebuild the mass number: $14 + 15 = 29$, the given A . ✓

✓ Worked example 1: the route on the map

silicon: $Z = 14 \cdot A = 29 \rightarrow 14 \text{ p}^+ \cdot 15 \text{ n}^0 \cdot 14 \text{ e}^-$
 given: Z and A · found: protons, neutrons, electrons



🧠 **Sense check:** Protons first, from Z . Neutrons by subtraction, $29 - 14 = 15$. Electrons by matching the protons. ✓

Your turn: fluorine

fluorine: $Z = 9$ · mass number $A = 19$
one neutral atom

step	question	answer
1 · match protons and Z	protons?	_____
2 · use $A = \text{protons} + \text{neutrons}$	$19 - 9 = ?$	_____ neutrons
3 · match electrons to protons	electrons?	_____

Complete the three counts.

fluorine $\rightarrow 9 \text{ p}^+ \cdot 10 \text{ n}^0 \cdot 9 \text{ e}^-$
protons = $Z = 9$ · neutrons = $19 - 9 = 10$ · electrons = $9 \rightarrow \text{neutral}$

⚠ Where this goes wrong

Naming the element from the electron count. A neutral atom holds equal electrons and protons, so the two counts agree. Electrons are gained and lost in chemical changes; the proton count is the one that names the element.

Reading the tile's decimal as a mass number. Chlorine's 35.45 is an average over many atoms, not a count. A mass number is a whole number and belongs to one specific atom.

Taking the mass number as the neutron count. $A = 29$ does not mean 29 neutrons. The mass number counts protons and neutrons together: for silicon, neutrons = $29 - 14 = 15$.



Practice 2

zinc: $Z = 30$ · mass number $A = 66$
one neutral atom

A neutral zinc atom has mass number 66. Which row counts its particles?

- A. p^+ : 30 · n^0 : 36 · e^- : 30
- B. p^+ : 30 · n^0 : 96 · e^- : 30
- C. p^+ : 30 · n^0 : 66 · e^- : 30
- D. p^+ : 36 · n^0 : 30 · e^- : 36

✓ Practice 2 · answer: A

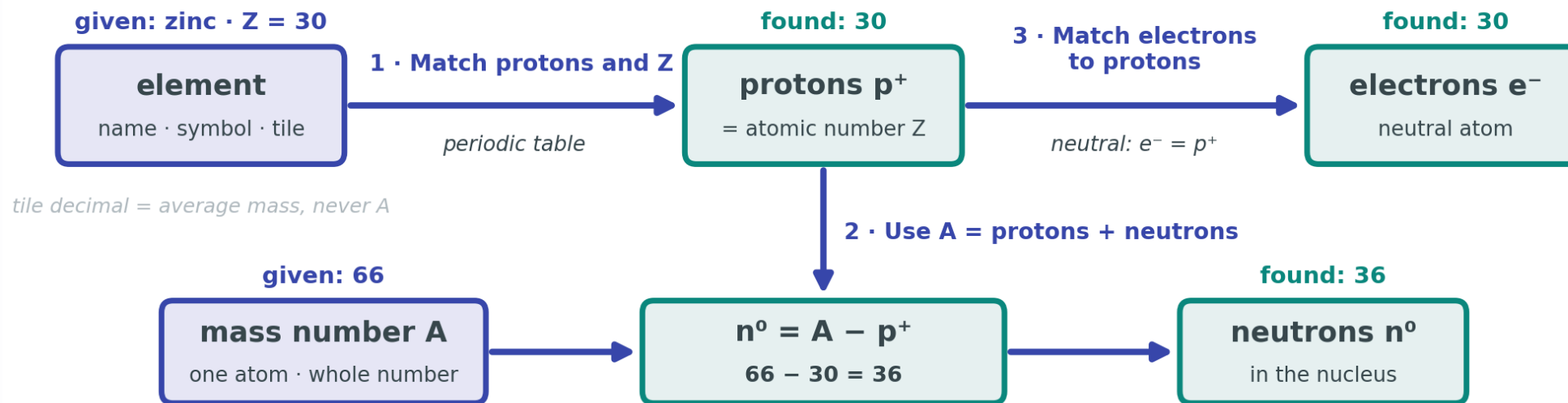
zinc, $Z = 30$, $A = 66 \rightarrow 30 \text{ p}^+ \cdot 36 \text{ n}^0 \cdot 30 \text{ e}^-$ (answer A)
protons = $Z = 30$ · neutrons = $66 - 30 = 36$ · electrons = $30 \rightarrow$ neutral

C read the mass number as the neutron count: 66. B added instead of subtracting: $66 + 30 = 96$. D swapped protons and neutrons: 36 protons is a different element: krypton, not zinc.

🧠 **Sense check:** 30 protons + 36 neutrons returns the mass number, 66. ✓

✓ Practice 2: the route on the map

zinc: $Z = 30 \cdot A = 66 \rightarrow 30 \text{ p}^+ \cdot 36 \text{ n}^0 \cdot 30 \text{ e}^-$
 given: Z and A · found: protons, neutrons, electrons



🧠 **Sense check:** Neutrons come only through the $A = \text{protons} + \text{neutrons}$ link: $66 - 30 = 36$, never 66 itself. ✓



Worked example 3: the element from the counts

one neutral atom: $24 \text{ p}^+ \cdot 28 \text{ n}^0 \cdot 24 \text{ e}^-$

wanted: the element and its mass number

An atom holds 24 protons, 28 neutrons, and 24 electrons. Identify the element and give the mass number.

A common first attempt: $A = \text{protons} + \text{electrons} = 24 + 24 = 48$. Test it against what the mass number counts.

✓ Worked example 3: solution

A common first attempt

$24 \text{ p}^+ \cdot 28 \text{ n}^0 \cdot 24 \text{ e}^- \cdot \text{attempt: } A = 24 + 24 = 48?$

electrons sit outside the nucleus and weigh about 1/1840 of a proton ✗

Step 1 · Match protons and Z

Step 2 · Use $A = \text{protons} + \text{neutrons}$

Step 3 · Match electrons to protons

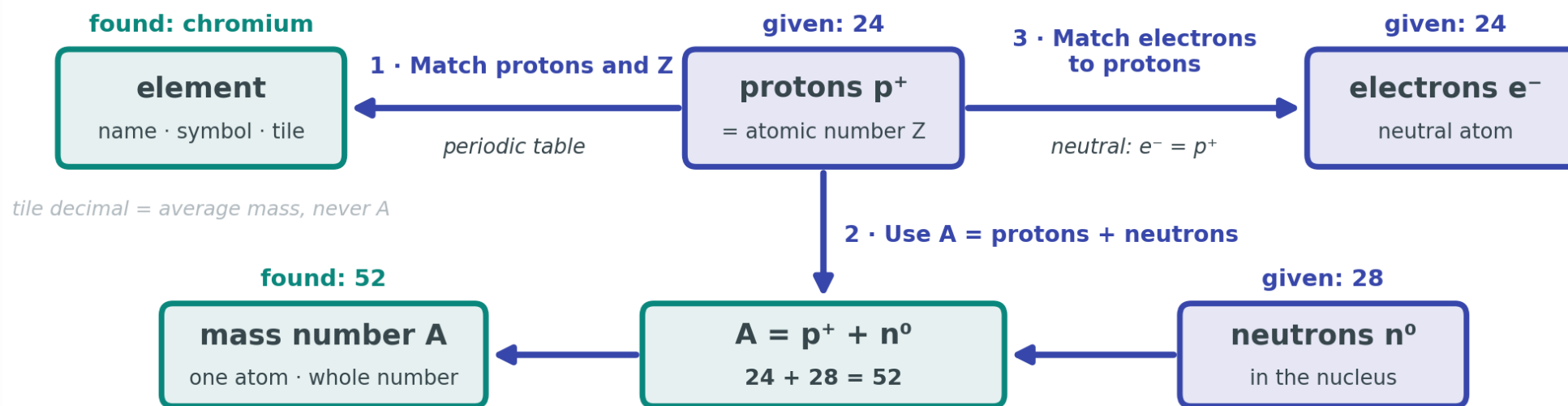
chromium: $Z = 24 \cdot A = 52$

$24 \text{ p}^+ \cdot 28 \text{ n}^0 \cdot 24 \text{ e}^- \cdot \text{electrons equal protons: neutral } \checkmark$

🧠 **Sense check:** A comes from the nucleus alone: $24 + 28 = 52$. The electrons never entered the sum.

✓ Worked example 3: the route on the map

$24 \text{ p}^+ \cdot 28 \text{ n}^0 \cdot 24 \text{ e}^- \rightarrow \text{chromium} \cdot A = 52$
 given: all three counts · found: the element and A



 **Sense check:** The links run the other way: protons out to the element, protons plus neutrons into A. The electrons only confirm neutral. ✓



Practice 3

$A = 27 \cdot 14 n^0 \cdot \text{no net charge}$
wanted: the element, its protons, its electrons

Which row identifies this atom?

- A. cobalt $\cdot 27 p^+ \cdot 27 e^-$
- B. silicon $\cdot 14 p^+ \cdot 14 e^-$
- C. aluminum $\cdot 13 p^+ \cdot 14 e^-$
- D. aluminum $\cdot 13 p^+ \cdot 13 e^-$

✓ Practice 3 · answer: D

protons = $A - \text{neutrons} = 27 - 14 = 13 \rightarrow \text{aluminum} \cdot 13 \text{ p}^+ \cdot 13 \text{ e}^-$ (answer D)

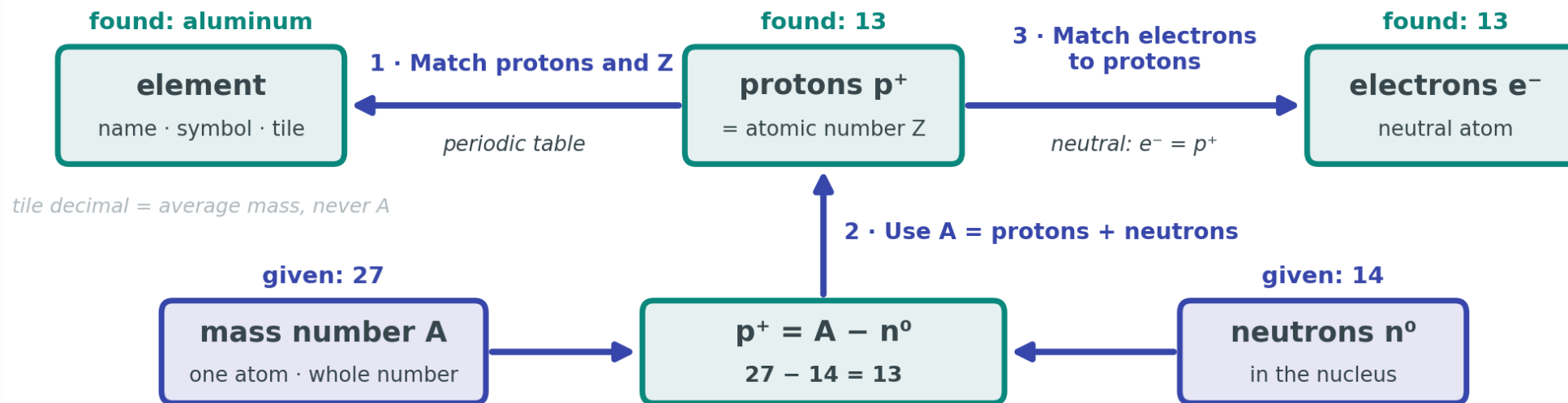
13 protons = Z = aluminum · neutral: electrons = protons = 13

A read the mass number as the atomic number: $Z = 27$ is cobalt, and 27 protons leave no room for 14 neutrons in a nucleus of 27. B read the neutron count as the proton count: $Z = 14$ is silicon, but neutrons never name the element. C matched the electrons to the neutrons; a neutral atom matches them to the protons, 13.

🧠 **Sense check:** Rebuild the nucleus: $13 + 14 = 27$, the given mass number. ✓

✓ Practice 3: the route on the map

$A = 27 \cdot 14 \text{ n}^0 \rightarrow 13 \text{ p}^+ \rightarrow \text{aluminum} \cdot 13 \text{ e}^-$
 given: A and neutrons · found: protons, element, electrons



🧠 **Sense check:** The protons come first, by subtraction. Only then does the periodic table name the element. ✓



Practice 4

one neutral atom: $50 \text{ e}^- \cdot 66 \text{ n}^0$
wanted: the element and its mass number

A neutral atom holds 50 electrons and 66 neutrons. Which choice gives the element and its mass number?

- A. tin · mass number 100
- B. tin · mass number 119
- C. dysprosium · mass number 116
- D. tin · mass number 66
- E. tin · mass number 116

✓ Practice 4 · answer: E

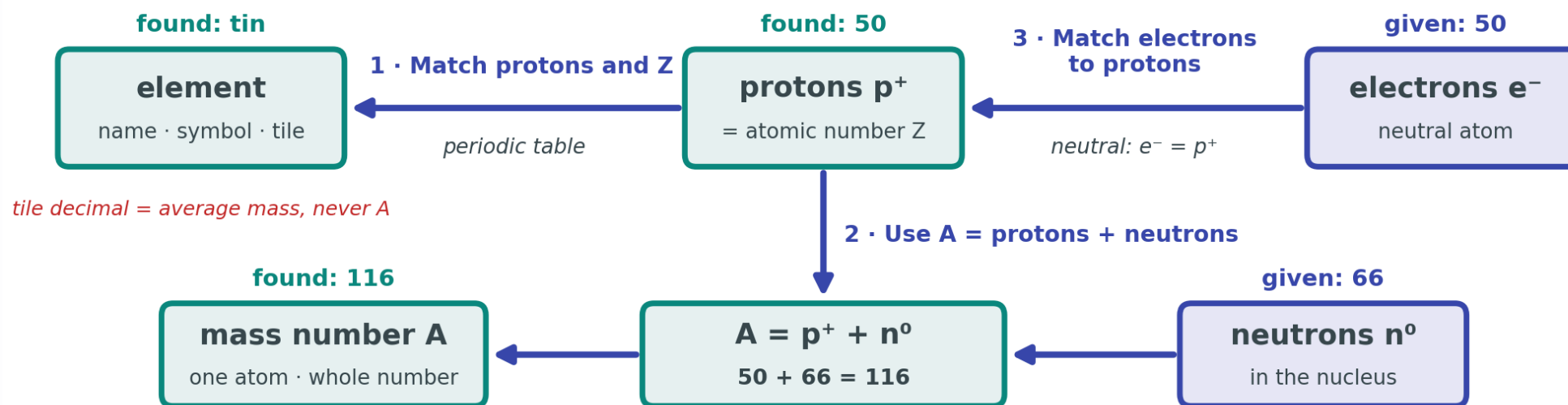
$50 \text{ e}^- \rightarrow 50 \text{ p}^+ \rightarrow \text{tin} \cdot A = 50 + 66 = 116 \text{ (answer E)}$
neutral: protons = electrons = 50 · $Z = 50$ is tin · $50 \text{ p}^+ \cdot 66 \text{ n}^0 \cdot 50 \text{ e}^-$

A added protons and electrons: $50 + 50 = 100$. Electrons never enter A. B took tin's tile mass, 118.71, rounded to 119: an average over many atoms, not this atom's count. C named the element from the neutrons: $Z = 66$ is dysprosium, but neutrons never name an element. D read the neutron count, 66, as the mass number.

🧠 **Sense check:** Rebuild: 50 protons + 66 neutrons = 116, and 50 electrons balance 50 protons. ✓

✓ Practice 4: the route on the map

$50 \text{ e}^- \cdot 66 \text{ n}^0 \rightarrow 50 \text{ p}^+ \rightarrow \text{tin} \cdot A = 116$
 given: electrons and neutrons · found: protons, element, A



 **Sense check:** The electrons reach the protons only because the atom is neutral. From the protons, one link names the element and one builds A. ✓

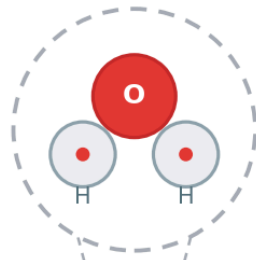
4 • Isotope Notation

Read and write isotope symbols in both notations and count the protons, neutrons, and electrons in a neutral atom of any isotope.

Heavy water

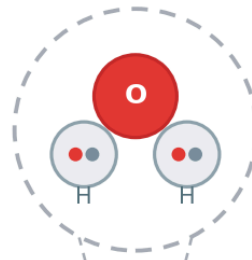
same look, same behavior: the heavier one has an extra particle in every hydrogen

inside each hydrogen: one particle



ordinary water
1 liter weighs 1.00 kg

inside each hydrogen: two particles



heavy water
1 liter weighs 1.11 kg

Heavy water looks, pours, and reacts like ordinary water, but a liter of it weighs about a tenth more. The extra mass sits inside its hydrogen atoms.

Isotopes: same Z, different A



three xenon atoms from air · lower left: 54 in all three · upper left: 129, 131, 132

Every xenon atom holds 54 protons, so the lower number never changes. The upper number counts protons plus neutrons; it varies by isotope.

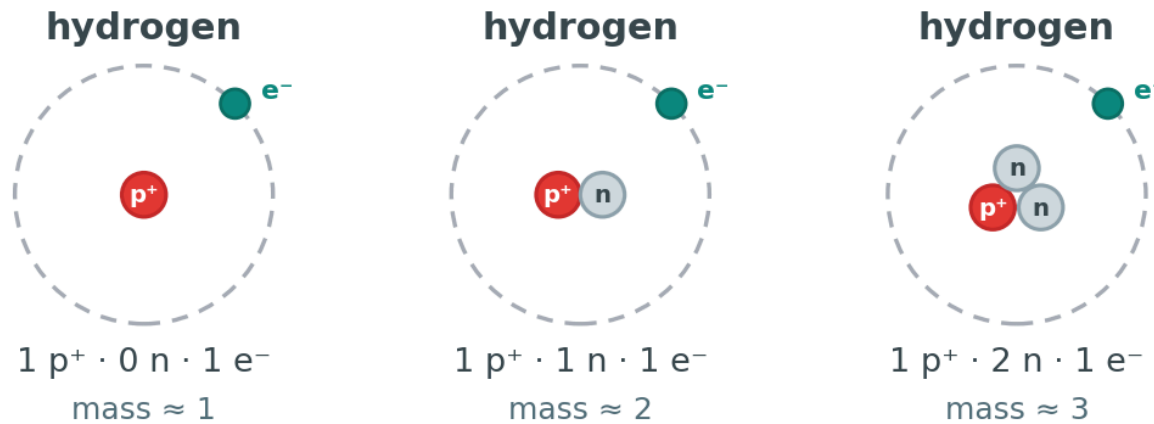
Which number in $^{132}_{54}\text{Xe}$ also appears on xenon's periodic-table tile?

54, the atomic number Z

the tile never shows 132: a mass number belongs to one isotope, not to the whole element

Same element, different mass

same proton count → all hydrogen · extra neutrons → extra mass, nothing else



The proton count fixes the element: one proton means hydrogen. Neutrons add mass and never change the element. Atoms with the same protons but different neutrons are **isotopes** of one element.

Two numbers label the nucleus

atomic number Z = protons

Z names the element: every chlorine atom has $Z = 17$

mass number A = protons + neutrons

a chlorine atom with 20 neutrons: $A = 17 + 20 = 37$

Both are whole-number counts of the particles in one atom. Rearranged, $A - Z$ isolates the neutrons.

Writing an isotope down

mass number A = protons + neutrons

37

17

Cl

= chlorine-37

hyphen notation: the name fixes Z ,
the number after it is A

$$\text{neutrons} = A - Z = 37 - 17 = 20$$

atomic number Z = protons

The nuclide symbol carries both counts: mass number upper left, atomic number lower left (though Z may be dropped, since the element symbol already fixes it). Hyphen notation writes the name, then A .

Isotopes of an element share chemistry



same electron count → same bonds · 18 vs 20 neutrons → different mass only

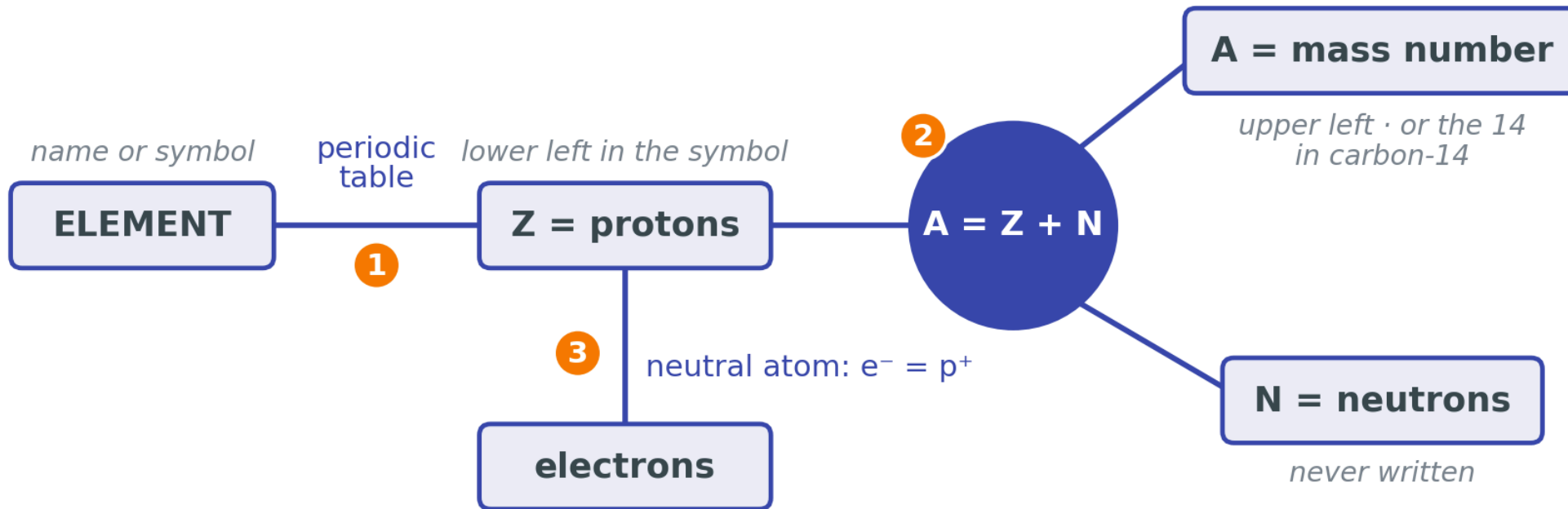
Electrons make the chemistry, and a neutral atom holds electrons equal to its protons. Isotopes share the proton count, so both chlorine isotopes form the same compounds.



