

Four Clear Liquids, No Labels

Investigation question: Four clear, colorless liquids arrive in bottles marked only A, B, C and D. Which measurements can name each one, and when is one measurement not enough?

Evidence-based mystery

Groups of 3

1 session

Setup 5 · Activity 38 · Cleanup 7 min

MS-PS1-2 · practice

Scientific purpose

Students identify four unknown liquids (water, saturated salt water, 70% isopropyl alcohol and vegetable oil) by measuring density, testing whether each mixes with water, and watching what a drop leaves behind on paper, then matching their results against a reference table that includes two distractors. The lab makes the lesson's central claim concrete: one property narrows the list, and a second independent property is needed before a name can be trusted.

Why this helps students with this chapter

Students have heard that density identifies a substance but have never had it fail them. Here the alcohol and the oil come out within 0.05 g/mL of each other and the reference table holds a near-twin for each, so density alone cannot name them. The mixing test settles it in seconds, which is a far more convincing argument for 'use several tests' than any sentence in a book. The lab also returns to the layered jar from the phenomenon with numbers attached.

Standards connections

MS-PS1-2 (practice, analyzing and interpreting property data (density and solubility) to identify substances): Students collect density and solubility data and interpret it against a reference table, which is the data-analysis practice the PE calls for using two of the properties named in its assessment boundary. No chemical reaction occurs, so the before-and-after half of the PE is left for Lesson 12.

Roles (rotate each session)

- **Measurer:** Pours exactly 20.0 mL into the graduated cylinder, reads the bottom of the curved surface at eye level, and transfers the liquid to the tared cup on the balance.
- **Tester:** Runs the mixing test (5 mL unknown plus 5 mL water in a capped vial, swirl, wait one minute) and the drop test on the paper towel, and calls out what is seen.
- **Recorder and checker:** Writes every mass and observation on the sheet as it is read, computes each density, flags any value that does not match a partner's expectation, and leads the matching against the reference table.

Materials

Item	Quantity	Per	Note
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Unknown liquids A-D in capped, labeled bottles or cups, about 60 mL each	1 set	group	Water, saturated salt water, 70% isopropyl alcohol and vegetable oil; assign letters at random per class and keep the key.
Graduated cylinder, 25 mL or 50 mL	1	group	
Digital balance reading to 0.1 g	1	group	Two groups can share one balance if cups are tared each time.
Small plastic cups (3 oz)	5	group	One per liquid plus a spare; label them A-D with a marker.
Clear vials or small test tubes with caps, about 15 mL	4	group	Small clear zip bags work in a pinch for the mixing test.
Tap water in a squeeze bottle for the mixing test	1	group	
Plastic droppers or pipettes	4	group	
Paper towels and a permanent marker	2 sheets	group	
Safety goggles	1 pair	student	
Reference table and recording sheet	1	student	
Vegetable oil, 1 L	1 bottle	class	
Isopropyl alcohol, 70%, 1 pint	1 bottle	class	
Table salt, 1 box	1	class	For the saturated salt water.

Estimated cost: 8 to 12 per class (an estimate; Vegetable oil about \$4, 70% isopropyl alcohol about \$2, salt about \$1, a sleeve of 3 oz cups about \$3; cylinders, balances, droppers and vials are standard lab stock.)

Safety

- 70% isopropyl alcohol is flammable: no flames, hot plates or heat sources anywhere in the room during this lab. Keep bottles capped when not pouring and keep volumes small.
- Wear goggles throughout. Alcohol stings badly in the eyes; if it splashes, rinse at the eyewash for 15 minutes and tell the teacher.
- Never taste or sniff an unknown. Identification is by measurement only; wafting is not used in this lab.
- Oil and alcohol spills make floors slippery. Wipe spills at once with paper towels and tell the teacher about anything on the floor.
- Alcohol vapor can irritate; keep the room ventilated and cap the alcohol bottle between uses.
- Wash hands at the end. Dispose of small volumes of alcohol and salt water down the sink with plenty of water; collect the oil in the waste cup provided, not the sink.

