

Mass, Volume and the Straight Line: Identifying Three Metals from Data

Learning target: I can calculate density from mass and volume data, graph mass against volume, and use the pattern plus a reference table to identify unknown metals.

Data and graphing

About 45 min

Individual

MS-PS1-2 · practice

data analysis

independent practice

Standards connections

MS-PS1-2 (practice): Analyzing density and melting-point data to identify substances is the data-interpretation skill the PE requires, applied here before any interaction between substances. The assessment boundary's properties (density, melting point) are the only ones used.

Purpose: practice · **Time:** about 45 minutes · **Format:** individual

Answers with reasoning

Part A: Three unknown metals, twelve pieces

Mass and volume of twelve metal pieces (teaching dataset)

Simulated teaching dataset: the numbers are invented to be realistic, not measured.

Piece	Mass (g)	Volume (cm ³)
A1	10.8	4.0
A2	20.3	7.5
A3	32.3	12.0
A4	41.9	15.5
B1	26.9	3.0
B2	58.1	6.5
B3	89.7	10.0
B4	125.6	14.0
C1	35.6	5.0
C2	57.2	8.0
C3	78.5	11.0
C4	114.1	16.0

Simulated data for teaching. Each metal was cut into four pieces of different sizes before measuring.

Reference table (real rounded values at normal air pressure)

Metal	Density (g/cm ³)	Melting point (°C)
Aluminum	2.7	660
Zinc	7.14	420
Tin	7.29	232
Iron	7.87	1538
Copper	8.96	1085
Silver	10.5	962
Lead	11.3	327

1. Calculate the density of every piece (mass ÷ volume). Write one full calculation below the table.

Answer: A1: $10.8 \div 4.0 = 2.70$. A2: $20.3 \div 7.5 = 2.71$. A3: $32.3 \div 12.0 = 2.69$. A4: $41.9 \div 15.5 = 2.70$. B1: $26.9 \div 3.0 = 8.97$. B2: $58.1 \div 6.5 = 8.94$. B3: $89.7 \div 10.0 = 8.97$. B4: $125.6 \div 14.0 = 8.97$. C1: $35.6 \div 5.0 = 7.12$. C2: $57.2 \div 8.0 = 7.15$. C3: $78.5 \div 11.0 = 7.14$. C4: $114.1 \div 16.0 = 7.13$. All in g/cm³.

Why: Each value is mass divided by volume, rounded to two decimals. The four values for each metal agree within about 0.03 g/cm³, which is the point: different-sized pieces of one substance share one density.

Also acceptable: Accept values that differ in the second decimal by rounding (for example 2.71 for A3 if the student rounded 2.692 up by mistake, note it).

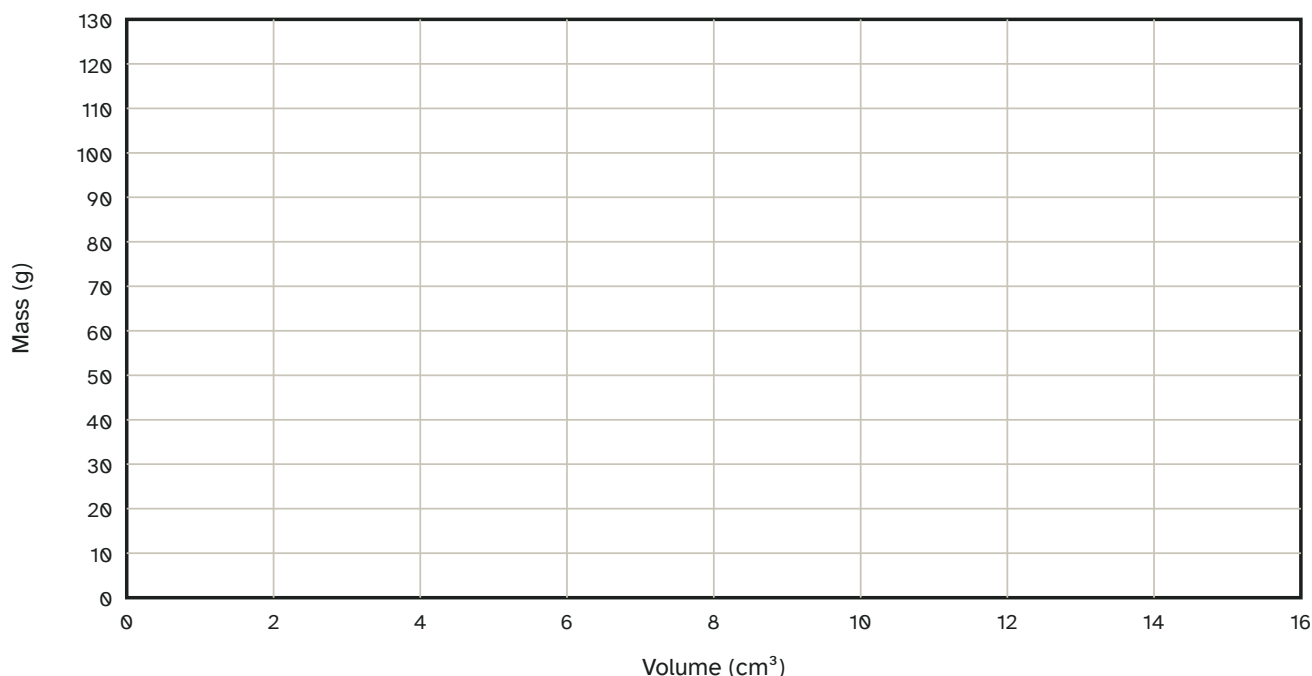
2. Find the average density of metal A, metal B and metal C (add the four values and divide by 4). Show the work for one metal.

