

The Rising Disks: What Makes a Sunken Leaf Float?

Investigation question: Leaf disks that have been made to sink rise again in some cups but not others. What is being made inside the leaf, and which inputs does the leaf need to make it?

Evidence-based mystery

Groups of 4

1 session

Setup 10 · Activity 35 · Cleanup 5 min

MS-LS1-6 · assesses

MS-LS2-3 · supports

Scientific purpose

Students receive a puzzle rather than a recipe: identical spinach disks, sunk by pulling the air out of them, rise within minutes in one cup and stay on the bottom in two others. By comparing a lit cup with a carbon dioxide source, a dark cup with the same source, and a lit cup with no source, they work out that a gas is being produced inside the leaf, that making it requires both light and carbon dioxide, and that the gas matches the oxygen product of photosynthesis. The lab is a modern version of Ingenhousz's submerged-leaf experiment and produces the evidence students use to explain where a plant's matter and energy come from.

Why this helps students with this chapter

Photosynthesis is invisible: a leaf in the sun looks exactly like a leaf in the shade. Watching sunken disks lift off the bottom one by one, in the lit cup only, makes gas production something students saw with their own eyes and timed with their own stopwatch. Because the gas is made inside the leaf from inputs that are themselves invisible, students must reason from the pattern of conditions to the inputs, which is the same move van Helmont could not make and de Saussure finally did.

Standards connections

MS-LS1-6 (assesses, the evidence-gathering half: using experimental results to explain that photosynthesis needs light and carbon dioxide and releases oxygen): Students collect their own light-versus-dark and carbon-dioxide-versus-none data and write an explanation that traces a matter input (carbon dioxide) and an energy input (light) into the leaf and a matter output (oxygen) out of it, which is evidence toward the PE as written and stays inside its boundary (no biochemical mechanism).

MS-LS2-3 (supports, the producer end of matter cycling): The cup is a small bounded system; students name what crosses into the leaf and what comes out, which is background for the ecosystem-level model in Lab 2 and Lessons 6 and 7.

Roles (rotate each session)

- **Preparer:** Punches the leaf disks away from the veins, mixes the baking soda solution and the plain-water control, and labels the three cups.

- **Syringe operator:** Loads disks and solution into the syringe, pulls the vacuum to sink the disks, and pours each batch into its cup without foam.
- **Timer and counter:** Starts the timer when the cups go under the lamp, calls out the number of floating disks in each cup every minute, and lifts the dark cover only for the count.
- **Recorder:** Writes every count in the table, flags anything unexpected, and plots the three cups on the graph as the data come in.

Materials

Item	Quantity	Per	Note
Fresh spinach leaves (flat, dark green, not baby spinach)	2 to 3 leaves	group	Ivy, pothos or fresh basil also work; avoid thick waxy leaves.
Standard single hole punch	1	group	
Plastic syringe, 10 mL or 20 mL, no needle	1	group	Oral-medicine syringes from a pharmacy are cheap and safe.
Clear plastic cups, about 250 mL	3	group	
Baking soda (sodium bicarbonate)	1 teaspoon	class	About 1/8 teaspoon makes 300 mL of solution.
Liquid dish soap	1 small bottle	class	One drop per 300 mL; it helps the solution wet the leaf.
Tap water, room temperature	1 litre	group	
LED desk lamp or a sunny window	1	group	LED stays cool; an incandescent bulb must be kept at least 30 cm from the cups.
Shoebox, opaque container or aluminum foil for the dark cup	1	group	
Timer or phone stopwatch	1	group	
Dark paper or cloth to place behind the cups	1 sheet	group	Floating disks are easier to count against a dark background.
Recording sheet and graph	1 set	student	

Estimated cost: 15 to 25 per class (an estimate; One bag of spinach (about \$3), a box of baking soda (\$1), a pack of ten 10 mL oral syringes (about \$8), clear cups (\$3) and dish soap. LED lamps and hole punches are usually stock; if lamps must be bought, add about \$10 each or use a sunny window.)

Safety

- Syringes have no needles and must never be fitted with one. Pull the plunger gently; a hard pull can pop it out and spray solution.
- Keep lamps and cords away from water. Place cups on a tray. If a lamp uses an incandescent bulb it gets hot: keep hands off the bulb and the cup at least 30 cm away so the water does not warm, which would change the result.

- Baking soda solution is harmless on skin but stings eyes; rinse with water if splashed. Do not eat the spinach or drink any solution used in the lab.
- Hole punches pinch; keep fingers clear of the jaws. Wipe spills at once so the floor does not get slippery.

Teacher preparation and setup

1. Run the lab yourself the day before with the same spinach and lamps. Note how many minutes the lit cup takes for half the disks to float; it is usually 5 to 15 minutes but depends on the leaf, the lamp and the room temperature.
2. Mix a class batch of 0.2 percent bicarbonate solution: about 1/8 teaspoon baking soda in 300 mL of water, with one drop of dish soap, stirred gently so it does not foam. Make a matching batch of plain water with one drop of soap and no baking soda, clearly labeled.
3. Keep spinach cold and crisp until class; wilted leaves give slow, scattered results. Rinse and pat dry.
4. Set up each lamp station so the cup will sit 15 to 20 cm below the bulb, with a dark background behind it and the lamp cord away from the water.
5. Print the recording sheet with the time column already filled in, and prepare the dark boxes or foil tents so the dark cup can be covered within seconds.