The method

1. **Find Z.** The element and its atomic number fix each other on the periodic table.
2. **Apply $A = Z + N$.** Any two of the three counts give the third.
3. **Count electrons.** Neutral atom: electrons = protons.

The method on the map



① find Z

② apply $A = Z + N$: any two give the third

③ count electrons

Step 1 joins the element and Z through the periodic table. Step 2 joins Z, N and A: any two give the third. Step 3 runs from protons to electrons.



Guided example: xenon-132

$^{132}_{54}\text{Xe}$: one neutral atom

given: $A = 132$ · $Z = 54$ · wanted: protons, neutrons, electrons

Xenon gas glows inside the bulbs of HID car headlights. Count the protons, neutrons, and electrons in one atom of xenon-132.

On the map, start at Z. Each step uses one link.

✓ Guided example: solution

$^{132}_{54}\text{Xe}$: one neutral atom

given: $A = 132$ · $Z = 54$ · wanted: protons, neutrons, electrons

Step 1 · Find Z

Step 2 · Apply $A = Z + N$

$$N = A - Z = 132 - 54 = 78$$

132 particles in the nucleus – 54 protons = 78 neutrons

Step 3 · Count electrons



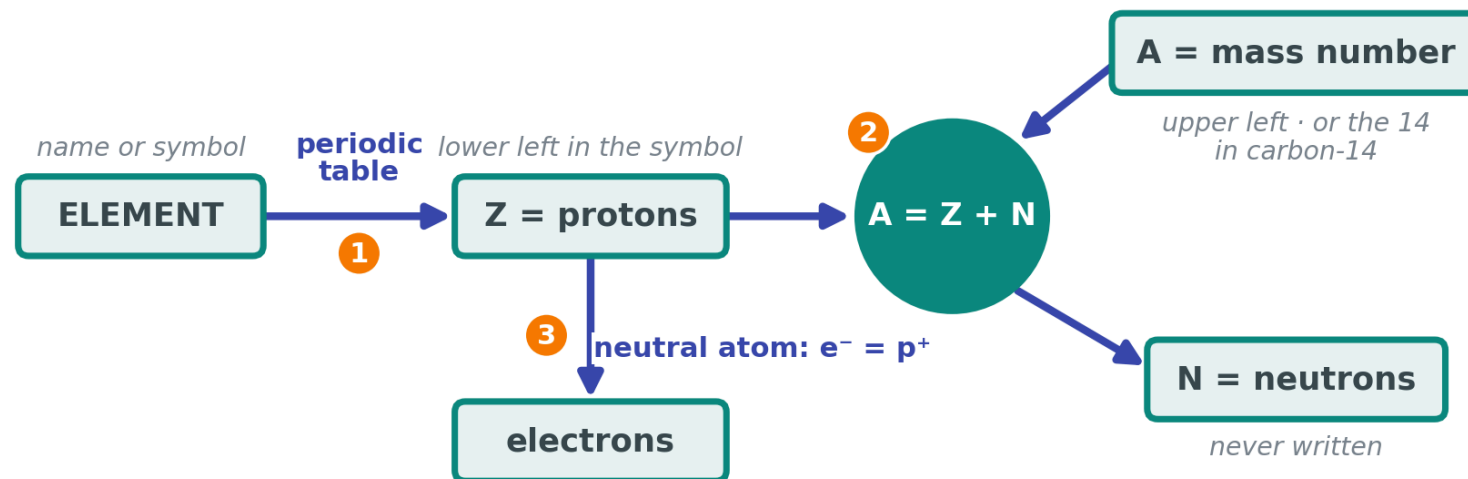
neutral atom: electrons = protons = 54 · check: $54 + 78 = 132 = A$ ✓

 **Sense check:** The sum rebuilds the mass number: $54 + 78 = 132$. Neutrons outnumber protons, 78 to 54, as in most heavy atoms. ✓

✓ Guided example: the route on the map

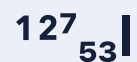
$^{132}_{54}\text{Xe}$: one neutral atom

given: $A = 132 \cdot Z = 54 \cdot$ found: $54 \text{ p}^+ \cdot 78 \text{ n}^0 \cdot 54 \text{ e}^-$



- ① find Z ② apply $A = Z + N$: any two give the third ③ count electrons

Sense check: Step 1: $Z = 54 \rightarrow$ xenon, 54 protons. Step 2: A and Z in, N out: $132 - 54 = 78$. Step 3: 54 protons $\rightarrow$ 54 electrons. ✓

 Practice 1

the only stable iodine atom: the iodine in iodized table salt

Iodized salt carries a trace of iodine, and every natural iodine atom is $^{127}_{53}\text{I}$. How many electrons does one neutral atom of $^{127}_{53}\text{I}$ hold?

- A. 127
- B. 74
- C. 180
- D. 53

✓ Practice 1 · answer: D

$^{127}_{53}\text{I}$: electrons = protons = $Z = 53$ (answer D)

$53 \text{ p}^+ \cdot 74 \text{ n}^0 \cdot 53 \text{ e}^-$ · neutral atom: 53 positive charges, 53 negative

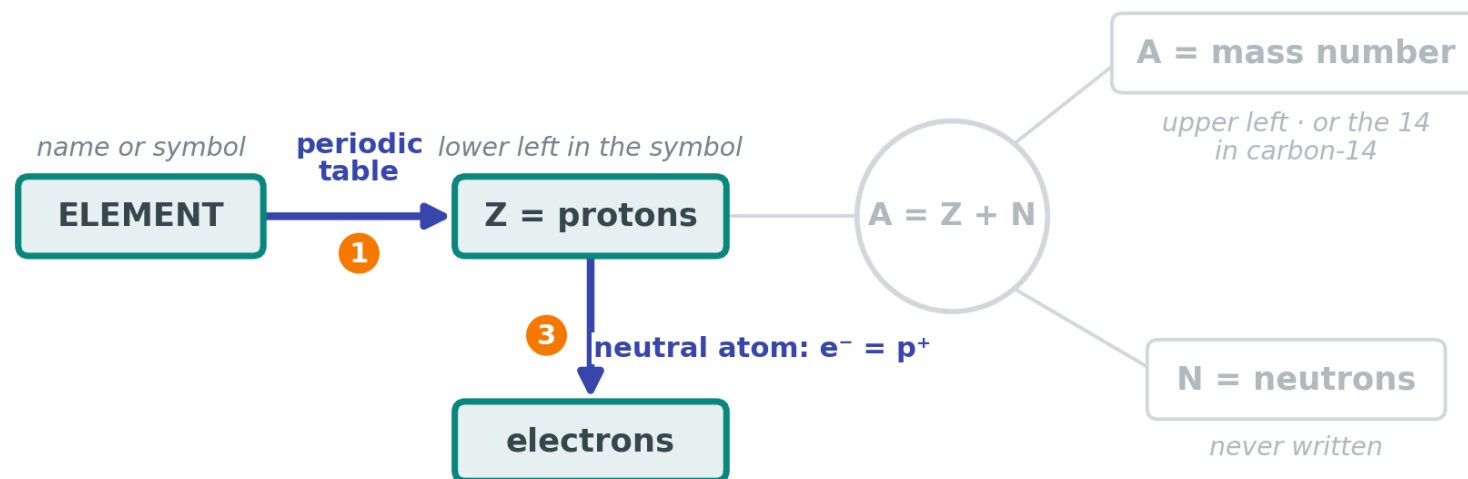
A read the mass number as the electron count; 127 counts protons and neutrons, and neutrons carry no charge. B gave the neutron count, $127 - 53 = 74$; the question asks for electrons. C added the two numbers: $127 + 53 = 180$.

🧠 **Sense check:** A neutral atom balances each proton with one electron; the neutrons never enter the count. ✓

✓ Practice 1: the route on the map



given: $A = 127$ · $Z = 53$ · found: 53 electrons



- ① find Z ② apply $A = Z + N$: any two give the third ③ count electrons

Sense check: Step 1: $Z = 53 \rightarrow$ iodine, 53 protons. Step 3: 53 protons $\rightarrow$ 53 electrons. The question never needs N, so Step 2 stays off the route. ✓



Worked example 1: reading a symbol

$^{65}_{29}\text{Cu}$: one neutral atom

given: $A = 65$ · $Z = 29$ · wanted: protons, neutrons, electrons

About a third of natural copper atoms carry this symbol. Count the protons, neutrons, and electrons in one of them.

✓ Worked example 1: solution

$^{65}_{29}\text{Cu}$: one neutral atom

given: $A = 65$ · $Z = 29$ · wanted: protons, neutrons, electrons

Step 1 · Find Z

Step 2 · Apply $A = Z + N$

$$\text{neutrons} = A - Z = 65 - 29 = 36$$

$$65 \text{ heavy particles} - 29 \text{ protons} = 36 \text{ neutrons}$$

Step 3 · Count electrons



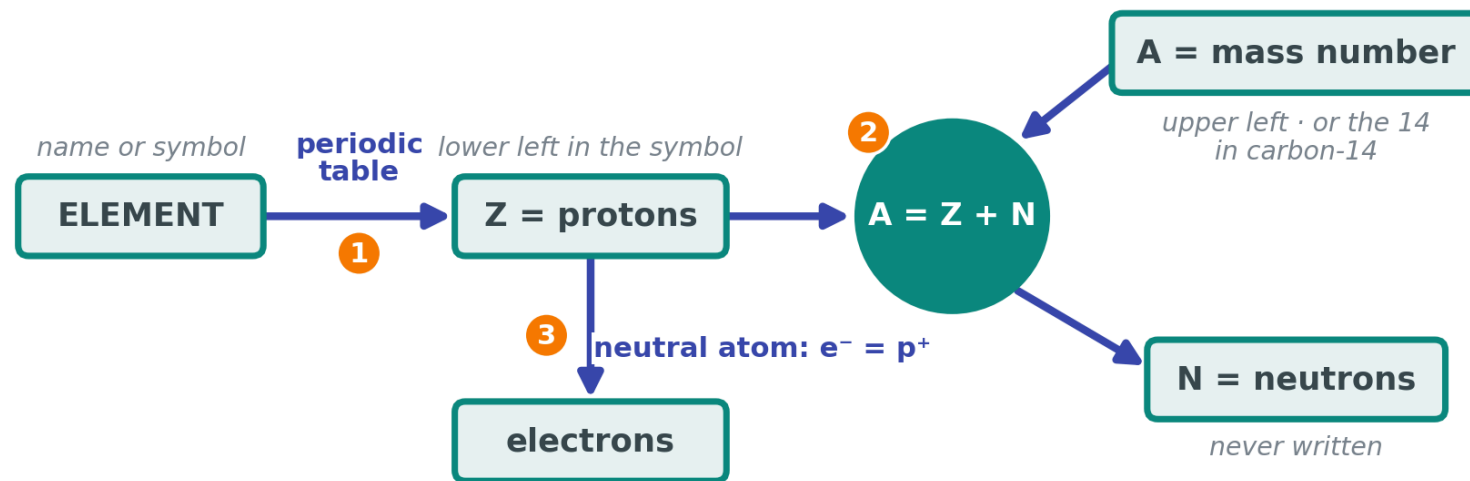
neutral atom: electrons = protons = 29 · check: $29 + 36 = 65 = A$ ✓

 **Sense check:** Neutrons outnumber protons, 36 to 29, typical beyond the lightest elements. The sum rebuilds A : $29 + 36 = 65$. ✓

✓ Worked example 1: the route on the map

$^{65}_{29}\text{Cu}$: one neutral atom

given: $A = 65 \cdot Z = 29 \cdot$ found: $29 \text{ p}^+ \cdot 36 \text{ n}^0 \cdot 29 \text{ e}^-$



- ① find Z ② apply $A = Z + N$: any two give the third ③ count electrons

🧠 **Sense check:** Step 1: $Z = 29 \rightarrow$ copper. Step 2: A and Z in, N out: $65 - 29 = 36$. Step 3: 29 protons $\rightarrow$ 29 electrons.





Worked example 2: hyphen notation

carbon-14: one neutral atom

given: the name carries $A = 14$ · wanted: protons, neutrons, electrons

Living wood holds a trace of carbon-14; the amount left in an artifact dates it. Count the particles in one neutral atom.

A common first attempt: carbon-14 holds 14 neutrons. Test it.

✓ Worked example 2: the first attempt

carbon-14: one neutral atom

given: $A = 14$ · Z not written: the periodic table supplies it

A common first attempt

carbon-14 → 14 neutrons?

14 counts protons and neutrons together; the protons are still inside ✗

The 14 is the mass number: every heavy particle in the nucleus. Some of those particles are protons, so the neutron count must be smaller than 14.

🧠 **Sense check:** A is a total; the protons take part of it. Finding neutrons needs a subtraction, not a copy of A .

✓ Worked example 2: solution

carbon-14: one neutral atom

given: $A = 14$ · Z not written: the periodic table supplies it

Step 1 · Find Z

Step 2 · Apply $A = Z + N$

$$\text{neutrons} = A - Z = 14 - 6 = 8$$

of the 14 heavy particles, 6 are protons and 8 are neutrons

Step 3 · Count electrons

$$\text{carbon-14} \rightarrow 6 \text{ p}^+ \cdot 8 \text{ n}^0 \cdot 6 \text{ e}^-$$

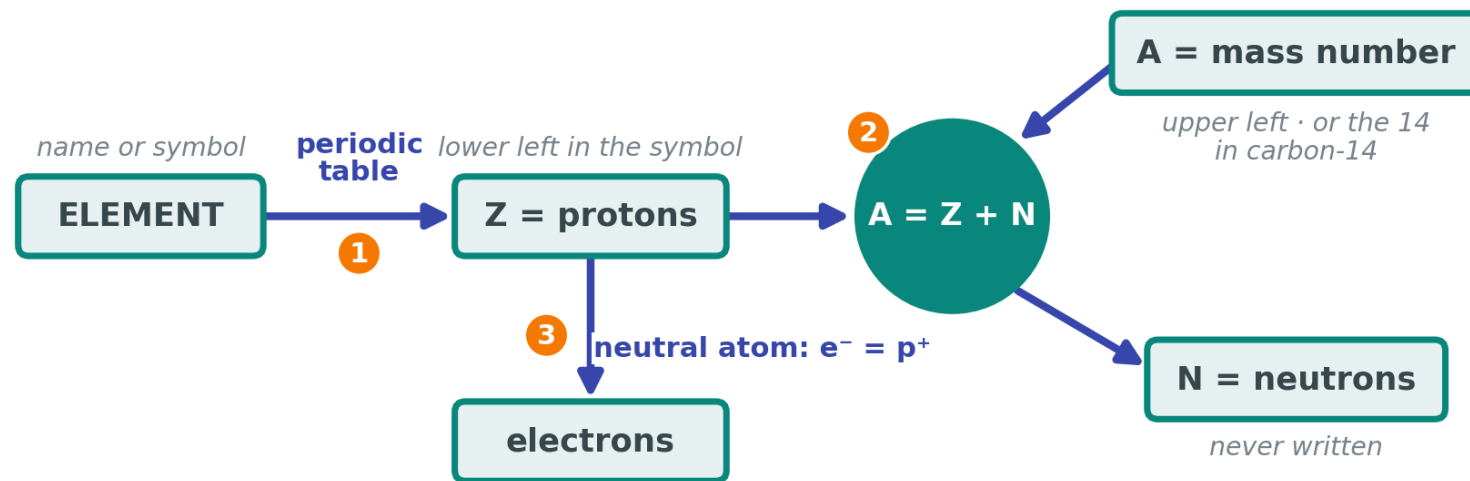
neutral atom: electrons = protons = 6 · check: $6 + 8 = 14$ ✓

🧠 **Sense check:** 8 of the 14 heavy particles are neutrons; the other 6 are the protons. The sum rebuilds A : $6 + 8 = 14$.

✓

✓ Worked example 2: the route on the map

carbon-14: one neutral atom
given: $A = 14 \cdot \text{found: } 6 \text{ p}^+ \cdot 8 \text{ n}^0 \cdot 6 \text{ e}^-$



- ① find Z ② apply $A = Z + N$: any two give the third ③ count electrons

 **Sense check:** Step 1 starts at the name: carbon $\rightarrow Z = 6$. Step 2: A and Z in, N out: $14 - 6 = 8$. Step 3: 6 electrons. The 14 enters at $A = Z + N$, never as N. ✓

Your turn: sulfur-34

$^{34}_{16}\text{S}$: one neutral atom

$A = 34$ upper left · $Z = 16$ lower left

step	reading	count
1 · Find Z	lower left: $Z = 16$	protons = <u> </u>
2 · Apply $A = Z + N$	$N = 34 - 16$	neutrons = <u> </u>
3 · Count electrons	neutral atom	electrons = <u> </u>

Complete the three counts.

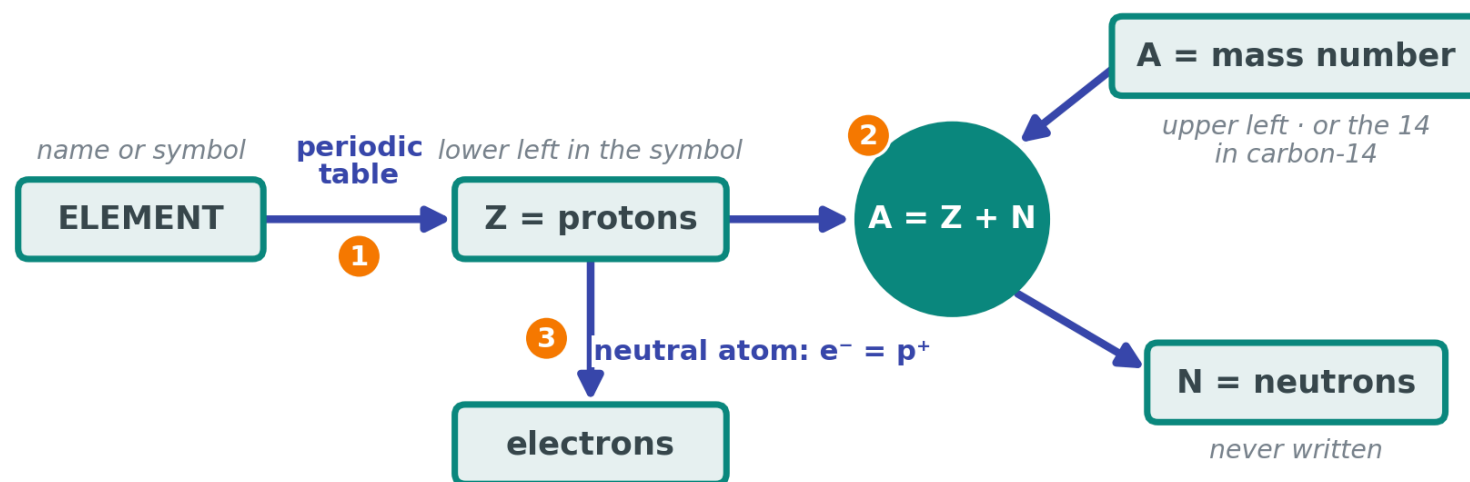


neutrons: $34 - 16 = 18$ · check: $16 + 18 = 34$ ✓

✓ Your turn: the route on the map

$^{34}_{16}\text{S}$: one neutral atom

given: $A = 34 \cdot Z = 16 \cdot$ found: $16 \text{ p}^+ \cdot 18 \text{ n}^0 \cdot 16 \text{ e}^-$



- ① find Z ② apply $A = Z + N$: any two give the third ③ count electrons

🧠 **Sense check:** Step 1: $Z = 16 \rightarrow$ sulfur. Step 2: A and Z in, N out: $34 - 16 = 18$. Step 3: $16 \text{ protons} \rightarrow 16 \text{ electrons}$. ✓

⚠ Where this goes wrong



$$A = 37 \cdot Z = 17 \cdot \text{neutrons} = 37 - 17 = 20$$

Reading A as the neutron count. "37 neutrons" reads a total as one of its parts. The 37 counts protons and neutrons together; subtract: $37 - 17 = 20$ neutrons.

Adding A and Z. $37 + 17 = 54$ counts the 17 protons twice: A already includes them. Neutrons = $A - Z$, never $A + Z$.

Reading Z as the neutron count. The 17 counts protons. The neutron count never appears in the symbol; only the subtraction produces it.

Expecting A on the periodic table. The table lists 35.45 for chlorine, and that is not a mass number. A is a whole-number count for one specific atom.



Practice 2

strontium-88 = ^{88}Sr · atomic number 38
the most common strontium atom in nature

How many neutrons are in one atom of strontium-88?