Answer: Metal A: $(2.70 + 2.71 + 2.69 + 2.70) \div 4 = 10.80 \div 4 = 2.70$ g/cm³. Metal B: $(8.97 + 8.94 + 8.97 + 8.97) \div 4 = 35.85 \div 4 = 8.96$ g/cm³. Metal C: $(7.12 + 7.15 + 7.14 + 7.13) \div 4 = 28.54 \div 4 = 7.14$ g/cm³ (7.135, rounds to 7.14).

Why: Averaging reduces the effect of the small measurement scatter.

Also acceptable: Accept 7.13 for C if the student kept more decimals ($28.537 \div 4 = 7.134$).

Mass versus volume for the three metals



3. Describe the three lines on your graph. Which is steepest? What does the steepness of a line tell you about the metal, and why do all three lines pass through (0, 0)?

Answer: All three are straight lines rising to the right through the origin. Line B (copper) is steepest, then C, then A, which is the flattest. The steepness is the mass gained per cubic centimeter, which is the density: a steeper line means a denser metal. All three pass through (0, 0) because a piece with no volume has no mass.

Why: Slope of mass versus volume equals density. The origin point is a check on the model.

Also acceptable: Accept 'the slope is the density' in any wording.

- Straight lines through the origin
- B steepest, A flattest
- Steepness interpreted as density
- Explains the origin

4. Use your averages from q2 and the reference table to identify metals A, B and C. For each, state the reference value you matched and how far off your average is.

Answer: A = aluminum (reference 2.70; average 2.70, difference 0.00). B = copper (reference 8.96; average 8.96, difference 0.00). C = zinc (reference 7.14; average 7.14, difference 0.00; tin at 7.29 is 0.15 away and iron at 7.87 is 0.73 away, so zinc is the closest match).

Why: Students must state the matched value and the difference. The C identification should mention that tin is close but zinc is closer.

Also acceptable: A student who writes 'C is zinc or tin' should be asked which is closer; accept with the 0.15 comparison.

- All three identified correctly
- Reference values and differences stated

5. Predict the mass of a 20.0 cm^3 piece of metal B. Show the calculation, then explain how you could check the prediction on your graph if the axes were extended.

Answer: Mass = density $\times$ volume = $8.96 \text{ g/cm}^3 \times 20.0 \text{ cm}^3 = 179.2 \text{ g}$, about 179 g. On the graph, extend line B to the right until it reaches 20 cm^3 on the volume axis and read the mass where the line crosses; it should be near 179 g.

Why: Rearranging the density formula and extending a line are both ways to use the pattern.

Also acceptable: Accept 179 g or 180 g; accept 'go up from 20 on the x-axis to the line, then across to the y-axis.'

6. Piece A4 (41.9 g) has more mass than piece C1 (35.6 g), yet metal A is much less dense than metal C. Explain how both facts can be true at the same time.

Answer: Mass depends on how much of the metal there is; density does not. A4 is a big piece (15.5 cm^3) and C1 is a small piece (5.0 cm^3). A4 has more total matter, so more mass, but each cubic centimeter of A has only 2.70 g while each cubic centimeter of C has 7.14 g. Comparing equal volumes, C always has more mass.

Why: This separates the object property (mass) from the substance property (density).

Also acceptable: Accept 'A4 is three times bigger, so even though it is less dense it ends up with more mass.'