Teacher preparation and setup

1. Make the saturated salt water the day before: stir about 360 g of table salt into 1 L of warm tap water until no more dissolves, let it cool to room temperature, and pour off the clear liquid, leaving undissolved salt behind. Its density should be about 1.20 g/mL; check it on the balance.
2. Fill one set of four bottles per group, assign the letters A-D at random for each class period, and record the key. Do not let the letters match the order on the reference table.
3. Check that each balance reads 0.1 g and that the cups can be tared; a cup that reads 2.3 g should return to 0.0 after taring.
4. Run the whole procedure yourself once with one set. Expect about 20.0 g, 24.0 g, 17.6 g and 18.4 g for 20.0 mL of water, salt water, alcohol and oil.
5. Post the reference table where every group can see it, and print it on the recording sheet as well.
6. Confirm there are no flames, hot plates or heat sources in use in the room during the period; the alcohol is flammable.

Investigation design

Independent variable	Which unknown liquid is being tested (A, B, C or D).
Dependent variable	Density in g/mL, number of layers formed with water, and what a drop leaves on paper.
Controlled	Always 20.0 mL measured in the same cylinder, read at eye level; Same balance, tared with the same cup type; Room-temperature liquids; Mixing test always 5 mL unknown plus 5 mL water, swirled 10 seconds, read at 1 minute; One drop per liquid on the same paper towel, read at 5 minutes
Trials	Two density trials per liquid, averaged; the mixing and drop tests are repeated only if the group disagrees about what they saw.
Comparison	Each measured density is compared with a reference table of six known liquids, two of which are distractors that nearly match an unknown's density.

Student procedure

1. Put on goggles. Label four cups A, B, C and D. Place cup A on the balance and press tare so it reads 0.0 g; if your balance cannot tare, record the empty cup's mass instead.
2. Pour liquid A into the graduated cylinder to exactly 20.0 mL. Read the bottom of the curved surface with your eye level with the mark. Add or remove drops with a dropper until it is right.
3. Pour the 20.0 mL into cup A on the balance and record the mass to 0.1 g. Compute density = mass $\div$ 20.0 mL and write it in the table. Pour the liquid back into bottle A.
4. Repeat steps 2 and 3 for a second trial of liquid A, then average the two densities. Do the same two trials for B, C and D, rinsing and drying the cylinder between liquids (a quick rinse with the next liquid is better than water for the oil).
5. Mixing test: put about 5 mL of liquid A in a vial, add about 5 mL of tap water, cap it, swirl gently for ten seconds, and stand it up. After one minute record whether you see one layer or two, and if two, which

liquid is on top. Repeat for B, C and D in separate vials.

6. Drop test: put one drop of each liquid on a paper towel in a labeled spot. After five minutes record what is left: nothing, a damp spot, a greasy translucent spot that does not dry, or a white residue.
7. Sketch each vial from the mixing test in the drawing box, labeling the layers.
8. Match: for each liquid, find every reference-table entry within 0.05 g/mL of your average density. If more than one entry fits, use the mixing test and the drop test to choose. Write the identity and the two pieces of evidence in the identification table.
9. Return the liquids to their bottles, put the oil waste in the waste cup, rinse the vials and cylinder, wipe the bench, and wash hands. Answer the analysis questions on your own.

Expected observations

- 20.0 mL masses near 20.0 g (water, 1.00 g/mL), 24.0 g (salt water, 1.20), 17.6 g (alcohol, 0.88) and 18.4 g (oil, 0.92), typically within ± 0.3 g.
- Mixing test: water, salt water and alcohol each form one clear layer with water; oil forms two layers with the oil on top, sometimes with small oil beads that take a minute to rise.
- Drop test: the alcohol spot vanishes within a minute or two; the water spot dries in a few minutes; the oil leaves a translucent greasy spot that never dries; the salt water leaves a faint white ring or crust once dry, which may take longer than five minutes in a humid room.