- A. 88
- B. 50
- C. 126
- D. 38

✓ Practice 2 · answer: B

^{88}Sr : neutrons = $A - Z = 88 - 38 = 50$ (answer B)

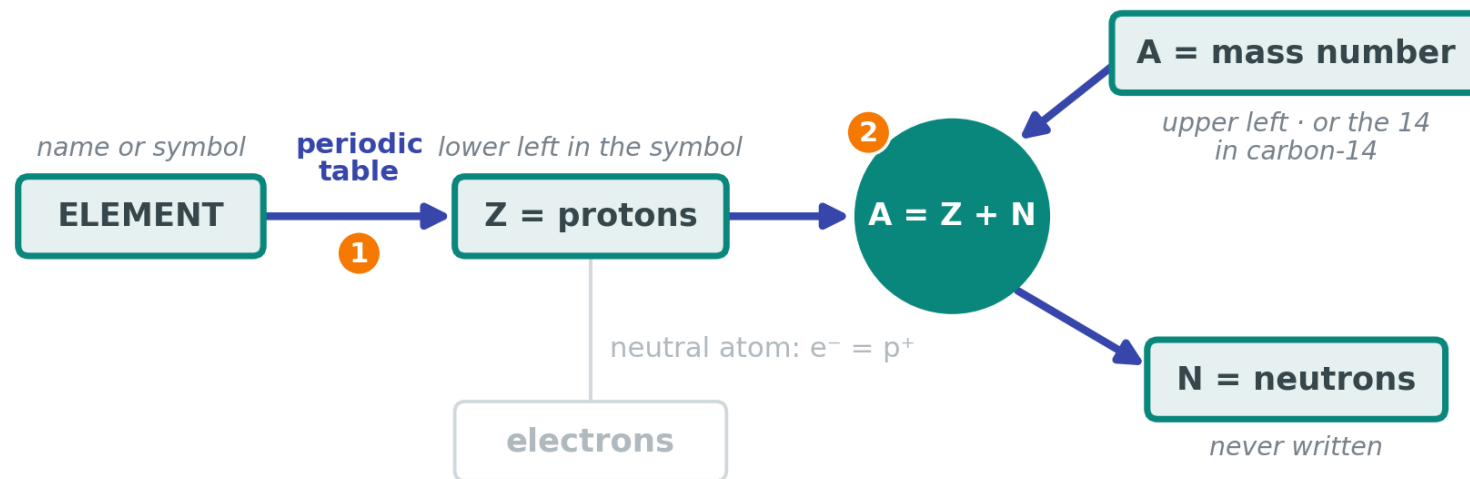
$38 \text{ p}^+ \cdot 50 \text{ n}^0 \cdot 38 \text{ e}^- \cdot \text{check: } 38 + 50 = 88 \checkmark$

A read the mass number as the neutron count; 88 counts protons and neutrons together. C added the two numbers: $88 + 38 = 126$, counting the protons twice. D read the atomic number; 38 counts the protons.

🧠 **Sense check:** Beyond the lightest elements, neutrons outnumber protons: $50 > 38$ fits. ✓

✓ Practice 2: the route on the map

^{88}Sr · atomic number 38
given: $A = 88$ · $Z = 38$ · found: 50 neutrons



- ① find Z ② apply $A = Z + N$: any two give the third ③ count electrons

 **Sense check:** Step 1: the atomic number 38 supplies Z, since the symbol shows no lower-left number. Step 2: A and Z in, N out: $88 - 38 = 50$. ✓



Practice 3

cadmium-114 (hyphen notation)

Z not written: the periodic table supplies it

Cadmium-114 is the most common cadmium atom. How many neutrons does one neutral atom hold?

- A. 114
- B. 48
- C. 66
- D. 162

✓ Practice 3 · answer: C

cadmium-114: neutrons = $A - Z = 114 - 48 = 66$ (answer C)

periodic table: cadmium is element 48 · 48 p^+ · 66 n^0 · 48 e^- · check: $48 + 66 = 114$ ✓

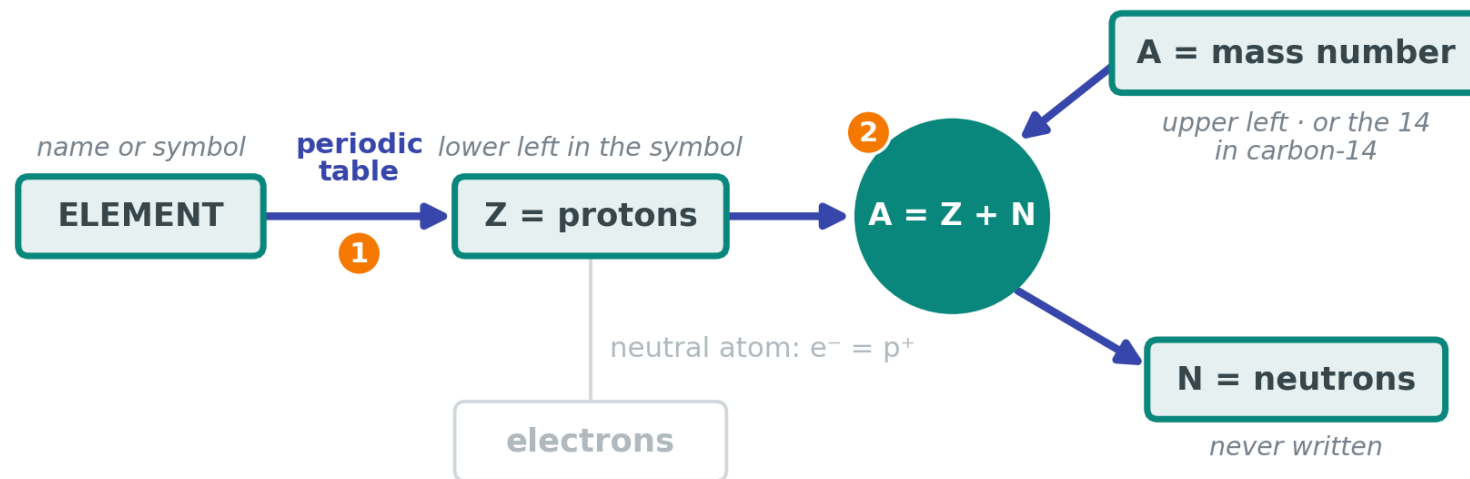
A read the mass number as the neutron count; 114 counts protons and neutrons together.
B read the atomic number; 48 counts the protons. D added the two numbers: $114 + 48 = 162$, counting the protons twice.

 **Sense check:** The neutron excess grows with heavier elements: 66 neutrons to 48 protons. ✓

✓ Practice 3: the route on the map

cadmium-114

given: $A = 114$ · found: $Z = 48$ from the table · 66 neutrons



- ① find Z ② apply $A = Z + N$: any two give the third ③ count electrons

 **Sense check:** Step 1 starts at the name: the periodic table puts cadmium at $Z = 48$. The 114 after the hyphen is A. Step 2: A and Z in, N out: $114 - 48 = 66$. ✓



Worked example 3: writing the symbol

a neutral gallium atom with 38 neutrons

given: the element · $N = 38$ · wanted: nuclide symbol and hyphen notation

This time the particle counts are given and the symbol is wanted. Write both notations for this atom. The same steps apply.

✓ Worked example 3: solution

a neutral gallium atom with 38 neutrons

given: the element · $N = 38$ · wanted: nuclide symbol and hyphen notation

Step 1 · Find Z

Step 2 · Apply $A = Z + N$

$$A = Z + N = 31 + 38 = 69$$

31 protons + 38 neutrons = 69 heavy particles

Assemble the notation

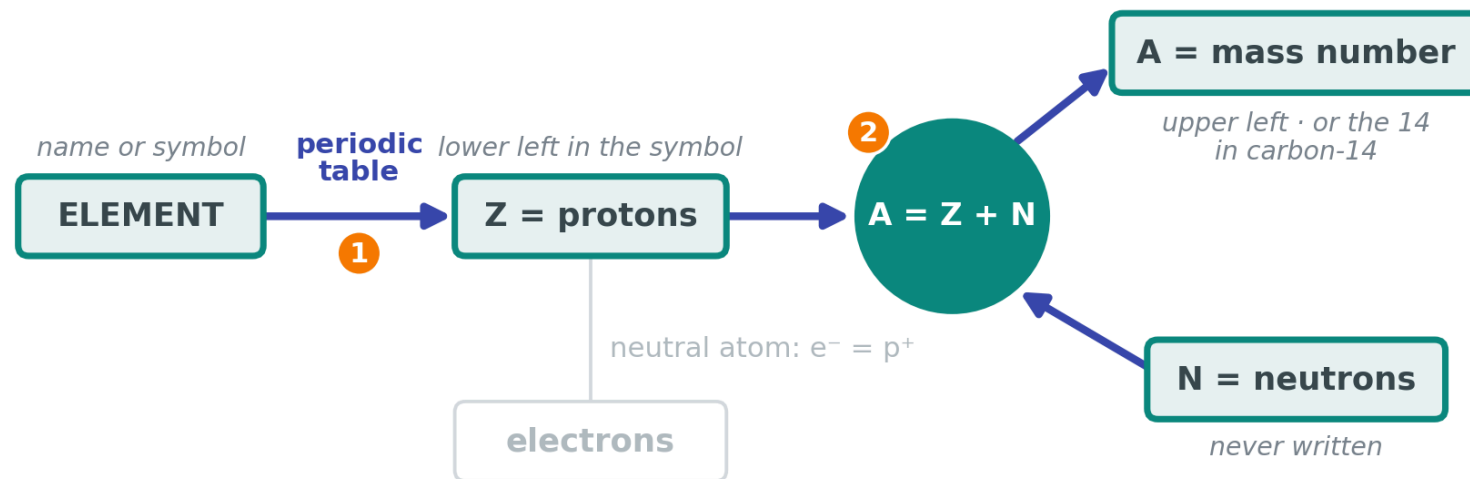


$A = 69$ upper left · $Z = 31$ lower left · the hyphen form keeps only A

🧠 **Sense check:** Subtraction runs the check in reverse: $69 - 31 = 38$, the given neutron count. ✓

✓ Worked example 3: the route on the map

a neutral gallium atom with 38 neutrons
given: gallium · N = 38 · found: $^{69}_{31}\text{Ga}$ = gallium-69



- ① find Z ② apply $A = Z + N$: any two give the third ③ count electrons

Sense check: The route crosses the junction the other way: Z and N in, A out: $31 + 38 = 69$. Step 3 stays off the route; no electron count was asked. ✓



Practice 4

atom 1: $26 \text{ p}^+ \cdot 32 \text{ n}^0$ · atom 2: ${}^{58}_{28}\text{Ni}$ · atom 3: $A = 56 \cdot 30 \text{ n}^0$
three neutral atoms

Which two of these atoms are isotopes of one element?

- A. Atoms 1 and 3
- B. Atoms 1 and 2
- C. Atoms 2 and 3
- D. No two: the three are different elements

✓ Practice 4 · answer: A

Z: atom 1 = 26 · atom 2 = 28 · atom 3 = 56 – 30 = 26 → atoms 1 and 3 (answer A)

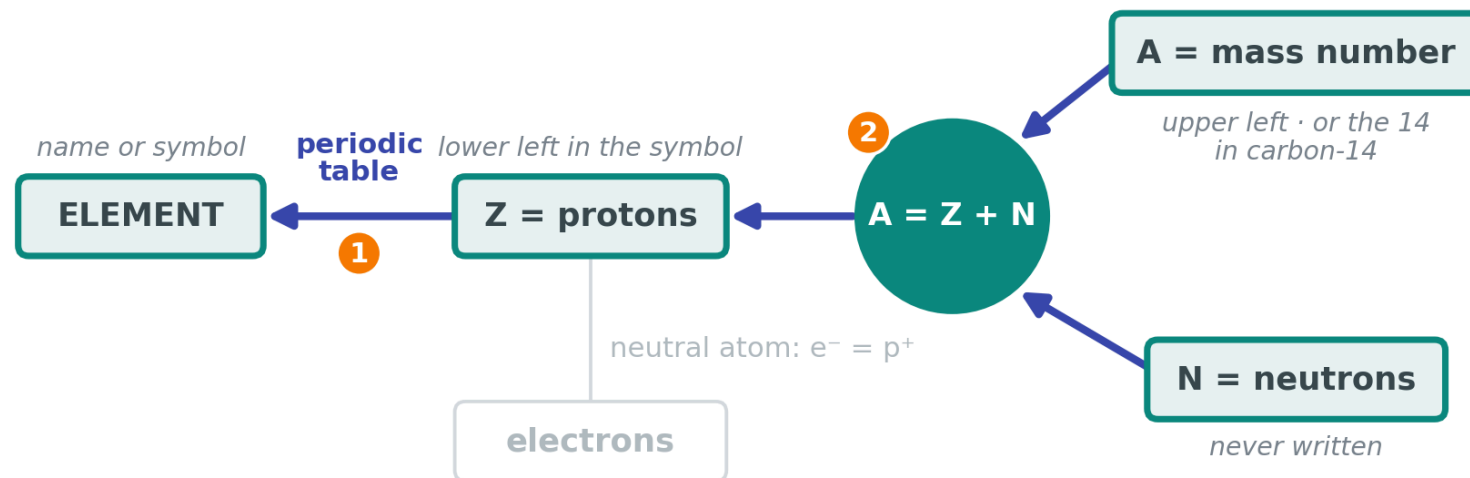
atom 1: $A = 26 + 32 = 58$, iron-58 · atom 3: iron-56 · atom 2: $58 - 28 = 30$ n°, nickel-58

B matched the mass numbers: atom 1 has $A = 26 + 32 = 58$, like nickel-58, but 26 and 28 protons are two elements. C matched the neutron counts: nickel-58 holds $58 - 28 = 30$ neutrons, like atom 3, but neutrons never name the element. D read atom 3's 30 neutrons as its proton count, zinc; subtract instead: $56 - 30 = 26$.

 **Sense check:** Same protons, different neutrons: iron-58 and iron-56 are isotopes. ✓

✓ Practice 4: the route on the map

atom 3: $A = 56 \cdot 30 \text{ n}^0$
 given: $A = 56 \cdot N = 30 \cdot \text{found: } Z = 26, \text{ iron}$



- ① find Z ② apply $A = Z + N$: any two give the third ③ count electrons

🧠 **Sense check:** Atom 3 enters with A and N: $Z = 56 - 30 = 26$, and the table names element 26 iron. Atom 1 starts at $Z = 26$ itself. Same Z, same element. ✓



Practice 5

argon-40 · potassium-39

nearly all the argon in air · most of the potassium in nature

How many more neutrons does an atom of argon-40 contain than an atom of potassium-39?

- A. 1
- B. 22
- C. 0
- D. 2
- E. 20

✓ Practice 5 · answer: D

argon-40: $40 - 18 = 22$ n° · potassium-39: $39 - 19 = 20$ n° $\rightarrow 22 - 20 = 2$ (answer D)
Z from the periodic table: Ar 18 · K 19 · two elements, two different proton counts

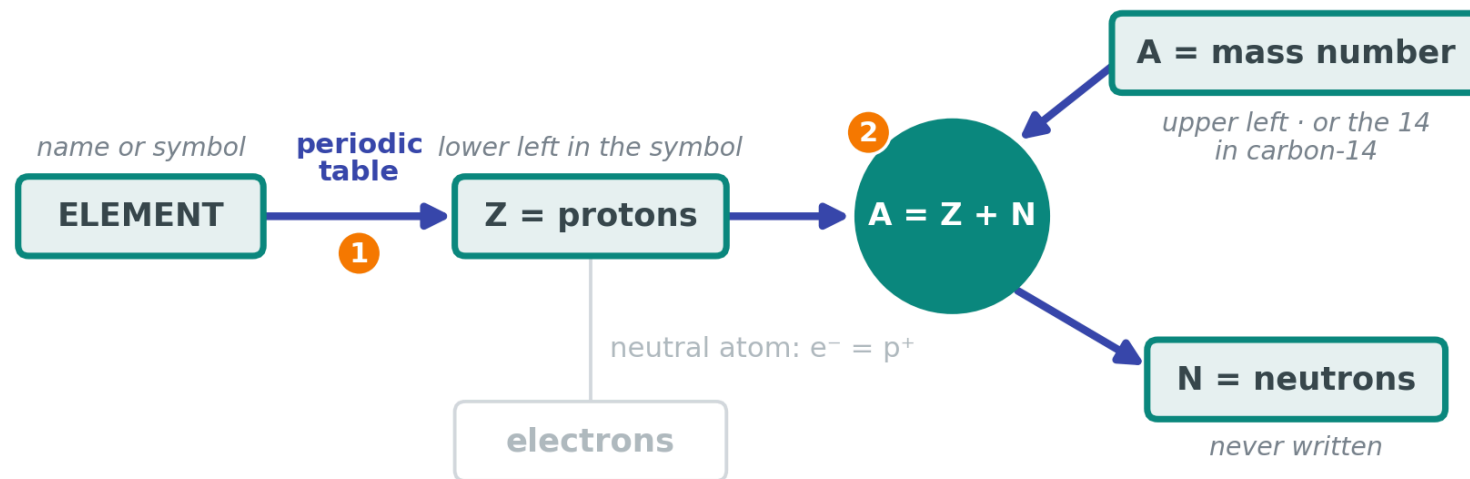
A subtracted the mass numbers: $40 - 39 = 1$. That shortcut works only for isotopes, which share Z. B stopped at argon-40's own count, 22. C added A and Z for each atom: $(40 + 18) - (39 + 19) = 0$. E gave potassium-39's own count, 20.

🧠 **Sense check:** Argon has one proton fewer yet one more unit of mass number, so its nucleus holds two extra neutrons. ✓

✓ Practice 5: the route on the map

argon-40 · potassium-39

given: $A = 40$ and $A = 39$ · found: 22 n^0 and 20 n^0 , a gap of 2



- ① find Z ② apply $A = Z + N$: any two give the third ③ count electrons

🧠 **Sense check:** The route runs once per atom. Step 1 finds a different Z for each element: 18 and 19. Isotopes share Step 1; these two atoms do not. ✓

5 • Average Atomic Mass

Calculate an element's average atomic mass from isotopic masses and percent abundances, and check that the answer lands between the isotope masses, closer to the more abundant one.

The number under every symbol

no single atom weighs 35.45 amu: the tile prints the average of the mixture

a sample of chlorine atoms



average
→

35 Cl-35 · one atom weighs 34.97 amu
37 Cl-37 · one atom weighs 36.97 amu



the periodic-table entry

A chlorine atom weighs 34.97 or 36.97 amu, never 35.45. Every periodic table lists 35.45: the average of the natural mix. That average, in g/mol, runs every mole calculation.

Each isotope has its own mass

H-1 · 1.0078 amu · 99.989% · H-2 · 2.0141 amu · 0.0115% · H-3 · 3.0160 amu · trace
isotopic mass: near the mass number · % natural abundance: share of the atoms

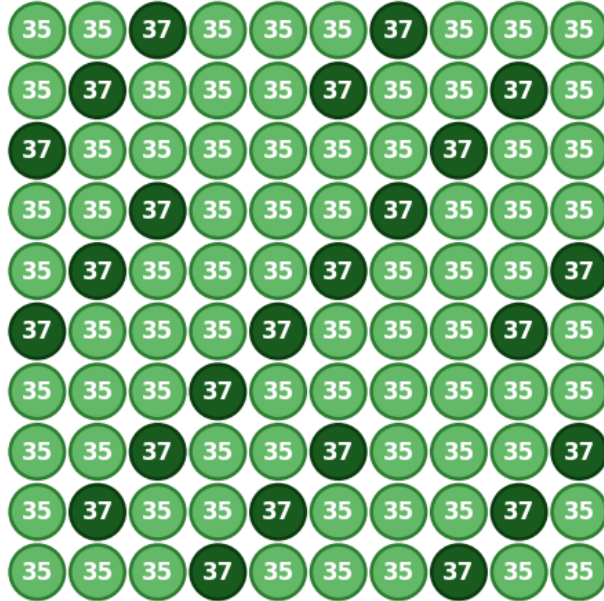
One isotope has one mass, close to its mass number. Natural hydrogen mixes three isotopes. The periodic table lists the mix's weighted average.

Hydrogen's entry is 1.008 amu. Which isotope sets it?

1.008 amu $\approx$ 1.0078 amu, the mass of H-1
H-1 is 99.989% of the atoms · H-2 and H-3 are too rare to move the average past 1.008

A natural sample is a fixed mix of isotopes

100 atoms of natural chlorine



35 Cl-35 · 75.76% → 76 atoms of the 100

37 Cl-37 · 24.24% → 24 atoms of the 100

**every natural sample keeps this split:
ocean salt, lab bottle, or star dust**

one fixed mixture → one average mass

Natural chlorine is always the same mixture: 75.76% Cl-35 and 24.24% Cl-37, in every bottle. The mass that describes chlorine is the sample's average, weighted by those fixed proportions.

Why each percent becomes a fraction

$$\text{average} = (76 \times 34.97 \text{ amu} + 24 \times 36.97 \text{ amu}) \div 100$$

100 chlorine atoms: add all 100 masses, then share the total over 100 atoms

$$= 34.97 \text{ amu} \times \frac{76}{100} + 36.97 \text{ amu} \times \frac{24}{100} = 34.97 \text{ amu} \times 0.76 + 36.97 \text{ amu} \times 0.24$$

each count $\div$ 100 is that isotope's fraction of the sample

Dividing the total by 100 atoms divides each count by 100. A percent abundance works the same way: divide it by 100 to get the isotope's fraction.

The weighted average

$$\text{average atomic mass} = (\text{mass}_1 \times \text{fraction}_1) + (\text{mass}_2 \times \text{fraction}_2) + \dots$$

one term per isotope · fraction = percent ÷ 100 · masses in amu · 1 amu = 1/12 the mass of one carbon-12 atom

Each isotope contributes its mass in proportion to its share of the sample. Convert every percent to a fraction first: 75.76% → 0.7576. Mass spectrometry measures the masses and the abundances.