- Says mass depends on amount
- Says density is per cubic centimeter
- Uses the volumes of A4 and C1 as evidence

Part B: A fourth sample and a second property

A single small gray piece, sample D, was measured next: mass 29.2 g, volume 4.0 cm^3 . The student then heated a chip of D in a test tube with a thermometer in the tube while the teacher supervised. The chip stayed solid at 150°C and at 200°C , began to melt at about 230°C , and was completely liquid by 240°C .

7. Calculate the density of sample D. List every metal in the reference table within 0.3 g/cm^3 of your result.

Answer: Density = $29.2 \text{ g} \div 4.0 \text{ cm}^3 = 7.30 \text{ g/cm}^3$. Within 0.3 g/cm^3 : zinc (7.14, difference 0.16) and tin (7.29, difference 0.01). Iron (7.87) is 0.57 away, outside the window.

Why: Two candidates survive, which is why Part B needs a second property.

Also acceptable: None.

8. The graduated cylinder reads only to the nearest 0.5 mL, so D's true volume could be anywhere from 3.5 to 4.5 cm^3 . Calculate the lowest and highest density that would give. Which reference metals fall inside that range?

Answer: Highest density: $29.2 \text{ g} \div 3.5 \text{ cm}^3 = 8.34 \text{ g/cm}^3$. Lowest density: $29.2 \text{ g} \div 4.5 \text{ cm}^3 = 6.49 \text{ g/cm}^3$. Inside the range 6.49 to 8.34: zinc (7.14), tin (7.29) and iron (7.87).

Why: A small sample makes the volume error a large fraction of the volume, so the density range is wide and even iron cannot be excluded.

Also acceptable: Accept 8.3 and 6.5 g/cm^3 .

9. Identify sample D. Explain why the density measurement alone could not settle it, what the melting-point result adds, and why the melting-point test would have given the same answer for a chip twice as large.

Answer: Sample D is tin. Density alone could not settle it: the best estimate (7.30) sits almost on tin (7.29) but close to zinc (7.14), and the cylinder's 0.5 mL uncertainty widens the possible range to 6.5 to 8.3 g/cm³, which also includes iron. The melting point adds a second, independent identifying property: the chip melted at about 230 °C, matching tin (232 °C) and ruling out zinc (420 °C) and iron (1538 °C), which would both still be solid at 240 °C. A chip twice as large would have melted at the same temperature, only more slowly, because melting point belongs to the substance, not to the amount.

Why: Full credit needs the identification, the reason density was not enough (closeness plus measurement uncertainty), the melting point as the deciding evidence with numbers, and the size-independence of melting point.

Also acceptable: A student who identifies tin from density alone and then uses the melting point only as confirmation has the right answer but should still address the uncertainty.

- Identifies tin
- Explains why density alone was insufficient, using the uncertainty from q8
- Uses the melting point with reference values to rule out zinc and iron
- States that melting point does not depend on sample size

Teacher notes

The dataset is simulated with realistic scatter around real densities: aluminum 2.70, copper 8.96, zinc 7.14 g/cm³. Reference values (real, rounded): tin 7.29 g/cm³ and 232 °C; iron 7.87 and 1538 °C; silver 10.5 and 962 °C; lead 11.3 and 327 °C. Sample D is tin; the Part B heating description is a scenario, not a procedure for students, since 230 °C requires teacher-handled equipment. The most common error in q1 is dividing volume by mass; the scaffold's 'bigger than 1' check catches it. In q8 some students will subtract 0.5 from the density instead of from the volume; insist on recomputing. The extension works out to a volume of at least 5 mL ($0.5 \div 5 = 10$ percent), which for aluminum is a piece of about 13.5 g, well within the balance's range; the lesson is that an identifying property still needs a sample big enough to measure well.

Scaffold offered to students: Keep the division straight

Density is always mass divided by volume, never the other way around. A quick check: for every piece in this dataset the mass number is bigger than the volume number, so every density must come out bigger than 1. If you get a density smaller than 1 for a metal, you divided in the wrong order. Write each calculation as 'mass $\div$ volume = density' with units: $10.8 \text{ g} \div 4.0 \text{ cm}^3 = 2.70 \text{ g/cm}^3$.

Extension: How small a piece can the balance handle?

The classroom balance reads to 0.1 g and the cylinder to 0.5 mL. For metal A (density about 2.7 g/cm³), find the smallest piece whose density you could measure to within 10 percent of the true value. Start by asking how large the volume must be so that a 0.5 mL error is less than 10 percent, then check whether the mass of that piece is large enough for the balance. Explain why a tiny flake gives a bad density even though density is an identifying property.