Likely difficulties

- Reading the cylinder from above instead of at eye level, which under-reads the volume and over-reads the density by a few percent; have the recorder check the measurer's eye position on the first reading.
- Forgetting to tare, or taring with a wet cup, which shifts every mass; the two-trial design catches most of these because the trials will disagree.
- Oil left in the cylinder contaminates the next liquid and makes the water read light; rinse with the next liquid before measuring it, or give the oil its own cylinder.
- Alcohol evaporates while students fuss with the balance, so trial 2 reads lighter than trial 1; tell groups to read the balance as soon as the number settles.
- Students see one layer for salt water and conclude it is 'the same as water'; q5 and the drop test are there to separate 'mixes with water' from 'is water'.

Structured debrief

1. Reveal the key and pool each group's average densities on the board, one column per liquid. Ask why water clusters tightly near 1.00 while the alcohol and oil spread more; the volatile alcohol loses a little mass while it sits on the balance, and oil clings to the cylinder walls.
2. Ask every group which liquid forced them to a second test. Most will name the alcohol or the oil, because the table holds mineral oil at 0.85 and vegetable oil at 0.92 on either side of the alcohol's 0.88 . Make the point explicitly: the table was built so that density alone could not finish the job, just as real reference tables hold many substances with similar densities.

3. Return to the phenomenon jar. With measured densities for oil and water, students can now explain two things: why oil is on top, and why the two layers never blend. Drip water-based food coloring into the jar: it falls through the oil as beads and spreads out the instant it reaches the water, which is the solubility idea in one gesture.
4. Close on q8: a reference-table match narrows the list; agreement of two independent properties is what scientists accept as an identification, and even then they say 'consistent with'. Preview that Lesson 12 will use the same toolkit to tell whether a new substance has formed.

Recording sheet: what students fill in

Lab 1 recording sheet: Four clear liquids, no labels

Record every mass as you read it. Compute each density before moving to the next liquid so you can catch a mistake while the liquid is still in front of you. Density = mass ÷ volume; since you always use 20.0 mL, divide each mass by 20.0.

Density measurements (20.0 mL each time)

Liquid	Trial 1 mass (g)	Trial 1 density (g/mL)	Trial 2 mass (g)	Trial 2 density (g/mL)	Average density (g/mL)
A					
B					
C					
D					

Mixing test and drop test

Liquid	Layers with water after 1 min (one or two)	If two layers, which is on top?	Drop on paper after 5 min (nothing / damp / greasy / white residue)
A			
B			
C			
D			

Reference table: known liquids at room temperature (rounded values)

Known liquid	Density (g/mL)	Mixes with water?	Drop on paper after 5 min
Mineral oil	0.85	No, floats on top	Greasy spot that does not dry
Isopropyl alcohol, 70%	0.88	Yes, one layer	Nothing; dries fast
Vegetable oil	0.92	No, floats on top	Greasy spot that does not dry
Water	1.00	Yes, one layer	Damp spot, then nothing
Saturated salt water	1.20	Yes, one layer	White residue when dry
Glycerin	1.26	Yes, slowly	Sticky clear film that does not dry

Two of these liquids are not in your set. Your density may differ from the table by up to about 0.05 g/mL because of how the cylinder is read.

-  Sketch the four vials from the mixing test side by side. Label each vial with its letter, draw the layer or layers you saw, and write which liquid you think each layer is.

Answer: Three vials show a single clear layer (water, salt water, alcohol). One vial shows two layers with a thinner oil layer on top of water, roughly equal heights since 5 mL of each was used, possibly with small oil droplets near the boundary.

Why: Oil is less dense than water and insoluble in it, so it floats as a separate layer; the other three are soluble in water and form one layer.

- Four labeled vials
- Exactly one vial with two layers, oil on top
- Layers labeled with the liquid names or letters

1. Identify each liquid. For each one give the density evidence and a second piece of evidence from the mixing or drop test.

Answer: Group-specific letters. Water: density about 1.00 g/mL, one layer with water, damp spot that dries. Saturated salt water: about 1.20 g/mL, one layer, white residue. Isopropyl alcohol 70%: about 0.88 g/mL, one layer with water (rules out mineral oil at 0.85 and vegetable oil at 0.92, which both float), spot vanishes fast. Vegetable oil: about 0.92 g/mL, two layers with the oil on top (rules out alcohol at 0.88), greasy spot that never dries.