Mass number and atomic mass

mass number $A = 35$

a whole-number count: 17 protons + 18 neutrons in one Cl-35 atom

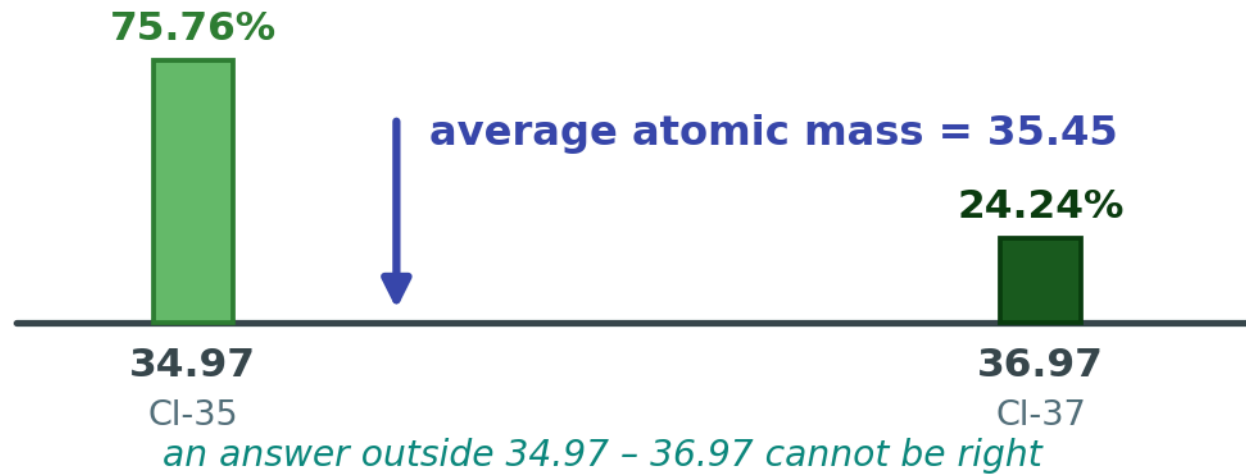
atomic mass = 35.45 amu

a weighted average over the natural sample, the periodic-table entry

A mass number counts particles in one atom, so it is whole. The periodic-table mass is an average over the sample; it is not whole, and it matches no single atom.

Where the average lands

the average lands between the two masses, closer to the abundant isotope



A weighted average lands between the lightest and heaviest masses, closer to the more abundant isotope. Check every answer against that range before trusting the arithmetic.

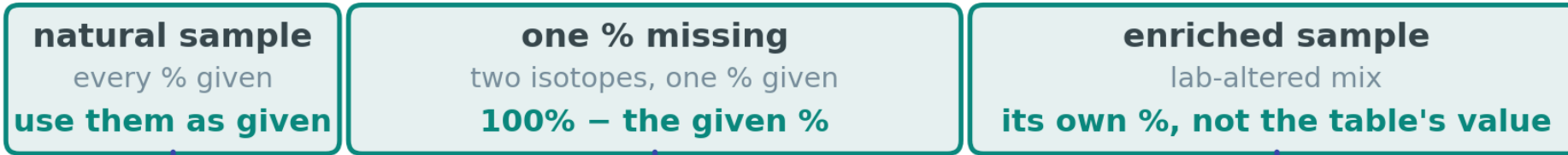


The method

1. **Percents → fractions:** divide each percent abundance by 100.
2. **Mass × fraction:** multiply each isotopic mass by its fraction of the sample.
3. **Add the contributions:** the sum is the average atomic mass.

One route for every average atomic mass

SET UP the abundances



CALCULATE



WRONG TURNS X



Set up one percent per isotope. Run the three steps, then check the range. The wrong turns sit off the route.



Guided example: rubidium

Rb-85 · 84.9118 amu · 72.17% · Rb-87 · 86.9092 amu · 27.83%

given: two isotopic masses with abundances · wanted: average atomic mass

Rubidium atoms keep time in the atomic clocks of GPS satellites. Natural rubidium is the two isotopes above. Calculate its average atomic mass.

Set up first: is every percent given?

✓ Guided example: solution

Rb-85 · 84.9118 amu · 72.17% · Rb-87 · 86.9092 amu · 27.83%
wanted: average atomic mass of rubidium

Set up the abundances

Step 1 · Percents → fractions

Step 2 · Mass × fraction

$84.9118 \times 0.7217 = 61.2808$ · $86.9092 \times 0.2783 = 24.1868$
one contribution per isotope, in amu

Step 3 · Add the contributions

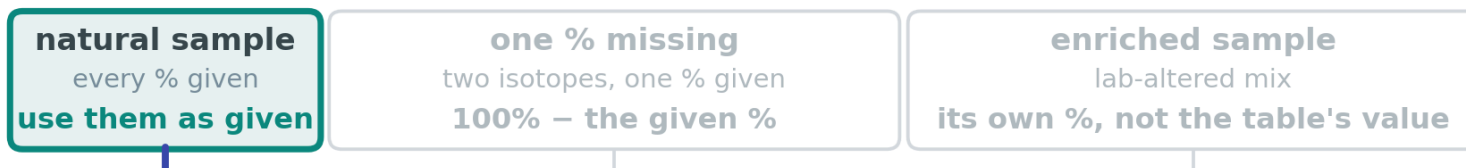
$61.2808 + 24.1868 = 85.47$ amu
the periodic-table entry for rubidium

🧠 **Sense check:** 85.47 lies between 84.9118 and 86.9092, closer to Rb-85, the isotope in 72.17% of the sample. ✓

✓ Guided example: the route on the map

Rb-85 · 84.9118 amu · 72.17% · Rb-87 · 86.9092 amu · 27.83%
found: 85.47 amu

SET UP the abundances



CALCULATE



WRONG TURNS X



🧠 **Sense check:** A natural sample with every percent given. Two isotopes, two terms, one sum, then the range check.
No wrong turn taken. ✓



Practice 1

Sb-121 · 120.9038 amu · 57.21% · Sb-123 · 122.9042 amu · 42.79%
natural antimony · wanted: one isotope's contribution

Antimony hardens the lead plates of car batteries. What does Sb-123 contribute to the average atomic mass of antimony, in amu?

- A. 70.31
- B. 61.45
- C. 52.59
- D. 5259

✓ Practice 1 · answer: C

$$\text{Sb-121} \cdot 120.9038 \text{ amu} \cdot 57.21\% \quad \cdot \quad \text{Sb-123} \cdot 122.9042 \text{ amu} \cdot 42.79\%$$

wanted: the Sb-123 contribution

$$122.9042 \times 0.4279 = 52.59 \text{ amu (answer C)}$$

$$\text{Sb-123's mass} \times \text{Sb-123's own fraction: } 42.79 \div 100 = 0.4279$$

A attached Sb-121's abundance to Sb-123: $122.9042 \times 0.5721 = 70.31$. B treated the sample as an even split: $122.9042 \times 0.50 = 61.45$. D used the whole percent: $122.9042 \times 42.79 = 5259$.

 **Sense check:** Sb-123 is under half of the atoms, so its term is under half its mass: $52.59 < 61.45$. Adding Sb-121's term, 69.17, gives the table's 121.76 amu. ✓

✓ Practice 1: the route on the map

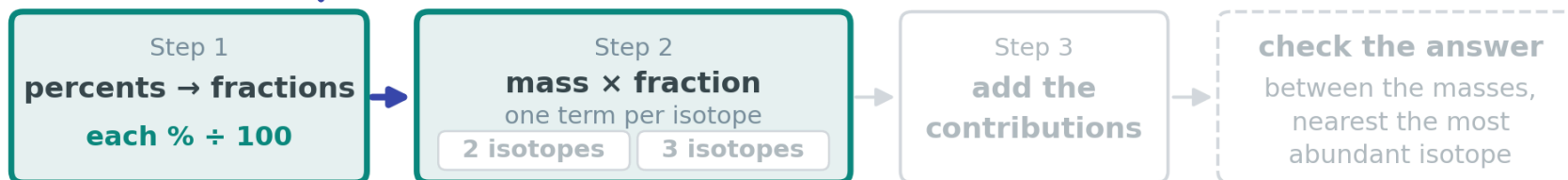
Sb-123 · 122.9042 amu · 42.79%

found: its contribution, 52.59 amu

SET UP the abundances



CALCULATE



WRONG TURNS ✗



🧠 **Sense check:** One term only: Step 1 and Step 2 for Sb-123. The sum and the range check belong to the full average. ✓



Worked example 1: boron

B-10 · 10.0129 amu · 19.9% · B-11 · 11.0093 amu · 80.1%
given: two isotopic masses with abundances · wanted: average atomic mass

Natural boron is the two isotopes above. Calculate the average atomic mass of boron.

✓ Worked example 1: solution

B-10 · 10.0129 amu · 19.9% · B-11 · 11.0093 amu · 80.1%
 wanted: average atomic mass of boron

Step 1 · Percents → fractions

Step 2 · Mass × fraction

$10.0129 \times 0.199 = 1.9926$ · $11.0093 \times 0.801 = 8.8184$
 one contribution per isotope, in amu

Step 3 · Add the contributions

$1.9926 + 8.8184 = 10.81$ amu
 the periodic-table entry for boron

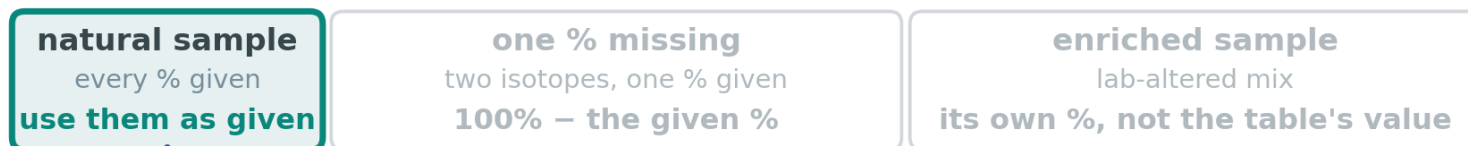
🧠 **Sense check:** 10.81 lies between 10.0129 and 11.0093, close to B-11, the isotope carrying 80.1% of the sample. ✓

✓ Worked example 1: the route on the map

$$\text{B-10} \cdot 10.0129 \text{ amu} \cdot 19.9\% \quad + \quad \text{B-11} \cdot 11.0093 \text{ amu} \cdot 80.1\%$$

found: 10.81 amu

SET UP the abundances



CALCULATE



WRONG TURNS X



🧠 **Sense check:** The rubidium path again: a natural sample, two terms, one sum, the range check. ✓



Worked example 2: chlorine

$\text{Cl-35} \cdot 34.97 \text{ amu} \cdot 75.76\%$ $\cdot$ $\text{Cl-37} \cdot 36.97 \text{ amu} \cdot 24.24\%$
given: two isotopic masses with abundances · wanted: average atomic mass

Chlorine disinfects drinking water. Calculate its average atomic mass.

A common first attempt: add the two masses and divide by two. Test it.

✓ Worked example 2: solution

Cl-35 · 34.97 amu · 75.76% · Cl-37 · 36.97 amu · 24.24%

wanted: average atomic mass of chlorine

A common first attempt

$$(34.97 + 36.97) \div 2 = 35.97 \text{ amu}$$

every periodic table prints 35.45: the even split fails ✗

Step 1 · Percents → fractions

Step 2 · Mass × fraction

Step 3 · Add the contributions

$$34.97 \times 0.7576 + 36.97 \times 0.2424 = 26.4933 + 8.9616 = 35.45 \text{ amu}$$

two contributions, one sum: the periodic-table entry ✓

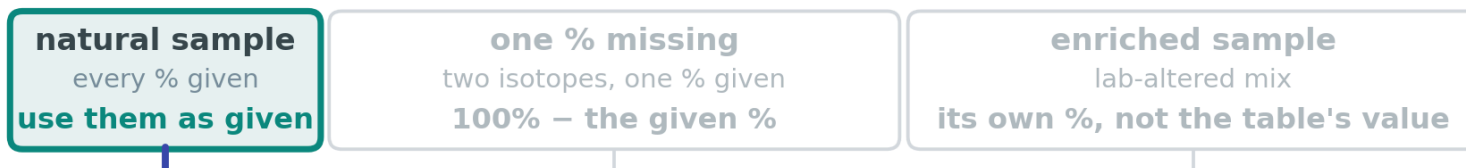
 **Sense check:** 35.45 lies between 34.97 and 36.97, closer to Cl-35, the isotope in three quarters of the sample. The even split lands at 35.97 because it ignores which isotope is common. ✓

✓ Worked example 2: the route on the map

Cl-35 · 34.97 amu · 75.76% · Cl-37 · 36.97 amu · 24.24%

tested: 35.97 amu × · found: 35.45 amu ✓

SET UP the abundances



CALCULATE



WRONG TURNS ×



Sense check: The even split is a wrong turn: it holds only when the abundances are equal. The route weights each mass by its fraction. ✓

Your turn: copper

Cu-63 · 62.9296 amu · 69.17% · Cu-65 · 64.9278 amu · 30.83%

wanted: average atomic mass of copper

$62.9296 \times \underline{\hspace{1cm}} + 64.9278 \times 0.3083 = \underline{\hspace{1cm}} + 20.0172 = \underline{\hspace{1cm}}$ amu

fractions from 69.17% and 30.83% · one contribution per isotope · then the sum

Fill the missing fraction, then complete the first contribution and the sum.

$62.9296 \times 0.6917 + 64.9278 \times 0.3083 = 43.5284 + 20.0172 = 63.55$ amu

between 62.9296 and 64.9278, closer to Cu-63, 69.17% of the sample ✓

⚠ Where this goes wrong

Cu-63 · 62.9296 amu · 69.17% · Cu-65 · 64.9278 amu · 30.83%
average atomic mass: 63.55 amu

Using whole percents. $62.9296 \times 69.17 + 64.9278 \times 30.83 = 6354.6$ amu: one hundred times too heavy. A share of a sample is a fraction: divide each percent by 100 first. 0.6917 and 0.3083 give 63.55 amu.

Attaching the abundances to the wrong isotopes. $62.9296 \times 0.3083 + 64.9278 \times 0.6917 = 64.31$ amu: closer to Cu-65, the rarer isotope. The average must sit closer to the 69.17% isotope: 63.55 amu.

Weighting mass numbers instead of isotopic masses. $63 \times 0.6917 + 65 \times 0.3083 = 63.62$ amu, not 63.55. Mass numbers count protons and neutrons; the average takes the measured masses, 62.9296 and 64.9278.



Practice 2

N-14 · 14.0031 amu · 99.636% · N-15 · 15.0001 amu · 0.364%

wanted: average atomic mass of nitrogen

Fertilizer plants pull nitrogen from the air to make ammonia. Natural nitrogen is the two isotopes above.

What is the average atomic mass of nitrogen, in amu?

- A. 15.00
- B. 14.01
- C. 14.50
- D. 1401

✓ Practice 2 · answer: B

$$\text{N-14} \cdot 14.0031 \text{ amu} \cdot 99.636\% \quad \cdot \quad \text{N-15} \cdot 15.0001 \text{ amu} \cdot 0.364\%$$

wanted: average atomic mass of nitrogen

$$13.9521 + 0.0546 = 14.01 \text{ amu (answer B)}$$

$14.0031 \times 0.99636 + 15.0001 \times 0.00364$: each mass weighted by its fraction of the sample

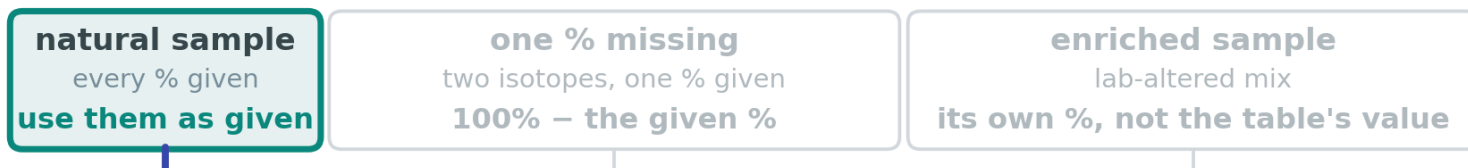
C averaged the masses equally: $(14.0031 + 15.0001) \div 2 = 14.50$. A attached the abundances to the wrong isotopes: $14.0031 \times 0.00364 + 15.0001 \times 0.99636 = 15.00$. D used whole percents: $14.0031 \times 99.636 + 15.0001 \times 0.364 = 1401$.

 **Sense check:** D is one hundred times too heavy. 15.00 leans to N-15, the rarer isotope; 14.50 ignores the abundances. Only 14.01 sits near N-14, 99.636% of the sample. ✓

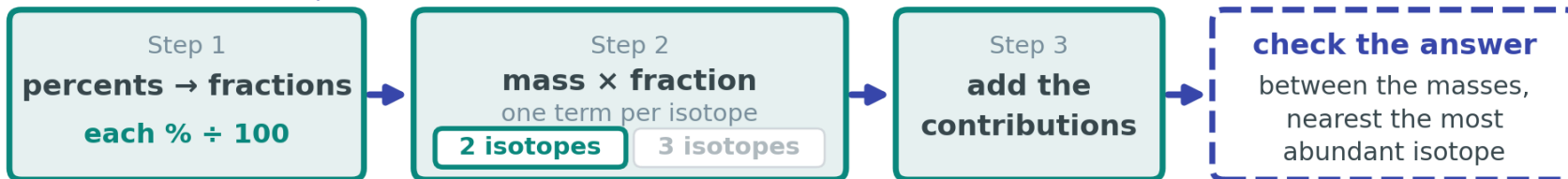
✓ Practice 2: the route on the map

N-14 · 14.0031 amu · 99.636% · N-15 · 15.0001 amu · 0.364%
found: 14.01 amu

SET UP the abundances



CALCULATE



WRONG TURNS X



Sense check: The boron route: two terms, one sum. Each wrong choice left it: A by swapped abundances, C by the even split, D by whole percents. ✓



Worked example 3: magnesium

$$\text{Mg-24} \cdot 23.9850 \text{ amu} \cdot 78.99\% \cdot \text{Mg-25} \cdot 24.9858 \text{ amu} \cdot 10.00\% \cdot \text{Mg-26} \cdot 25.9826 \text{ amu} \cdot 11.01\%$$

abundances: $78.99 + 10.00 + 11.01 = 100.00$: the whole sample

Magnesium has three natural isotopes. The method does not change: one term per isotope. Calculate the average atomic mass.

✓ Worked example 3: fractions and contributions

Mg-24 · 23.9850 amu · 78.99% · Mg-25 · 24.9858 amu · 10.00% · Mg-26 ·
25.9826 amu · 11.01%

wanted: average atomic mass of magnesium

Step 1 · Percents → fractions

Step 2 · Mass × fraction

$$23.9850 \times 0.7899 = 18.9458 \text{ amu}$$

$$24.9858 \times 0.1000 = 2.4986 \text{ amu}$$

$$25.9826 \times 0.1101 = 2.8607 \text{ amu}$$

one contribution per isotope, the largest from the most abundant

🧠 **Sense check:** Mg-24 supplies 18.9458 of the total; nearly four fifths of the sample is Mg-24. ✓

✓ Worked example 3: the sum

contributions: Mg-24 → 18.9458 amu · Mg-25 → 2.4986 amu · Mg-26 → 2.8607 amu

from $23.9850 \times 0.7899 \cdot 24.9858 \times 0.1000 \cdot 25.9826 \times 0.1101$

Step 3 · Add the contributions

$$18.9458 + 2.4986 + 2.8607 = 24.305 \text{ amu}$$

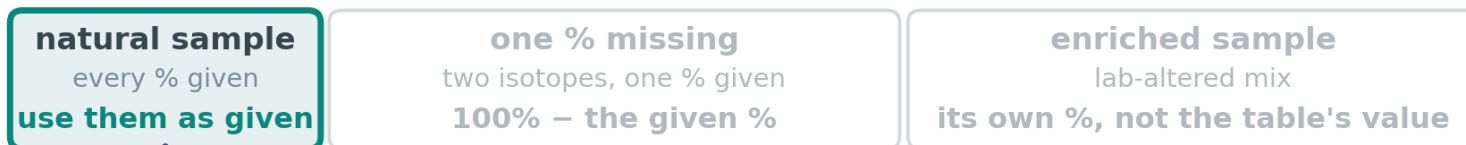
the periodic-table entry for magnesium

🧠 **Sense check:** 24.305 lies between 23.9850 and 25.9826, close to Mg-24, 78.99% of the sample. The two heavier isotopes hold 21.01% between them and raise the average only slightly. ✓

✓ Worked example 3: the route on the map

Mg-24 · 78.99% · Mg-25 · 10.00% · Mg-26 · 11.01%
found: 24.305 amu

SET UP the abundances



CALCULATE



WRONG TURNS X



🧠 **Sense check:** Three isotopes, three terms. Every other box matches the two-isotope route. ✓



Practice 3

C-12 · 12.0000 amu · C-13 · 13.0034 amu · 1.07%
the only two natural isotopes · wanted: average atomic mass of carbon

Natural carbon is these two isotopes and nothing else. What is the average atomic mass of carbon, in amu?

- A. 12.99
- B. 0.14
- C. 12.50
- D. 0.27
- E. 12.01

✓ Practice 3 · answer: E

$$\text{C-12} \cdot 12.0000 \text{ amu} \cdot \text{C-13} \cdot 13.0034 \text{ amu} \cdot 1.07\%$$

$$\text{C-12: } 100 - 1.07 = 98.93\% \cdot \text{fractions } 0.9893 \text{ and } 0.0107$$

$$12.0000 \times 0.9893 + 13.0034 \times 0.0107 = 11.8716 + 0.1391 = 12.01 \text{ amu (answer E)}$$

the missing abundance first, then one contribution per isotope

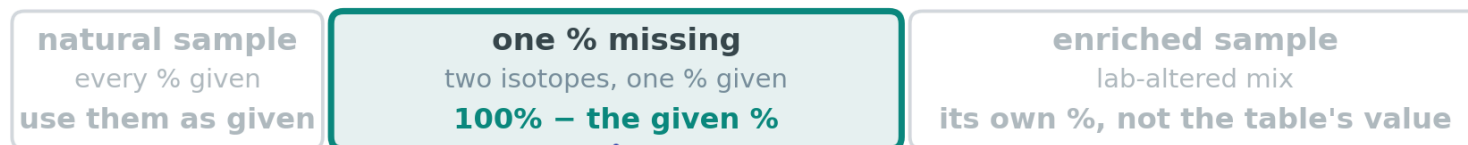
B stopped at the C-13 contribution, 0.14. D skipped the missing abundance and reused 0.0107 for C-12: $12.0000 \times 0.0107 + 0.1391 = 0.27$, a sample only 2.14% complete. A attached 1.07% to the wrong isotope: $12.0000 \times 0.0107 + 13.0034 \times 0.9893 = 12.99$. C averaged the masses equally: 12.50.

🧠 **Sense check:** 12.01 sits just above 12.0000, near C-12, the 98.93% isotope. ✓

✓ Practice 3: the route on the map

C-12 · 12.0000 amu · C-13 · 13.0034 amu · 1.07%
found: 12.01 amu

SET UP the abundances



CALCULATE



WRONG TURNS ✗



🧠 **Sense check:** One percent missing: $100 - 1.07 = 98.93\%$ comes first. Then the same three steps and the range check. ✓



Practice 4

Ca-44 · 43.9555 amu · 88.00% · Ca-40 · 39.9626 amu · 10.00% · Ca-42 · 41.9586 amu · 2.00%

calcium enriched in Ca-44 · wanted: average atomic mass of the tracer calcium

A calcium-absorption study feeds volunteers calcium carbonate enriched in Ca-44. What average atomic mass, in amu, does the tracer calcium have?

- A. 40.08
- B. 41.96
- C. 38.68
- D. 43.52
- E. 42.68

✓ Practice 4 · answer: D

$$\text{Ca-44} \cdot 43.9555 \text{ amu} \cdot 88.00\% \cdot \text{Ca-40} \cdot 39.9626 \text{ amu} \cdot 10.00\% \cdot \text{Ca-42} \cdot 41.9586 \text{ amu} \cdot 2.00\%$$

enriched: use the sample's own percents

$$38.6808 + 3.9963 + 0.8392 = 43.52 \text{ amu (answer D)}$$

$$43.9555 \times 0.8800 + 39.9626 \times 0.1000 + 41.9586 \times 0.0200: \text{one contribution per isotope}$$

A took the periodic-table value, 40.08: natural calcium, mostly Ca-40, not this sample. B weighted the three masses equally: $(43.9555 + 39.9626 + 41.9586) \div 3 = 41.96$. C stopped at the first contribution: 38.68. E left out Ca-42: $38.6808 + 3.9963 = 42.68$.

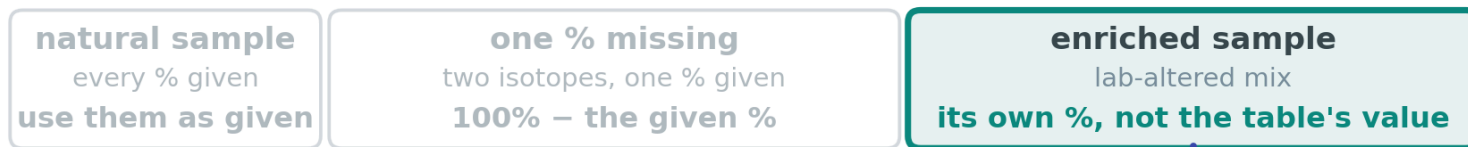
 **Sense check:** 43.52 lies between 39.9626 and 43.9555, near Ca-44, 88.00% of this sample. An enriched sample never matches the table. ✓

✓ Practice 4: the route on the map

Ca-44 · 88.00% · Ca-40 · 10.00% · Ca-42 · 2.00%

found: 43.52 amu, not the table's 40.08

SET UP the abundances



CALCULATE



WRONG TURNS X



 **Sense check:** An enriched sample takes its own percents, never the table value. Three isotopes, three terms, one sum. ✓

6 • Periodic Table Organization

Locate an element by period and group, name its family, classify it as a metal, nonmetal, or metalloid, and predict its bench behavior from its position.

Same column, same chemistry

group →

period

H: a nonmetal parked over group 1

the staircase

period \ group	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	H																	He
2	Li	Be											B	C	N	O	F	Ne
3	Na	Mg											Al	Si	P	S	Cl	Ar
4	K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
5	Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe
6	Cs	Ba	57-71	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn
7	Fr	Ra	89-103	Rf	Db	Sg	Bh	Hs	Mt	Ds	Rg	Cn	Nh	Fl	Mc	Lv	Ts	Og

alkali metals · group 1

alkaline earth metals · group 2

transition metals · groups 3-12

metalloids · the staircase

halogens · group 17

noble gases · group 18

metals: left of the staircase

nonmetals: upper right

a row is a period · a column is a group · a named column is a family

Sodium explodes in water. Potassium does too, more violently. The periodic table seats them in one column: elements with matching behavior stack vertically, on purpose.

Order by atomic number, and behavior repeats

Li (3) · Na (11) · K (19): soft metals, violent in water
 $11 - 3 = 8$ · $19 - 11 = 8$: the behavior returns at regular intervals

one list, in order of atomic number

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
H	He	Li	Be	B	C	N	O	F	Ne	Na	Mg	Al	Si	P	S	Cl	Ar	K	Ca
cut									cut									cut	

behavior repeats
→ new row

the same tiles, one row per cut

1																	2								
H																	He								
3	4	5	6	7	8	9	10																		
Li	Be	B	C	N	O	F	Ne																		
11	12	13	14	15	16	17	18																		
Na	Mg	Al	Si	P	S	Cl	Ar																		
19	20																								
K	Ca																								

look-alikes stack

and stack

cut at each repeat, and the look-alikes stack into columns

The table lists elements in order of atomic number. Cut the list at each repeat, and the look-alikes stack into columns.

Rows are periods, columns are groups

groups: columns, 1 to 18

periods: rows, 1 to 7

	1															18		
1	H															He		
2	Li	Be										B	C	N	O	F	Ne	
3	Na	Mg										Al	Si	P	S	Cl	Ar	
4	K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
5	Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe
6	Cs	Ba	57-71	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn
7	Fr	Ra	89-103	Rf	Db	Sg	Bh	Hs	Mt	Ds	Rg	Cn	Nh	Fl	Mc	Lv	Ts	Og

row 3 and column 17 cross at one element

the address: period 3, group 17 = Cl

Every element has an address: period, then group. Chlorine sits in row 3, column 17: period 3, group 17. Two numbers locate any element.

Counting groups, and the A labels

row 2: Li 1 · Be 2 · B 13 · C 14 · N 15 · O 16 · F 17 · Ne 18

rows 2 and 3 skip groups 3 to 12: $12 - 3 + 1 = 10$ columns · A labels: 1A, 2A, then 3A to 8A for groups 13 to 18

Count groups across the full width, gap included. The tall columns also carry A labels; for groups 13 to 18, drop the 1.

Aluminum sits directly below boron. Give its group both ways.

Al: group 13 = group 3A

never group 3: aluminum sits right of the gap · 13 → drop the 1 → 3A

Five columns carry family names

group →

period

H: a nonmetal parked over group 1

the staircase

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	
1	H																He	
2	Li	Be										B	C	N	O	F	Ne	
3	Na	Mg										Al	Si	P	S	Cl	Ar	
4	K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
5	Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe
6	Cs	Ba	57-71	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn
7	Fr	Ra	89-103	Rf	Db	Sg	Bh	Hs	Mt	Ds	Rg	Cn	Nh	Fl	Mc	Lv	Ts	Og

alkali metals · group 1

alkaline earth metals · group 2

transition metals · groups 3-12

metalloids · the staircase

halogens · group 17

noble gases · group 18

metals: left of the staircase

nonmetals: upper right

a row is a period · a column is a group · a named column is a family

Group 1: alkali metals. Group 2: alkaline earth metals. Groups 3 to 12: transition metals. Group 17: halogens. Group 18: noble gases. A family name is a summary of shared behavior.

Metals, nonmetals, metalloids

H: a nonmetal parked over group 1

the staircase: B to Te

metals: left of the staircase
nonmetals: upper right, plus H
metalloids: B Si Ge As Sb Te, on the line

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18					
1	H											B	C	N	O	F	He					
2	Li	Be										Al	Si	P	S	Cl	Ar					
3	Na	Mg										Ga	Ge	As	Se	Br	Kr					
4	K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	In	Sn	Sb	Te	I	Xe				
5	Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn
6	Cs	Ba	57-71	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn				
7	Fr	Ra	89-103	Rf	Db	Sg	Bh	Hs	Mt	Ds	Rg	Cn	Nh	Fl	Mc	Lv	Ts	Og				

most of the table is metal · six elements on the line fit neither class cleanly

A stepped line runs from boron to tellurium. Metals sit to its left: most of the table. Nonmetals fill the upper right, plus hydrogen. The six elements on the line are metalloids: neither class fits cleanly.

What the classes mean at the bench

metals	metalloids	nonmetals
Cu · Fe · Al · Ca	B Si Ge As Sb Te	O · S · Br · Cl
 shiny (metallic luster)	metallic look, in-between behavior	 dull
 malleable and ductile: bend and draw, never shatter	 Si	 brittle as solids: shatter, never bend
 conduct heat and electricity	semiconductors: silicon runs electronics	 insulators: no current flows
all solid at room temp except mercury, a liquid		varied room-temp states: 5 solids · liquid Br · 11 gases
 e^- in reactions: lose electrons		 e^- in reactions: gain electrons

left of the staircase

the staircase

right of the staircase

The classes are bench descriptions. Metals are shiny, bend without shattering, and conduct heat and electricity. Nonmetals are dull, brittle as solids, and insulate. In reactions, metals lose electrons; nonmetals gain them.

Main group and transition block

main group: 1, 2, 13 to 18 · transition: 3 to 12

the tall columns at both edges · the block in the middle · main group = the representative elements, the A columns · the two rows set below the table: inner transition metals

Groups 1, 2, and 13 through 18 are the main group. Groups 3 through 12 are the transition metals. Family behavior runs cleanest in the main group; the transition block is all metals.

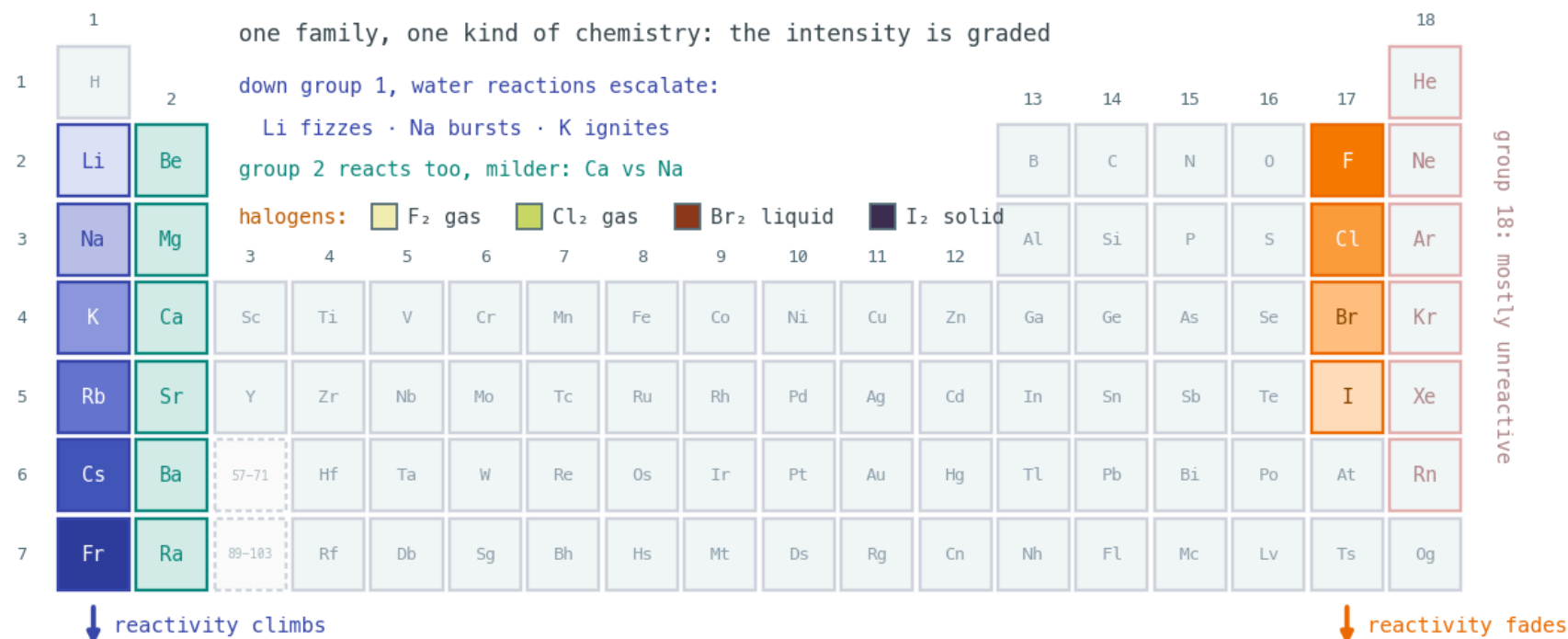
Why a family behaves alike

Li · Na · K: 1 outer electron each

F · Cl · Br · I: 7 outer electrons each, $8 - 7 = 1$ short of a full set

Elements in one column hold the same number of outer electrons, and outer electrons do the chemistry. Same count, same behavior. Row neighbors hold different counts, so they differ.

Reactivity is graded down a family



family members share behavior, not intensity: the gradation runs down the column

A family shares behavior, not intensity. Down group 1 the water reaction escalates: lithium fizzes, sodium bursts, potassium ignites. Down group 17 it fades, fluorine to iodine.

The table predicts missing elements

1871: a gap below silicon, named eka-silicon · predicted mass ≈ 72 , density ≈ 5.5 g/cm³

1886: germanium isolated · mass 72.6, density 5.32 g/cm³ · 1886 – 1871 = 15 years

Mendeleev left the space under silicon empty and forecast the missing element's properties from its neighbors. Germanium, found fifteen years later, matched. The table predicts chemistry; it does not just file elements.



The method

1. **Find the period.** Count rows down; hydrogen's row is period 1.
2. **Find the group.** Count columns 1 to 18.
3. **Name the family** if the column has one.
4. **Classify with the staircase.** Left: metal. Right: nonmetal. On it: metalloid.

One map for every address question

group (A label for the main-group columns)

	1A 1																	8A 18
1	H	2A 2																He
2	Li	Be																Ne
3	Na	Mg	3	4	5	6	7	8	9	10	11	12	Al	Si	P	S	Cl	Ar
4	K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
5	Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe
6	Cs	Ba		Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn
7	Fr	Ra		Rf	Db	Sg	Bh	Hs	Mt	Ds	Rg	Cn	Nh	Fl	Mc	Lv	Ts	Og

ELEMENT: start here, or land here		
1 period	count rows: 1 to 7, top down	
2 group	count columns: 1 to 18, or 1A to 8A	
3 family	alkali metals · 1	alkaline earth · 2
	halogens · 17	noble gases · 18
4 class	transition · 3-12	no name · 13-16
	metal left of the line	metalloid the six on it
		nonmetal right of it, + H

Steps 1 and 2 read the address. Steps 3 and 4 read what it means. A problem that starts from an address, a family, or bench properties runs the same map in reverse.



Guided example: xenon

Xe · atomic number 54

wanted: period, group, family, class

Xenon fills the bright flash lamps of cameras. Find its period and group, name its family, and classify it.

Each step on the map reads one thing off the table.

✓ Guided example: solution

Xe · atomic number 54
wanted: period, group, family, class

Step 1 · Find the period

Step 2 · Find the group

Step 3 · Name the family

Step 4 · Classify with the staircase

Xe: period 5, group 18 (8A) · noble gas · nonmetal
right of the staircase: nonmetal · period 5 holds $54 - 37 + 1 = 18$ elements

🧠 **Sense check:** Xenon glows in a flash lamp and comes out unchanged, like neon and argon above it. The address predicted an unreactive gas. ✓

Xe · atomic number 54

given: Xe · found: period 5, group 18 (8A), noble gas, nonmetal

period

group (A label for the main-group columns)

	1A	2A											3A	4A	5A	6A	7A	8A
	1	2											13	14	15	16	17	18
1	H	He																
2	Li	Be											B	C	N	O	F	Ne
3	Na	Mg	3	4	5	6	7	8	9	10	11	12	Al	Si	P	S	Cl	Ar
4	K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
5	Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe
6	Cs	Ba		Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn
7	Fr	Ra		Rf	Db	Sg	Bh	Hs	Mt	Ds	Rg	Cn	Nh	Fl	Mc	Lv	Ts	Og

	Xe · Z = 54			given
1	period	period 5		found
2	group	group 18 = 8A		found
3	family	alkali metals · 1	alkaline earth · 2	found
		transition · 3-12		
		halogens · 17	noble gases · 18	
		no name · 13-16		
4	class	metal left of the line	metalloid the six on it	nonmetal right of it, + H
				found

 **Sense check:** Row 5, then the last column. The column names the family; the side of the staircase names the class.





Practice 1

aluminum · arsenic · selenium · tin
wanted: the metalloid

Which of these four elements is a metalloid?

- A. Arsenic
- B. Aluminum
- C. Selenium
- D. Tin

✓ Practice 1 · answer: A

arsenic: on the staircase → metalloid (answer A)

metalloids: B, Si, Ge, As, Sb, Te · Al and Sn: metals · Se: nonmetal

B stretched the staircase: aluminum touches the line but is a metal, an excellent conductor. C sits one column right of arsenic, past the line: selenium is a nonmetal. D carried germanium's class down group 14: tin, below it, is a metal.

🧠 **Sense check:** Membership is the list of six, not closeness to the line. Arsenic is the only one of the four on it. ✓

✓ Practice 1: the route on the map

aluminum · arsenic · selenium · tin
given: four elements · found: arsenic, a metalloid

		group (A label for the main-group columns)																			
		1A																	8A		
		1																	18		
period	1	H	2A											3A	4A	5A	6A	7A	He		
	2	Li	Be											B	C	N	O	F	Ne		
	3	Na	Mg	3	4	5	6	7	8	9	10	11	12	Al	Si	P	S	Cl	Ar		
	4	K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr		
	5	Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe		
	6	Cs	Ba		Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn		
	7	Fr	Ra		Rf	Db	Sg	Bh	Hs	Mt	Ds	Rg	Cn	Nh	Fl	Mc	Lv	Ts	Og		

As (from Al · As · Se · Sn)			given
1 period	not needed		
2 group	not needed		
3 family	alkali metals · 1	alkaline earth · 2	transition · 3-12
	halogens · 17	noble gases · 18	no name · 13-16
4 class	metal left of the line	metalloid the six on it	nonmetal right of it, + H
			found

🧠 **Sense check:** Only Step 4 was needed. Arsenic is on the line; aluminum and tin sit left of it, selenium right of it. ✓



Worked example 1: locating chlorine

Cl · atomic number 17

wanted: period, group, family, class

Find chlorine's period and group, name its family, and classify it: metal, nonmetal, or metalloid.

✓ Worked example 1: solution

Cl · atomic number 17
wanted: period, group, family, class

Step 1 · Find the period

Step 2 · Find the group

Step 3 · Name the family

Step 4 · Classify with the staircase

Cl: period 3, group 17 · halogen · nonmetal
right of the staircase: nonmetal

 **Sense check:** Chlorine's column-mates F, Br, and I are all reactive nonmetals. The address alone predicted the behavior. ✓

✓ Worked example 1: the route on the map

Cl · atomic number 17

given: Cl · found: period 3, group 17 (7A), halogen, nonmetal

group (A label for the main-group columns)

	1A																	8A
	1	2A											3A	4A	5A	6A	7A	18
1	H												B	C	N	O	F	He
2	Li	Be											B	C	N	O	F	Ne
3	Na	Mg											Al	Si	P	S	Cl	Ar
4	K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
5	Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe
6	Cs	Ba		Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn
7	Fr	Ra		Rf	Db	Sg	Bh	Hs	Mt	Ds	Rg	Cn	Nh	Fl	Mc	Lv	Ts	Og

	Cl · Z = 17			given
1	period	period 3		found
2	group	group 17 = 7A		found
3	family	alkali metals · 1	alkaline earth · 2	found
		transition · 3-12		
		halogens · 17	noble gases · 18	found
			no name · 13-16	
4	class	metal left of the line	metalloid the six on it	found
			nonmetal right of it, + H	

 **Sense check:** Row 3 and column 17 cross at chlorine. The halogen column sits right of the staircase: F, Cl, Br, and I are all nonmetals. ✓

Worked example 2: predicting strontium

Sr · atomic number 38 · directly below Ca (20)

wanted: family, class, expected chemistry

Strontium sits directly below calcium. Name its family and class, and predict how its chemistry compares with calcium's.

A common first attempt: strontium holds nearly twice calcium's protons, so its chemistry should differ. Test it.