Why: Each identification needs a density within about 0.05 g/mL of the table and one observation that excludes the nearest other entry. The alcohol and the oil are the two that cannot be settled by density alone.

- All four identities correct for the class key
- A density value compared to the table for each liquid
- A second observation for each liquid that rules out the closest alternative

2. Which of your four liquids could not be named by density alone? Name the two reference-table entries it could have been, and say which test decided it.

Answer: Usually the alcohol (0.88): it sits between mineral oil (0.85) and vegetable oil (0.92), both within or near the 0.05 tolerance. The mixing test decided it: alcohol makes one layer with water while both oils float. Some groups will name the oil (0.92) instead, with alcohol (0.88) as the other candidate; the mixing test decides that one too.

Why: The reference table was built with distractors so that one of the four unknowns always has a near-twin in density.

Also acceptable: Accept either the alcohol or the oil as the ambiguous liquid, provided the two candidates named are within about 0.05 g/mL and the deciding test is the mixing test (or the drop test for alcohol versus oil).

Analysis questions: answer key

3. A group measured 17.6 g for 20.0 mL of one liquid. Calculate its density. Which reference liquids are within 0.05 g/mL of that value, and what single test tells the alcohol from the oils?

Answer: $17.6 \text{ g} \div 20.0 \text{ mL} = 0.88 \text{ g/mL}$. Within 0.05 g/mL: isopropyl alcohol 70% (0.88, exact), mineral oil (0.85, 0.03 away) and vegetable oil (0.92, 0.04 away); water, salt water and glycerin are far outside. The mixing test separates them: the alcohol makes one layer with water, while either oil floats as a second layer.

Why: Students must show the division with units and read the tolerance off the table. The drop test (alcohol vanishes, oil stays greasy) is an acceptable deciding test as well.

Also acceptable: Accept an answer that names only the alcohol and one of the two oils if the student states the tolerance; the deciding test may be the mixing test or the drop test (alcohol vanishes, oil stays greasy).

4. Why did the procedure use 20.0 mL rather than 5.0 mL for the density measurement? Use the balance's 0.1 g limit in your answer.

Answer: The balance reads only to 0.1 g. With 5.0 mL, the alcohol and the oil would differ by only 0.2 g (4.4 g versus 4.6 g), which is two balance steps, so a single misread would swap them. With 20.0 mL they differ by 0.8 g (17.6 versus 18.4), so a 0.1 g error changes the density by only 0.005 g/mL. A larger sample makes the same balance error a smaller fraction of the result.

Why: This is the proportional-reasoning point: absolute error stays fixed while the measured quantity grows, so relative error shrinks.

- Mentions the 0.1 g limit
- Explains that a bigger mass makes the same error matter less, with numbers

5. Water and saturated salt water have different densities, yet the salt water formed one layer with water in the mixing test. Explain why, using the word solubility.

Answer: Salt water is water with salt dissolved in it, and the salt is soluble in water, so adding more water simply makes a weaker salt solution; there is no boundary to see. Two layers form only when the liquids are not soluble in each other, like oil and water. A different density does not by itself make layers.

Why: Students often fuse 'different density' with 'forms layers'. Layers need both a density difference and insolubility.

- States that salt water and water are soluble in each other (or that salt water is a water solution)
- States that layers require insolubility, not just a density difference

6. Suppose you gently poured your salt water, oil and water into one tall glass. Using your measured densities, predict the layers from top to bottom. Then predict what the glass looks like one minute after stirring it hard.

Answer: Top to bottom when poured gently: vegetable oil (about 0.92), water (1.00), salt water (1.20), three layers. After hard stirring and one minute: the oil separates out again and floats on top, but the water and salt water mix into one layer of in-between density (about 1.10 if equal amounts), so only two layers remain. The oil separates because it is insoluble in water; the salt water does not because it is soluble in water.

Why: Combines density ordering with solubility. The water/salt-water boundary is real when poured carefully but is not stable.

- Correct top-to-bottom order using the measured densities
- After stirring: oil separates again on top
- After stirring: water and salt water form one mixed layer, with a reason

7. The drop test showed that salt water leaves a white residue and alcohol leaves nothing. What does the residue tell you happened to the salt when it dissolved? Why does the alcohol leave nothing?