✓ Worked example 2: solution

Sr · atomic number 38 · directly below Ca (20)
wanted: family, class, expected chemistry

A common first attempt

Step 1 · Find the period

Step 2 · Find the group

Step 3 · Name the family

Step 4 · Classify with the staircase

Sr: period 5, group 2 · alkaline earth metal · metal
2 outer electrons, the same count as Ca: the same chemistry follows

 **Sense check:** The prediction is physical: bone takes up strontium because the body processes it like calcium. Same family, same chemistry. ✓

✓ Worked example 2: the route on the map

Sr · atomic number 38 · directly below Ca (20)
 given: Sr · found: period 5, group 2 (2A), alkaline earth metal, metal

group (A label for the main-group columns)

	1A																	8A
	1																	18
1	H	2A																He
2	Li	Be																Ne
3	Na	Mg	3	4	5	6	7	8	9	10	11	12	Al	Si	P	S	Cl	Ar
4	K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
5	Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe
6	Cs	Ba		Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn
7	Fr	Ra		Rf	Db	Sg	Bh	Hs	Mt	Ds	Rg	Cn	Nh	Fl	Mc	Lv	Ts	Og

Sr · Z = 38		given
1 period	period 5	found
2 group	group 2 = 2A	found
3 family	alkali metals · 1 alkaline earth · 2 transition · 3-12 halogens · 17 noble gases · 18 no name · 13-16	found
4 class	metal left of the line metalloids the six on it nonmetals right of it, + H	found

 **Sense check:** One row below calcium, in the same column. The column carries the family, the class, and the chemistry down with it. ✓

Your turn: barium

Ba · atomic number 56 · directly below Sr (38)

$56 - 38 = 18$: one full row lower

step	answer
1 · find the period	one row below strontium's period 5: period _____
2 · find the group	the column of Be, Mg, Ca, Sr: group _____
3 · name the family	_____
4 · classify	left of the staircase: _____

Complete the four steps.

Ba: period 6, group 2 · alkaline earth metal · metal

2 outer electrons, like Mg, Ca, and Sr

✓ Your turn: the route on the map

Ba · atomic number 56 · directly below Sr (38)

given: Ba · found: period 6, group 2 (2A), alkaline earth metal, metal

		group (A label for the main-group columns)																	
		1A											3A	4A	5A	6A	7A	8A	
		1											13	14	15	16	17	18	
period	1	H	2A																He
	2	Li	Be											B	C	N	O	F	Ne
	3	Na	Mg	3	4	5	6	7	8	9	10	11	12	Al	Si	P	S	Cl	Ar
	4	K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
	5	Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe
	6	Cs	Ba		Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn
	7	Fr	Ra		Rf	Db	Sg	Bh	Hs	Mt	Ds	Rg	Cn	Nh	Fl	Mc	Lv	Ts	Og

	Ba · Z = 56			given
1	period	period 6		found
2	group	group 2 = 2A		found
3	family	alkali metals · 1	alkaline earth · 2	found
		halogens · 17	noble gases · 18	
4	class	metal left of the line	metalloid the six on it	found
			nonmetal right of it, + H	

🧠 **Sense check:** Each row down keeps the column: Be, Mg, Ca, Sr, and Ba all sit in group 2, left of the staircase. ✓

⚠ Where this goes wrong

Swapping period and group. Period 3, group 17 names a row, then a column: chlorine. Reversed it names nothing: the table holds 7 periods, and no period 17 exists. Period counts rows; group counts columns.

Filing hydrogen with the alkali metals. Hydrogen sits over group 1, but it is a colorless nonmetal gas. The alkali family starts at lithium.

Stretching the staircase. The metalloids are exactly B, Si, Ge, As, Sb, Te. Aluminum touches the line and is still a metal: household foil, an excellent conductor. Membership is the list, not proximity.

Expecting row-mates to behave alike. Sodium and chlorine share period 3: a soft metal stored under oil, and a corrosive yellow-green gas. Alike runs down a column, never across a row.



Practice 2

wanted: the element at period 4, group 17
row 4 · column 17

Which element sits in period 4, group 17?

- A. Iodine
- B. Bromine
- C. Manganese
- D. Krypton

✓ Practice 2 · answer: B

period 4, group 17 → bromine (answer B)

period 4 spans $Z = 19$ to 36 : $36 - 19 + 1 = 18$ elements, ending at Kr

A counted rows inside the halogen column: fluorine's row is period 2, so the fourth halogen down is iodine, period 5. C read group 17 as group 7 and landed in the transition block: manganese sits in period 4, group 7. D overshoot by one column: krypton is group 18, a noble gas.

 **Sense check:** Bromine at this address is a halogen and a nonmetal: the only element in its column that is liquid at room temperature. ✓

given: period 4, group 17 · found: Br, halogen, nonmetal

given: period 4, group 17 · found: Br, halogen, nonmetal

		group (A label for the main-group columns)																			
		1A															7A	8A			
		1															17	18			
1		H	2A													3A	4A	5A	6A	Br	He
2		Li	Be													B	C	N	O	F	Ne
3		Na	Mg	3	4	5	6	7	8	9	10	11	12	Al	Si	P	S	Cl	Ar		
4		K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr		
5		Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe		
6		Cs	Ba		Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn		
7		Fr	Ra		Rf	Db	Sg	Bh	Hs	Mt	Ds	Rg	Cn	Nh	Fl	Mc	Lv	Ts	Og		

	Br · bromine			found
1	period	period 4		given
2	group	group 17 = 7A		given
3	family	alkali metals · 1	alkaline earth · 2	found
		transition · 3-12		
		halogens · 17	noble gases · 18	
			no name · 13-16	
4	class	metal left of the line	metalloid the six on it	nonmetal right of it, + H
				found





Worked example 3: tellurium and iodine

Te: $Z = 52$, mass 127.6 · I: $Z = 53$, mass 126.9

wanted: which comes first, and each element's class

Tellurium outweighs iodine: $127.6 - 126.9 = 0.7$. State which element comes first on the table, then classify both.

✓ Worked example 3: solution

Te: $Z = 52$, mass 127.6 · I: $Z = 53$, mass 126.9

wanted: which comes first, and each element's class

The ordering rule

Classify with the staircase

Te: period 5, group 16 · on the staircase · metalloid

I: period 5, group 17 · halogen · nonmetal · order: $Z = 52$, then 53

🧠 **Sense check:** One proton separates a semiconducting metalloid from a violet-vapor halogen. Position, and the chemistry it encodes, follows the proton count, not the mass. ✓

✓ Worked example 3: the route on the map

Te: $Z = 52$, mass 127.6 · I: $Z = 53$, mass 126.9

given: Te and I · found: Te: period 5, group 16 (6A), metalloid · I: group 17 (7A), halogen, nonmetal

group (A label for the main-group columns)

	1A																	8A
	1	2A																18
1	H																	He
2	Li	Be																Ne
3	Na	Mg																Ar
4	K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
5	Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe
6	Cs	Ba		Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn
7	Fr	Ra		Rf	Db	Sg	Bh	Hs	Mt	Ds	Rg	Cn	Nh	Fl	Mc	Lv	Ts	Og

Te · $Z = 52$ (then I · $Z = 53$)		given
1 period	period 5	found
2 group	group 16 = 6A	found
3 family	alkali metals · 1 alkaline earth · 2 transition · 3–12 halogens · 17 noble gases · 18 no name · 13–16	found
4 class	metal left of the line metalloid the six on it nonmetal right of it, + H	found

 **Sense check:** Tellurium's column, group 16, has no family name, and tellurium sits on the staircase. The next seat, $Z = 53$, is iodine: group 17, a halogen. ✓



Practice 3

Na · K: one column, group 1

Na: $Z = 11$ · K: $Z = 19$ · $19 - 11 = 8$

Sodium and potassium react with water the same violent way. Which statement explains why?

- A. They share a period, and elements in a period behave alike
- B. Their atomic masses are close, and mass sets chemical behavior
- C. They hold the same number of outer electrons: one each
- D. Both are transition metals, and that block reacts with water

✓ Practice 3 · answer: C

group 1: one outer electron per atom (answer C)

same outer count → same chemistry · $19 - 11 = 8$, one behavior repeat apart

A misreads the geometry: sodium and potassium share a group, a column; period-mates differ. B fails on its own numbers: $39.10 - 22.99 = 16.11$, the masses are not close, and mass does not set behavior. D misfiles them: group 1 is a main-group column; the transition block starts at group 3.

 **Sense check:** One easily lost outer electron is the alkali signature. Rubidium and cesium extend the column, and their water reactions escalate in order. ✓

✓ Practice 3: the route on the map

Na · K: one column, group 1

given: Na and K · found: both group 1 (1A), alkali metals, metals

group (A label for the main-group columns)

	1A																	8A
	1	2A											3A	4A	5A	6A	7A	18
1	H	He											B	C	N	O	F	Ne
2	Li	Be											Al	Si	P	S	Cl	Ar
3	Na	Mg											Ga	Ge	As	Se	Br	Kr
4	K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	In	Sn	Sb	Te	I	Xe
5	Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	Hg	Tl	Pb	Bi	Po	At
6	Cs	Ba		Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn
7	Fr	Ra		Rf	Db	Sg	Bh	Hs	Mt	Ds	Rg	Cn	Nh	Fl	Mc	Lv	Ts	Og

	Na · Z = 11 and K · Z = 19			given
1	period	period 3 and 4		found
2	group	group 1 = 1A		found
3	family	alkali metals · 1	alkaline earth · 2	found
		halogens · 17	noble gases · 18	
4	class	metal left of the line	metalloid the six on it	found
			nonmetal right of it, + H	

 **Sense check:** Two rows, one column. A shared column means a shared outer-electron count, a shared family, and shared chemistry. ✓



Worked example 4: the address in reverse

wanted: the alkaline earth metal in period 3

given: a family name and a row · wanted: one element

A problem names no element, only a description: the alkaline earth metal in period 3.
Find the element.

✓ Worked example 4: solution

wanted: the alkaline earth metal in period 3

given: a family name and a row · wanted: one element

Family → group

Period → row

Read the intersection

group 2, period 3 → Mg, magnesium

row 3 opens at Na ($Z = 11$) in group 1 · the group-2 seat is next: $Z = 11 + 1 = 12$

 **Sense check:** Check the column: Be above, Ca below, all group 2. The address ran in reverse and still landed on a single element. ✓

✓ Worked example 4: the route on the map

wanted: the alkaline earth metal in period 3

given: alkaline earth metal, period 3 · found: group 2 (2A), Mg

group (A label for the main-group columns)

	1A 1																	8A 18
1	H	2A 2																He
2	Li	Be																Ne
3	Na	Mg	3	4	5	6	7	8	9	10	11	12	Al	Si	P	S	Cl	Ar
4	K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
5	Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe
6	Cs	Ba		Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn
7	Fr	Ra		Rf	Db	Sg	Bh	Hs	Mt	Ds	Rg	Cn	Nh	Fl	Mc	Lv	Ts	Og

	Mg · magnesium		found
1	period	period 3	given
2	group	group 2 = 2A	found
3	family	alkali metals · 1	alkaline earth · 2
		halogens · 17	noble gases · 18
			no name · 13-16
4	class	metal left of the line	metalloid the six on it
			nonmetal right of it, + H
			found

 **Sense check:** The family fixed the column and the period fixed the row. The map ran from the steps up to the element. ✓



Practice 4

shiny · malleable · conducts electricity · loses two electrons
wanted: the one element fitting every observation

A sample is shiny, flattens under a hammer without shattering, and conducts electricity. Each of its atoms loses two electrons when it reacts. Which element fits?

- A. Potassium
- B. Silicon
- C. Calcium
- D. Sulfur

✓ Practice 4 · answer: C

metal properties + two electrons lost → calcium (answer C)
shiny, malleable, conducting: a metal, left of the staircase · 2 outer electrons: group 2

A fits the bench tests, but potassium sits in group 1: one outer electron, so it loses one, never two. B fails at the bench: silicon is a metalloid on the staircase, a semiconductor, not a full conductor. D reverses the electron move: sulfur is a brittle nonmetal, and nonmetals gain electrons.

 **Sense check:** Bench properties place the region; the electron count picks the column. Magnesium and barium, calcium's family-mates, fit the same description. ✓

✓ Practice 4: the route on the map

shiny · malleable · conducts electricity · loses two electrons
 given: metal properties, two electrons lost · found: group 2 (2A), alkaline earth metal, Ca

group (A label for the main-group columns)

	1A 1																	8A 18
1	H	2A 2																He
2	Li	Be																Ne
3	Na	Mg	3	4	5	6	7	8	9	10	11	12	Al	Si	P	S	Cl	Ar
4	K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
5	Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe
6	Cs	Ba		Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn
7	Fr	Ra		Rf	Db	Sg	Bh	Hs	Mt	Ds	Rg	Cn	Nh	Fl	Mc	Lv	Ts	Og

	Ca · calcium	found
1 period	not needed	
2 group	group 2 = 2A	found
3 family	alkali metals · 1 alkaline earth · 2 transition · 3-12	found
	halogens · 17 noble gases · 18 no name · 13-16	
4 class	metal left of the line	metalloid the six on it
	nonmetal right of it, + H	given

 **Sense check:** The bench tests picked the class; the two electrons picked the column. The period was never needed: Mg and Ba share the column. ✓



Practice 5

group 5A · period 6
wanted: the element and its class

Which entry correctly describes the element in group 5A, period 6?

- A. Tantalum · metal
- B. Bismuth · metal
- C. Tellurium · metalloid
- D. Bismuth · metalloid

✓ Practice 5 · answer: B

5A = group 15 · period 6 → bismuth, a metal (answer B)

5A: put the 1 back → group 15 · row 6 crosses column 15 at Bi, Z = 83 · left of the staircase in row 6

A read 5A as group 5: period 6, group 5 is tantalum, a transition metal; an A label always marks a main-group column. C swapped the two numbers: period 5, group 6A (16) is tellurium, a metalloid on the staircase. D carried antimony's class one row down: bismuth sits left of the staircase, a metal.

 **Sense check:** Down column 15 the class shifts: N and P are nonmetals, As and Sb metalloids, Bi a metal. The label stays 5A all the way down. ✓

✓ Practice 5: the route on the map

group 5A · period 6

given: group 5A, period 6 · found: Bi, no family name, metal, representative element

group (A label for the main-group columns)

	1A 1																				8A 18
1	H	2A 2																			He
2	Li	Be																			Ne
3	Na	Mg	3	4	5	6	7	8	9	10	11	12	Al	Si	5A 15	6A 16	7A 17				Ar
4	K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br				Kr
5	Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I				Xe
6	Cs	Ba		Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At				Rn
7	Fr	Ra		Rf	Db	Sg	Bh	Hs	Mt	Ds	Rg	Cn	Nh	Fl	Mc	Lv	Ts				Og

Bi · bismuth				found
1	period	period 6		given
2	group	group 5A = 15		given
3	family	alkali metals · 1	alkaline earth · 2	found
		transition · 3-12		
		halogens · 17	noble gases · 18	
		no name · 13-16		
4	class	metal left of the line	metalloid the six on it	found
		nonmetal right of it, + H		

 **Sense check:** 5A became column 15, and row 6 crosses it at bismuth, one row below antimony, the last metalloid in the column. ✓



Check yourself

1. Selenium sits in period 4, group 16. Classify it: metal, nonmetal, or metalloid. Is it a halogen?
2. Radium sits directly below barium. Name its family, predict its class, and state whether its reaction with water should be gentler or more violent than barium's.

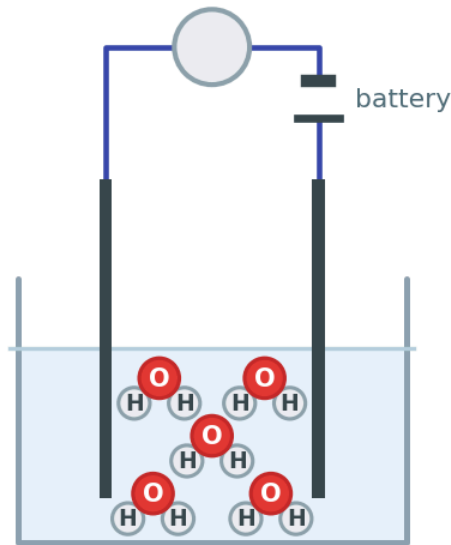
The address also says how many outer electrons an atom holds, and that count decides which atoms give up electrons and which take them when ions form.

7 • Ions

Predict the charge a main-group atom takes when it forms an ion, count the particles in the ion, and write its symbol.

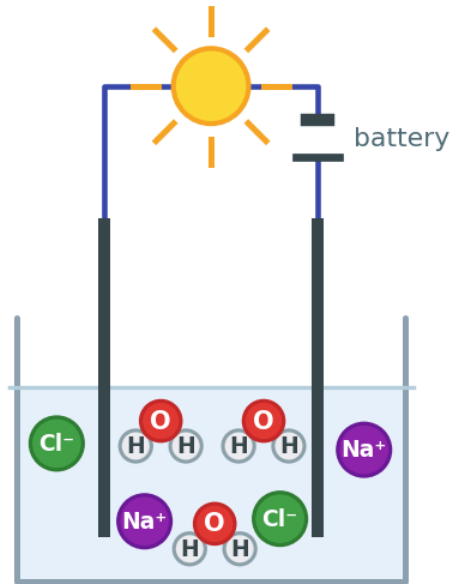
Salt water conducts electricity

pure water: the bulb stays dark



whole molecules: no charge carriers

salt water: the bulb lights



charged particles drift: a current

Pure water barely conducts electricity. Stir in table salt and the same water lights a bulb. Dissolved salt releases charged particles, and moving charges are an electric current.

Protons against electrons

charge = protons – electrons

Ar: $18 \text{ p}^+ \cdot 18 \text{ e}^- \rightarrow 18 - 18 = 0$, a neutral atom

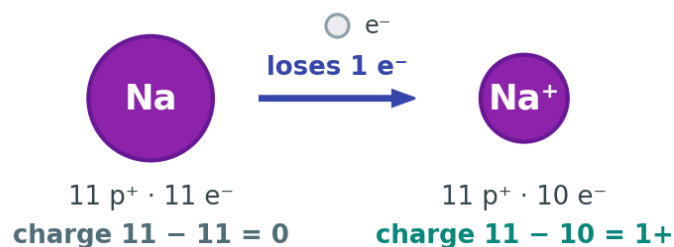
Ca²⁺: $20 \text{ p}^+ \cdot 18 \text{ e}^- \rightarrow 20 - 18 = 2+$

Cl⁻: $17 \text{ p}^+ \cdot 18 \text{ e}^- \rightarrow 17 - 18 = 1-$

Each proton carries one positive charge; each electron carries one negative charge. A neutral atom holds equal numbers. When the counts differ, the particle is an ion, and its charge is the difference.

Ions form by losing or gaining electrons

lose an electron → charge 1+

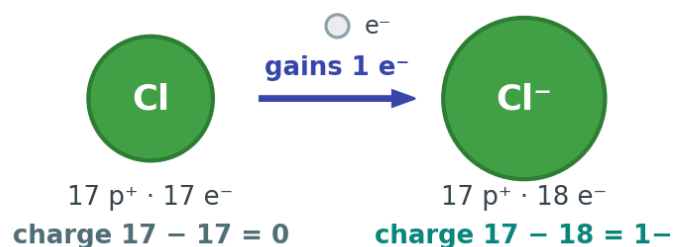


11 p⁺ before, 11 p⁺ after

still sodium ✓

smaller than the atom: the outer shell left

gain an electron → charge 1-



17 p⁺ before, 17 p⁺ after

still chlorine ✓

larger than the atom: one more electron, same pull

A neutral atom holds equal protons and electrons. Losing or gaining **electrons** makes an **ion**: charge = protons – electrons. Protons never change: they name the element. Cations shrink; anions swell.

Cation or anion



cation: $11 \text{ p}^+ \cdot 10 \text{ e}^- \rightarrow \text{charge } 11 - 10 = 1+$ · the t is a plus sign



anion: $17 \text{ p}^+ \cdot 18 \text{ e}^- \rightarrow \text{charge } 17 - 18 = 1-$ · A Negative ION

Losing electrons removes negative charge: a positive ion, a **cation**. Gaining electrons adds negative charge: a negative ion, an **anion**. Metals lose; nonmetals gain.

Predicting the charge

group 1	group 2							group 13	group 14	group 15	group 16	group 17	group 18
1+	2+							3+	none	3-	2-	1-	0
Li⁺	Be²⁺							B	C	N³⁻	O²⁻	F⁻	Ne
Na⁺	Mg²⁺							Al³⁺	Si	P³⁻	S²⁻	Cl⁻	Ar
K⁺	Ca²⁺							Ga³⁺	Ge	As³⁻	Se²⁻	Br⁻	Kr

groups 3-12

no simple ion

already stable

lose 1 · 2 · 3 e⁻ → cation

gain 3 · 2 · 1 e⁻ → anion

destination: the electron count of the nearest noble gas

Noble gases react with almost nothing: their electron counts are stable. Atoms lose or gain to reach the nearest one. Groups 1, 2, 13 lose: 1+, 2+, 3+. Groups 15, 16, 17 gain: 3-, 2-, 1-.