Answer: The salt did not disappear or change when it dissolved; its particles spread out in the water and were carried into the drop. When the water evaporated it left the salt behind as a white solid. The alcohol and the water in the 70% alcohol both evaporate at room temperature, so nothing is left; there was no dissolved solid in it.

Why: This is the 'dissolved is not gone' idea with direct evidence, and it previews the evaporation test in Lab 3.

- States that the salt was still present in the solution and was left behind by evaporation
- States that the alcohol (and its water) evaporated completely because nothing dissolved in it remained

8. A classmate says 'my density matched the table, so that proves what the liquid is.' Explain why a match is consistent with an identity but not proof of it, and describe one thing you did in this lab, or could do, to be more certain.

Answer: Many substances share a density within measurement error; the table itself has mineral oil, alcohol and vegetable oil within 0.07 g/mL of each other, so a match only says 'this liquid could be one of these'. Proof needs a second independent property that the alternatives do not share. In this lab the mixing test (soluble in water or not) and the drop test (residue, greasy spot or nothing) were the second properties. To be more certain still, we could measure boiling point under the same conditions, or compare several properties at once.

Why: This is the lesson's main claim. Full credit requires both the limitation of a single match and a specific second test.

- Explains that more than one substance can match a single density
- Names at least one independent second test actually used in the lab
- Optionally names a further test from the lesson (boiling point) with its condition

Individual evidence of learning

Each student submits their own completed density table, mixing and drop test table, vial drawing, identification table (q1) and written answers to q2 through q8. The identification table with two pieces of evidence per liquid is the main evidence for the identify-an-unknown target; q3 is the evidence for the density calculation target.

Assessment criteria

Criterion	Proficient looks like
Measurement and calculation	Both trials recorded for every liquid, densities computed correctly to two decimal places with units, averages within about 0.05 g/mL of the expected values.
Identification with two properties	All four liquids named correctly, each with a density comparison to the table and a second independent observation that rules out the near-twin.
Reasoning about evidence	Explains why the alcohol or oil needed a second test, why a match is not proof, and how the two tests together make the identification trustworthy.
Use of vocabulary	Uses density, solubility, mixture and substance correctly in written answers.

Accessibility adaptations

- Provide a recording sheet with the volume already written as 20.0 in every row and a density column that shows the division set up ($\text{mass} \div 20.0 = \underline{\hspace{1cm}}$).
- Let a student with limited fine-motor control take the recorder role and read the balance while a partner pours; a balance with a large display helps.
- Offer the reference table in large print with icons: a layered glass for 'does not mix', a single glass for 'mixes', a droplet for the drop test.
- Accept a spoken explanation for q6 and q8 recorded on a device, and allow the vial drawing to be replaced by labeling a printed outline of four vials.

Low-cost alternative

Use three liquids instead of four (drop the salt water) and share one balance between three groups; or run density only on 10.0 mL with a 10 mL cylinder if that is all you have, accepting larger scatter. If no balance is available, replace the density measurement with a layering test: pour each unknown gently onto water and onto oil in clear cups and record whether it floats, sinks or mixes, then rank the liquids by density from the results.

Model limitations

The reference table's densities are room-temperature values rounded to two decimals; the 70% alcohol value depends on the brand's exact concentration and on evaporation during the measurement, and vegetable oils vary by about 0.01 g/mL. The 0.05 g/mL tolerance is a rule of thumb for a 25 mL cylinder and 0.1 g balance, not a calculated uncertainty. The drop test is a quick visual check, not a measurement of solubility. This activity has not been physically tested by the authors; the expected masses are calculated from reference densities.

Teacher notes

Grade q1 against your letter key for that period. Accept densities within about 0.05 g/mL of the table; a group whose alcohol reads 0.85 has probably lost mass to evaporation, and a group whose oil reads 0.95

has probably had water in the cylinder; both are good discussion cases rather than errors to penalize. For q3, any answer that shows $17.6 \div 20.0$ and names two candidates within the tolerance earns full credit.