Writing the ion symbol



charge upper-right · number before sign: 2+, never +2

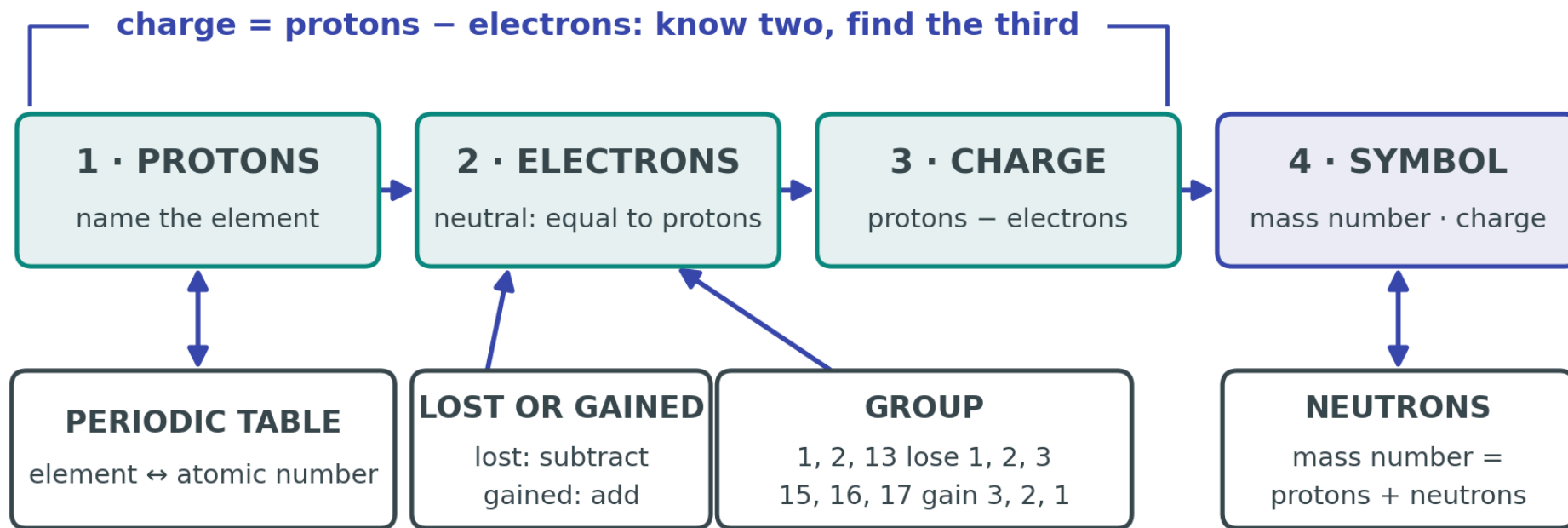
The charge sits at the upper right of the element symbol, number before sign. A charge of one shows the sign alone: Na^+ , Cl^- .



The method

1. **Count the protons.** The atomic number; it never changes.
2. **Count the electrons.** Neutral = protons; subtract lost, add gained.
3. **Compute the charge.** Charge = protons – electrons.
4. **Write the symbol.** Charge upper-right, number before sign.

One map for every ion question



Every ion question runs the same four steps. What the problem gives decides where each count comes from: the periodic table, electrons lost or gained, the group, or a charge already known.



Guided example: the oxide ion



given: the ion symbol · wanted: protons and electrons

Rust and lime are metal oxides: both hold the oxide ion. Count the protons and electrons in one O^{2-} ion.

✓ Guided example: solution



given: the ion symbol · wanted: protons and electrons

Step 1 · Count the protons

Step 2 · Count the electrons

Step 3 · Compute the charge

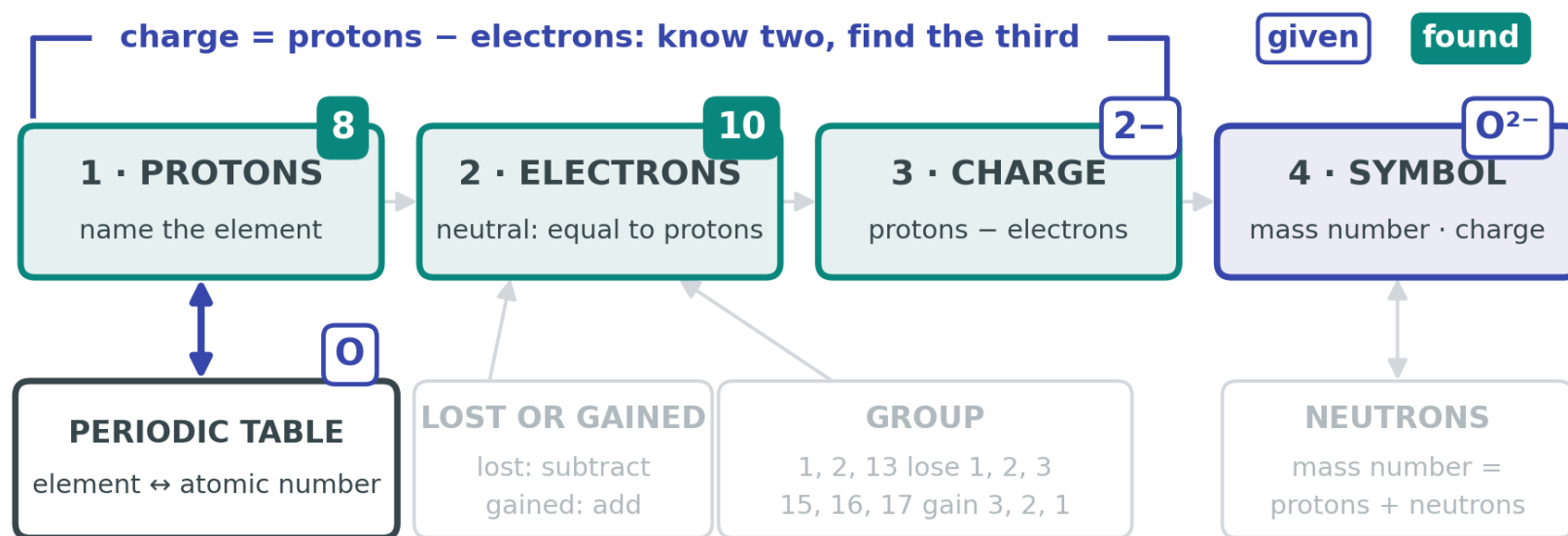
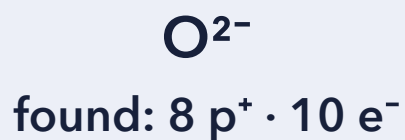
Step 4 · Write the symbol



$8 \text{ p}^+ \cdot 10 \text{ e}^- \rightarrow \text{charge } 8 - 10 = 2^- \cdot \text{matches the symbol}$

🧠 **Sense check:** Two electrons beyond the protons: 2^- . Oxygen sits in group 16, two short of neon's 10 electrons. ✓

✓ Guided example: the route on the map



Sense check: The symbol gave the element and the charge. The table gave the protons; the charge link gave the electrons. ✓



Practice 1



one aluminum ion

How many electrons does this ion hold?

- A. 10
- B. 13
- C. 14
- D. 16
- E. 24

✓ Practice 1 · answer: A

$$^{27}\text{Al}^{3+}: 13 - 3 = 10 \text{ e}^{-} \text{ (answer A)}$$

$$13 \text{ p}^{+} \cdot 10 \text{ e}^{-} \rightarrow \text{charge } 13 - 10 = 3+$$

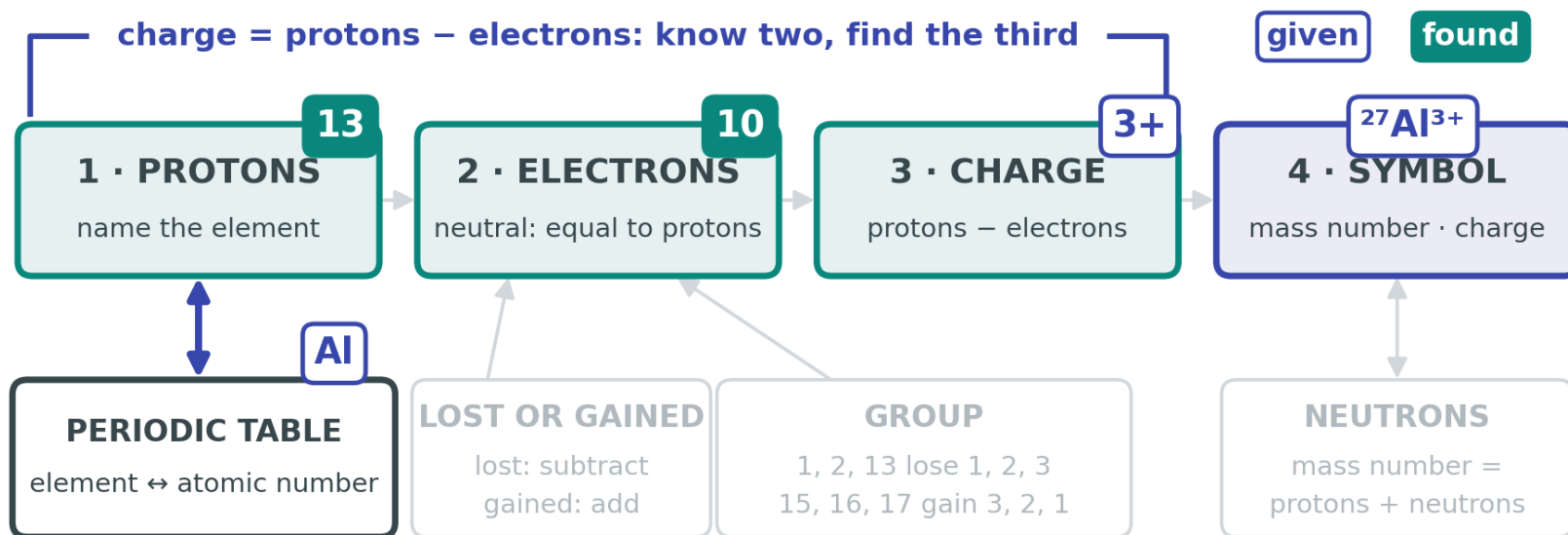
B ignored the charge: 13 electrons is the neutral atom. C counted neutrons: $27 - 13 = 14$. D added electrons for a positive charge: $13 + 3 = 16$ computes $13 - 16 = 3-$. E took the charge off the mass number: $27 - 3 = 24$.

🧠 **Sense check:** Aluminum sits in group 13: it loses three electrons and keeps neon's 10. ✓

✓ Practice 1: the route on the map



found: 13 p⁺ · 10 e⁻



Sense check: A positive charge means electrons were lost: subtract. The mass number never enters an electron count. ✓



Worked example 1: magnesium

^{24}Mg loses $2\text{ e}^- \rightarrow ?$

neutral atom: $12\text{ p}^+ \cdot 12\text{ n}^0 \cdot 12\text{ e}^-$ · wanted: particle counts and symbol

A magnesium atom loses two electrons. Count each particle in the ion and write its symbol.

✓ Worked example 1: solution

^{24}Mg loses $2\text{ e}^- \rightarrow ?$
 neutral atom: $12\text{ p}^+ \cdot 12\text{ n}^0 \cdot 12\text{ e}^-$

Step 1 • Count the protons

Step 2 • Count the electrons

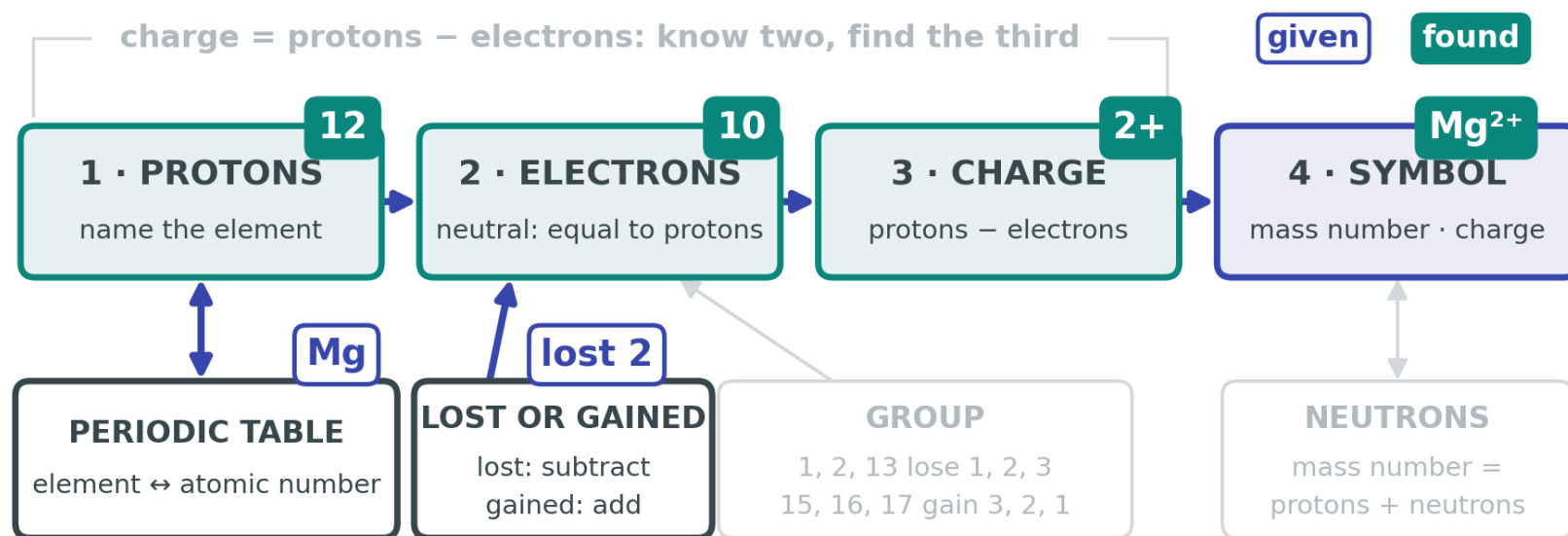
Step 3 • Compute the charge

Step 4 • Write the symbol

Mg^{2+}
 $12\text{ p}^+ \cdot 12\text{ n}^0 \cdot 10\text{ e}^- \rightarrow \text{charge } 12 - 10 = 2+$

 **Sense check:** Twelve positive protons against ten negative electrons: two positives are unmatched, so the ion carries 2+. ✓

✓ Worked example 1: the route on the map



Sense check: All four steps ran in order. The problem said how many electrons left, so the lost-or-gained card set the electron count. ✓



Worked example 2: sulfur



neutral atom: 16 p⁺ · 16 n⁰ · 16 e⁻ · group 16 · wanted: charge, counts, symbol

Sulfur forms an ion. Predict how many electrons move, count the particles, and write the symbol.

A common first attempt: an ion that gains electrons gains particles, so its charge comes out positive. Test it.

✓ Worked example 2: solution



neutral atom: $16 \text{ p}^+ \cdot 16 \text{ n}^0 \cdot 16 \text{ e}^- \cdot \text{group } 16$

A common first attempt

S gains $2 \text{ e}^- \rightarrow \text{S}^{2+}?$

$16 \text{ p}^+ \cdot 18 \text{ e}^- \rightarrow \text{charge } 16 - 18 = 2-, \text{ not } 2+ \times$

Step 1 · Count the protons

Step 2 · Count the electrons

Step 3 · Compute the charge

Step 4 · Write the symbol



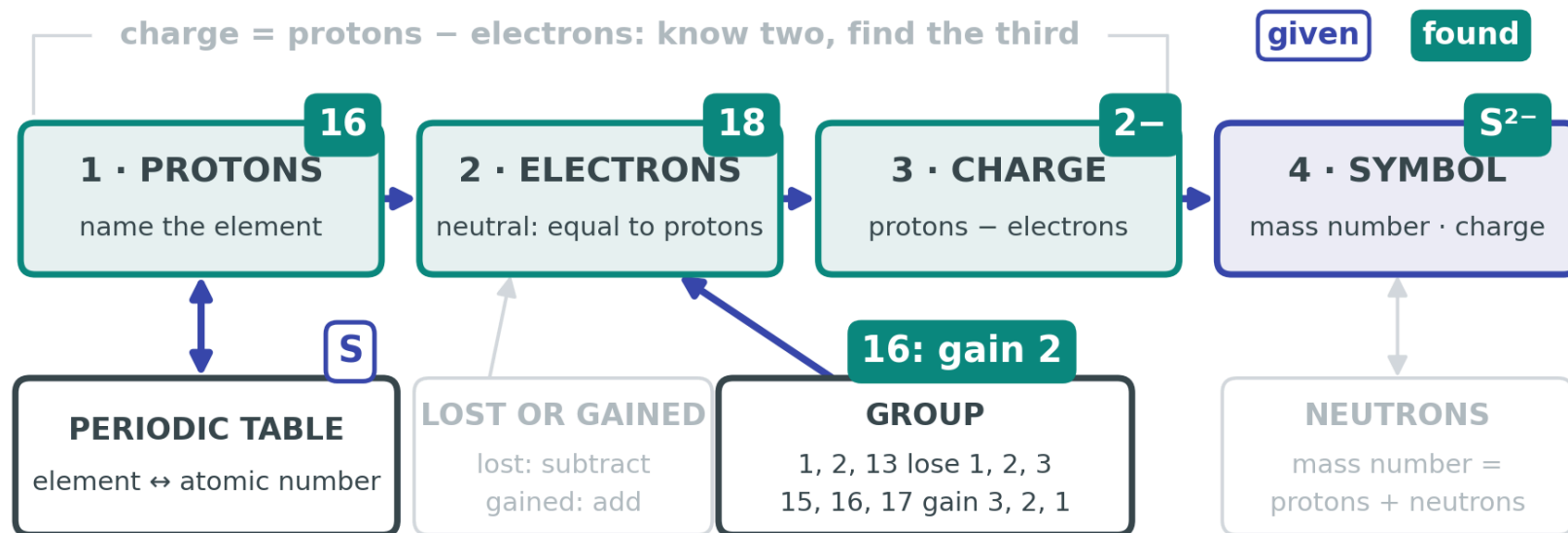
$16 \text{ p}^+ \cdot 16 \text{ n}^0 \cdot 18 \text{ e}^- \rightarrow \text{charge } 16 - 18 = 2-$

 **Sense check:** Two electrons beyond the protons, each carrying one negative charge: $2-$. Gained electrons always land the charge negative. ✓

✓ Worked example 2: the route on the map



found: group 16 gains 2 · 16 p⁺ · 18 e⁻ · charge 2-



🧠 **Sense check:** Nothing said how many electrons move. The group decided it: two short of argon, so gain two. ✓

Your turn: potassium



neutral atom: 19 p⁺ · 20 n⁰ · 19 e⁻ · group 1

step	count
1 · protons	19, unchanged
2 · electrons	argon holds 18, so one electron leaves: 19 – 1 = <u> </u>
3 · charge	19 – 18 = <u> </u>
4 · symbol	<u> </u>

Complete the counts and write the symbol.



19 p⁺ · 20 n⁰ · 18 e⁻ → charge 19 – 18 = 1+

⚠ Where this goes wrong

Reading "lost" as negative. Mg loses 2 e⁻, leaving 12 p⁺ and 10 e⁻: charge $12 - 10 = 2+$. The particles lost were the negative ones. Losing electrons always leaves a positive ion.

Charging the nucleus. A 2+ charge never comes from added protons: 12 protons is magnesium, 14 is silicon. Ion formation moves electrons only.

Naming the element from the electrons. Na⁺, Mg²⁺, and O²⁻ each hold 10 electrons, and none is neon. Protons identify the element.

Counting electrons into the mass number. Only nucleus particles count: ²⁴Mg²⁺ keeps mass number $12 + 12 = 24$, with 12 electrons or with 10.



Practice 2



neutral atom: 56 p⁺ · 56 e⁻ · group 2

A neutral barium atom becomes a Ba²⁺ ion. Which statement describes what happens?

- A. The atom loses two electrons; with more protons than electrons left, it carries the 2+ charge
- B. The nucleus gains two protons, which makes the atom 2+
- C. The atom gains two electrons; the extra particles give it the 2+ charge
- D. The atom loses two protons from its nucleus, leaving a 2+ charge

✓ Practice 2 · answer: A



$$56 \text{ p}^{+} \cdot 54 \text{ e}^{-} \rightarrow \text{charge } 56 - 54 = 2+$$

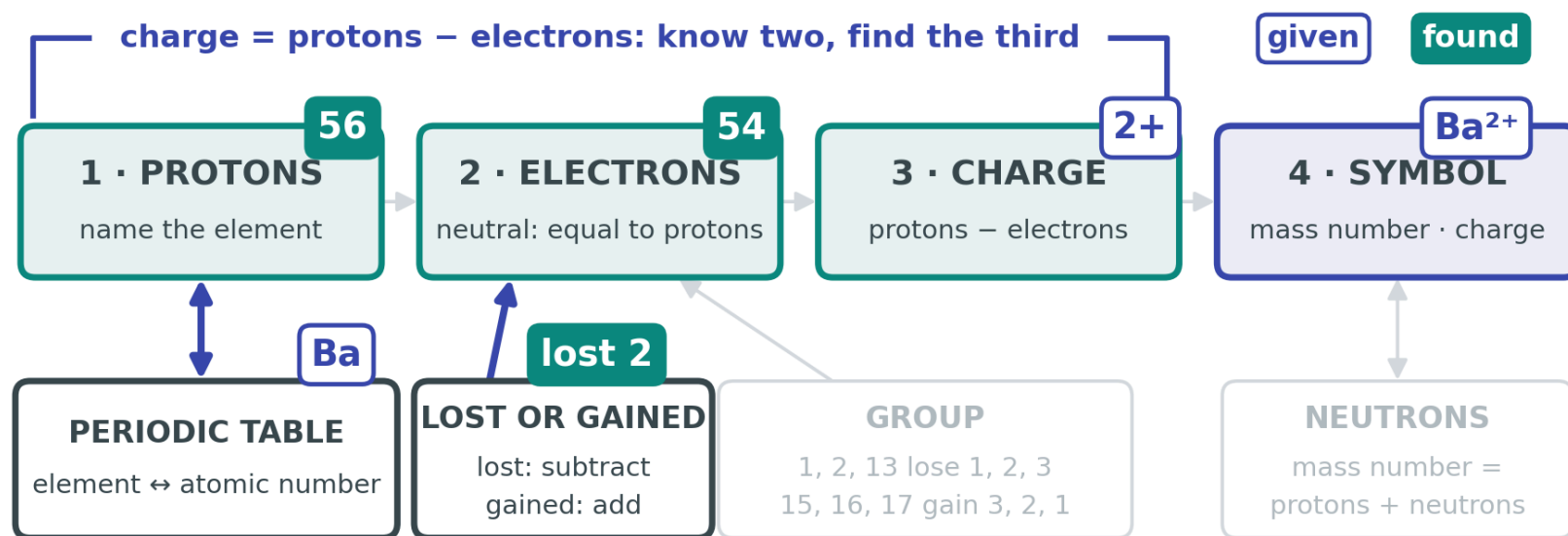
B: 58 protons is no longer barium; protons never change in chemistry. C: gaining two electrons computes $56 - 58 = 2-$, an anion. D: losing two protons changes the element too, and 54 p^{+} against 56 e^{-} computes $54 - 56 = 2-$.

 **Sense check:** Barium sits in group 2: it loses two electrons, and 54 electrons is xenon's count, the nearest noble gas. ✓

✓ Practice 2: the route on the map



found: 56 p⁺ · 54 e⁻ · two electrons lost



Sense check: The charge link turned 2+ into an electron count: 56 – 2 = 54. Two fewer than the neutral atom means two lost. ✓



Practice 3

N → ?

neutral atom: 7 p⁺ · 7 e⁻

Predict nitrogen's ion. Which choice gives its charge and electron count?

- A. N³⁺ with 4 electrons
- B. N⁵⁺ with 2 electrons
- C. N⁻ with 8 electrons
- D. N³⁻ with 4 electrons
- E. N³⁻ with 10 electrons

✓ Practice 3 · answer: E



group 15: gains $3 \cdot 7 + 3 = 10 \text{e}^-$ · charge $7 - 10 = 3-$

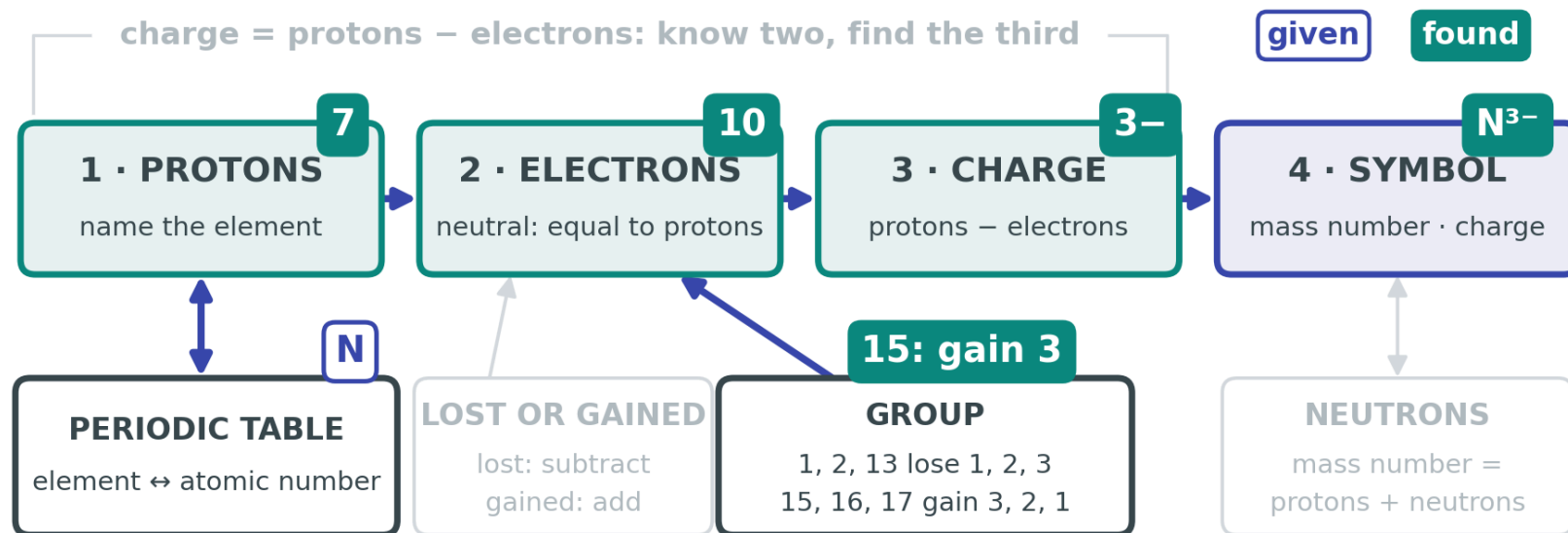
A gave nitrogen a metal's move: losing three leaves $7 - 3 = 4 \text{e}^-$ and a $3+$ charge. B lost all five outer electrons, $7 - 5 = 2$: the long way to a noble-gas count. C used group 17's charge: $7 + 1 = 8 \text{e}^-$, two short of neon. D kept the $3-$ label but subtracted: $7 - 3 = 4 \text{e}^-$ computes $7 - 4 = 3+$.

 **Sense check:** Ten electrons is neon's count, the nearest noble gas. Nonmetals gain electrons, so the charge lands negative. ✓

✓ Practice 3: the route on the map



found: group 15 gains 3 · 7 p⁺ · 10 e⁻ · charge 3-



🧠 **Sense check:** No electron count was given. The group set it: three short of neon, so gain three. ✓



Worked example 3: identifying an unknown ion

?: 34 p⁺ · 46 n⁰ · 36 e⁻

given: the particle counts · wanted: element, mass number, charge, full symbol

A particle holds 34 protons, 46 neutrons, and 36 electrons. Identify it and write its full symbol.

✓ Worked example 3: solution

?: $34 \text{ p}^+ \cdot 46 \text{ n}^0 \cdot 36 \text{ e}^-$

given: the particle counts · wanted: element, mass number, charge, full symbol

Step 1 · Count the protons

Step 2 · Count the electrons

Step 3 · Compute the charge

The mass number

Step 4 · Write the symbol

$^{80}\text{Se}^{2-}$

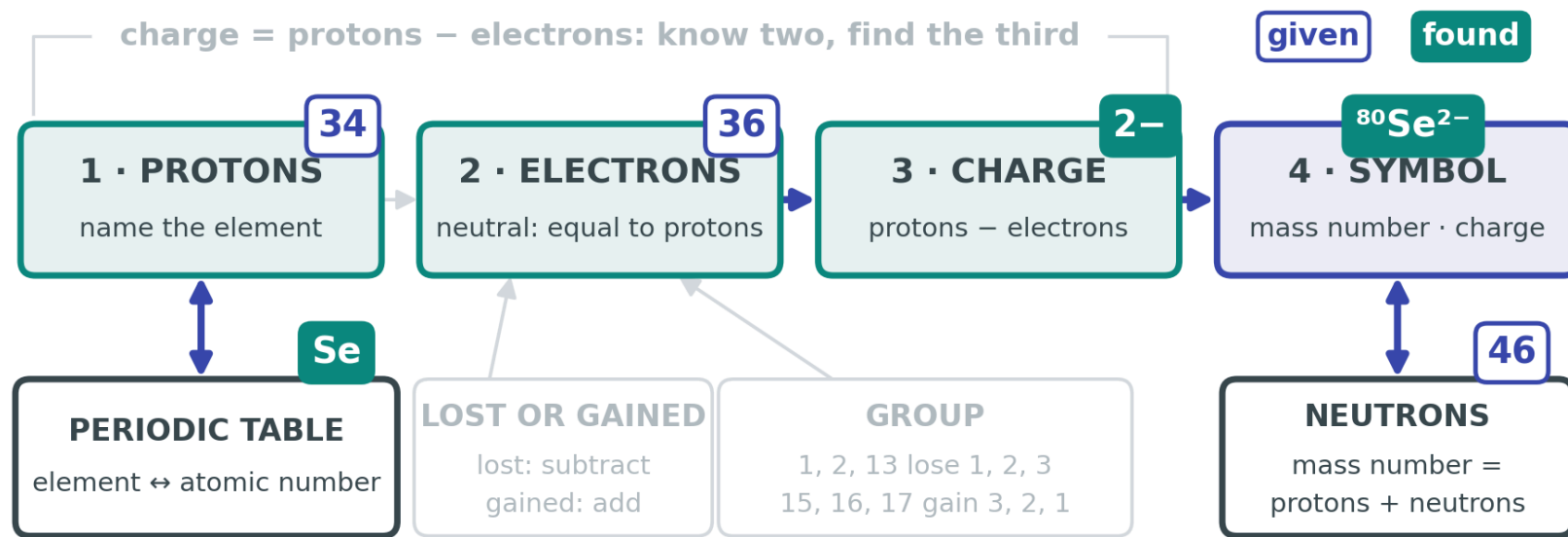
$34 \text{ p}^+ \cdot 46 \text{ n}^0 \cdot 36 \text{ e}^- \cdot \text{mass number } 34 + 46 = 80 \cdot \text{charge } 34 - 36 = 2-$

 **Sense check:** Selenium sits in group 16, two electrons short of krypton, and a 2– anion is exactly what the periodic table predicts. ✓

✓ Worked example 3: the route on the map



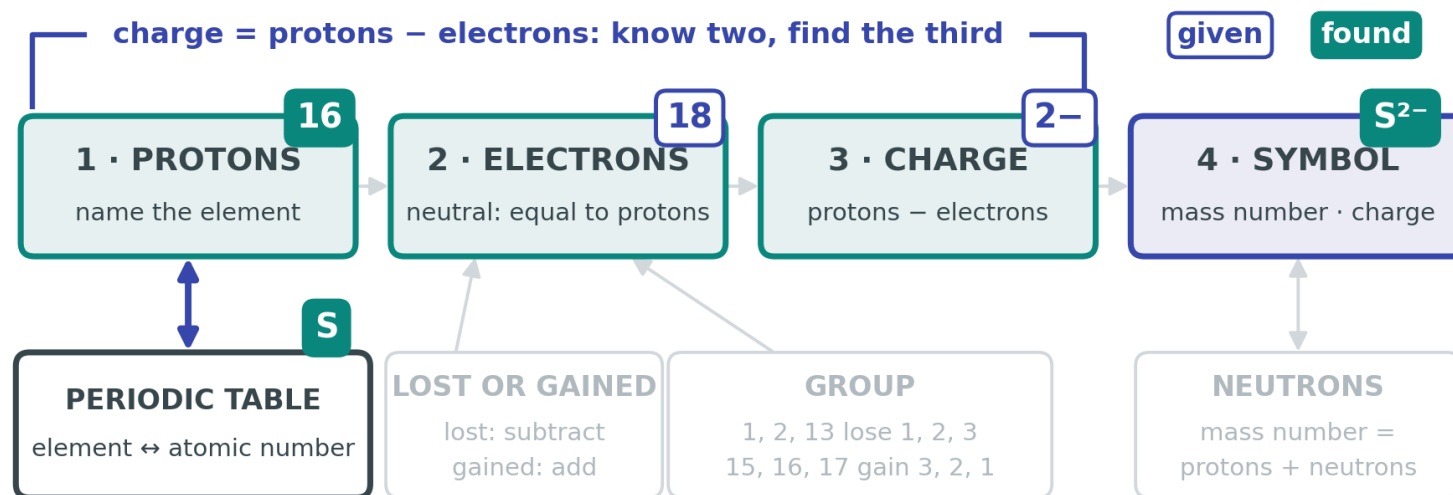
found: selenium · charge $34 - 36 = 2-$ · mass number $34 + 46 = 80$



Sense check: The counts came given. The table read 34 protons as selenium; the neutrons fed only the mass number. ✓

Reading the charge backward

2- ion with 18 e⁻ → protons = 18 - 2 = 16 → S²⁻
a 2- ion holds two more electrons than protons · 16 protons: sulfur



The charge link joins three counts. Given the electrons and the charge, the protons follow, and the protons name the element.



Practice 4

	decoded symbol
1	$^{40}\text{Ca}^{2+}$ has mass number 38, since it lost two electrons
2	$^{31}\text{P}^{3-}$ holds $15\text{ p}^+ \cdot 16\text{ n}^0 \cdot 18\text{ e}^-$
3	$^{85}\text{Rb}^+$ holds $37\text{ p}^+ \cdot 48\text{ n}^0 \cdot 36\text{ e}^-$

Three ion symbols, three decodings. Which statements are correct?

- A. Statements 1, 2 and 3
- B. Statement 3 only
- C. Statement 2 only
- D. Statements 2 and 3 only

✓ Practice 4 · answer: D

correct: 2 and 3 · false: 1 (answer D)

$^{31}\text{P}^{3-}$: $31 - 15 = 16$ n^0 · $15 + 3 = 18$ e^- · $^{85}\text{Rb}^+$: $85 - 37 = 48$ n^0 · $37 - 1 = 36$ e^- · $^{40}\text{Ca}^{2+}$ keeps $A = 40$

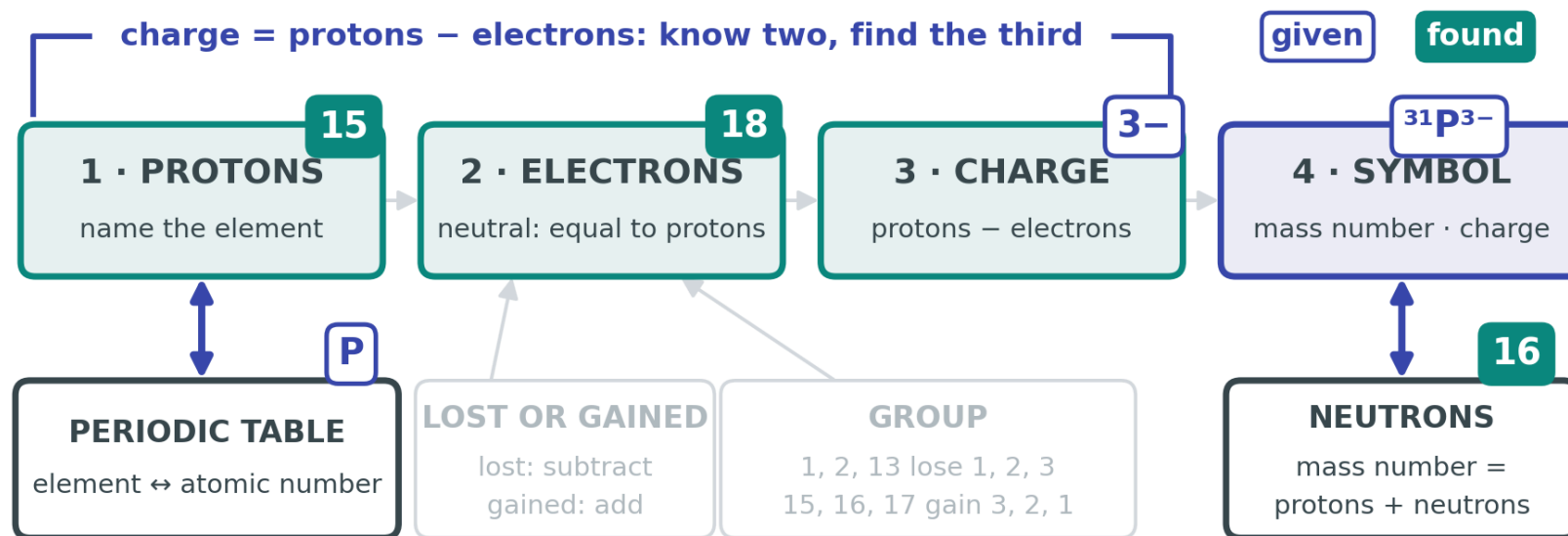
A accepted statement 1: electrons never enter the mass number, so $^{40}\text{Ca}^{2+}$ keeps $A = 20 + 20 = 40$, not $40 - 2 = 38$. B read $3-$ as three electrons lost, $15 - 3 = 12$, and rejected statement 2; a negative ion gained them. C found neutrons by subtracting electrons, $85 - 36 = 49$, and rejected statement 3; neutrons = $A - \text{protons} = 48$.

🧠 **Sense check:** A charge moves electrons only. Protons, neutrons, and the mass number stay put. ✓

✓ Practice 4: the route on the map



$$\text{found: } 15 \text{ p}^+ \cdot 31 - 15 = 16 \text{ n}^0 \cdot 15 + 3 = 18 \text{ e}^-$$



Sense check: Decoding runs from the symbol: protons from the table, neutrons from the mass number, electrons from the charge. ⁸⁵Rb⁺ and ⁴⁰Ca²⁺ take the same path. ✓



Practice 5

one monatomic ion

charge $2-$ · 54 e^- · 76 n^0

Which identification of this ion is correct?

- A. xenon, mass number 130
- B. barium, mass number 132
- C. tellurium, mass number 128
- D. tellurium, mass number 130
- E. tellurium, mass number 182

✓ Practice 5 · answer: C

tellurium, mass number 128: $^{128}\text{Te}^{2-}$ (answer C)

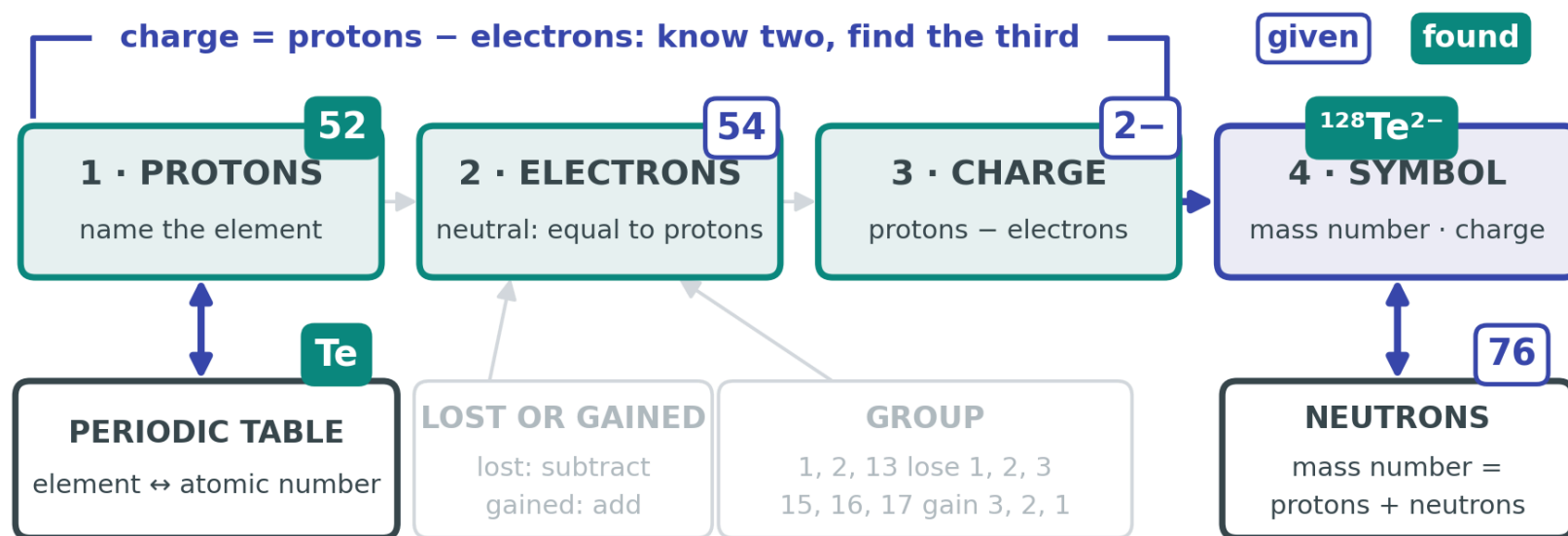
protons $54 - 2 = 52$: tellurium · mass number $52 + 76 = 128$ · check $52 - 54 = 2-$

A named the element from the electrons: 54 is xenon's count, and $54 + 76 = 130$. B ran the charge backward: $54 + 2 = 56$ protons is barium, and $56 - 54$ computes $2+$. D added the two gained electrons to the mass number: $52 + 76 + 2 = 130$. E added all 54: $52 + 76 + 54 = 182$.

 **Sense check:** Tellurium sits in group 16 under selenium. A $2-$ ion holding xenon's 54 electrons is what the group predicts. ✓

✓ Practice 5: the route on the map

charge $2-$ · 54 e^- · 76 $n^0 \rightarrow {}^{128}\text{Te}^{2-}$
 found: 52 p^+ · tellurium · mass number 128



Sense check: The charge link ran backward to the protons. The table named tellurium; the neutrons set the mass number. ✓

Check yourself

1. Strontium (38 protons) sits in group 2. How many electrons does its ion hold, what is the charge, and what is the symbol?
2. A particle holds 30 protons, 34 neutrons, and 28 electrons. Which element is it, and what is its full symbol?

Cations and anions attract into **ionic compounds**, and the charges must cancel: Na^+ pairs one-to-one with Cl^- , while Ca^{2+} takes two F^- . These predicted charges fix the formula and the name of every ionic compound.

Can you...?

- ☐ locate protons, neutrons, and electrons in the atom and state what each count determines?
- ☐ read and write isotope symbols, converting between mass number, atomic number, and particle counts?
- ☐ calculate the average atomic mass of an element from isotope masses and abundances?
- ☐ give an element's period, group, family, and metal/nonmetal/metalloid class?
- ☐ predict the charge an atom takes when it forms an ion, and count the particles in that ion?

If any box stays empty, the practice site has a drill for it. 