Investigation design

Independent variable	The conditions the disks receive: light with a carbon dioxide source (A), dark with the same source (B), light without an added source (C)
Dependent variable	Number of disks floating at each minute, and the time for half the disks to float
Controlled	Ten disks per cup from the same leaves; Same volume and depth of liquid in each cup; Same vacuum procedure for every batch; Same distance from the same lamp for the lit cups; Room temperature, with the lamp kept far enough away not to warm the water; Same person counting with the same rule for 'floating'
Trials	Each group runs one set of three cups; the class pools the half-float times for A, B and C on the board so the pattern can be seen across six to eight groups.
Comparison	Cup A against cup B isolates light; cup A against cup C isolates the carbon dioxide source.

Student procedure

1. Label three cups: A (light, baking soda), B (dark, baking soda), C (light, plain water). Pour the bicarbonate solution into A and B and plain soapy water into C, each about 3 cm deep.
2. Punch 30 leaf disks, avoiding the thick veins. Keep them in a damp paper towel so they do not dry out. You will use 10 per cup.
3. Remove the plunger from the syringe, drop 10 disks in, replace the plunger and draw up about 5 mL of the liquid from cup A. Hold the syringe tip up, tap it, and push out the air at the top.
4. Cover the tip firmly with a finger and pull the plunger back to about the 10 mL mark. Hold for 10 seconds. You are lowering the pressure so the air inside the leaf's spaces bubbles out and liquid moves

- in. Release, then repeat two or three times until all the disks sink when the syringe is tilted.
5. Gently push the disks and liquid into cup A so they settle on the bottom. Repeat steps 3 to 5 for cup B using cup B's solution, and for cup C using plain soapy water. If a disk refuses to sink after four pulls, set it aside and note it.
 6. Place cups A and C under the lamp side by side at the same distance from the bulb. Place cup B under the lamp too, but cover it with the box or foil tent so no light reaches it. Start the timer at the moment the light reaches cup A.
 7. Every minute for 20 minutes, count the disks floating at the surface of each cup and record the number. For cup B, lift the cover only long enough to count, then re-cover. A disk counts as floating when any part of it has left the bottom.
 8. After the 20-minute count, if cup A has floating disks, move cup A into the dark box, keep timing, and count every 2 minutes for 10 more minutes. Record what the disks do.
 9. Plot the counts for A, B and C on the same graph with three different symbols. Mark the minute at which five of the ten disks were floating in any cup that reached five.
 10. Answer the recording-sheet questions as a group, then the analysis questions individually.

Expected observations

- Cup A: the first disk usually lifts between minute 3 and minute 8; five of ten are floating somewhere between minute 6 and minute 15; most or all are up by minute 20. Tiny bubbles are often visible on the disk edges before they rise.
- Cup B: no disks float during the 20 minutes. Occasionally one that was never fully sunk drifts up at minute 0 and should be noted and excluded.
- Cup C: none, or one to three disks rising slowly late in the run; clearly behind cup A.
- After cup A is moved into the dark, floating disks begin to sink, usually within 5 to 15 minutes, as the oxygen in their air spaces is used up; in the 10-minute window some disks may still be up at the end, so the trend is what to record.

Likely difficulties

- Disks that will not sink: the leaf still has air in it. Pull the plunger more slowly and hold longer, make sure the disks are fully wetted (the drop of soap matters), and do not use more than ten disks per syringe.
- Foam from too much soap traps disks at the surface and ruins the count. One drop per 300 mL is enough; pour slowly.
- A lamp too close warms the water, which speeds the result but confounds it. Keep the stated distance and use LED lamps where possible.
- Counting rules drift: decide in advance that a disk 'floats' when it has left the bottom, and have one person count all three cups.
- Groups sometimes conclude the disks rise because the baking soda 'fizzes.' Cup B has baking soda and nothing rises, which settles it.

Structured debrief

1. Pool every group's half-float time for cup A on the board and ask why they vary (leaf age, lamp brightness, how well the vacuum worked, temperature). Then ask whether any group saw a cup B disk float; a stray one usually means the cover leaked light or the disk was never fully sunk.
2. Build the logic chain together: A versus B shows light is required; A versus C shows carbon dioxide is required; the equation says the gas product is oxygen; so the disks filled with oxygen made inside the leaf from carbon dioxide and water, powered by light. Write the chain on the board in that order.
3. Discuss cup C honestly: a few disks sometimes rise slowly because tap water holds a little dissolved carbon dioxide and the leaf's own cells release some. That is why C is 'slow and few,' not 'never,' and why the baking soda makes A fast.
4. Close on the dark extension: disks sinking again shows the leaf uses oxygen continuously to break down sugar, and in the dark nothing replaces it. Connect this to the day-and-night slide and to Lesson 5.

Recording sheet: what students fill in

Lab 1 recording sheet: The rising disks

Record the number of disks floating in each cup at every minute. Cup A is lit with baking soda; cup B is dark with baking soda; cup C is lit with plain water. Start the timer when the lamp first reaches cup A.

Floating disks per minute (10 disks in each cup)

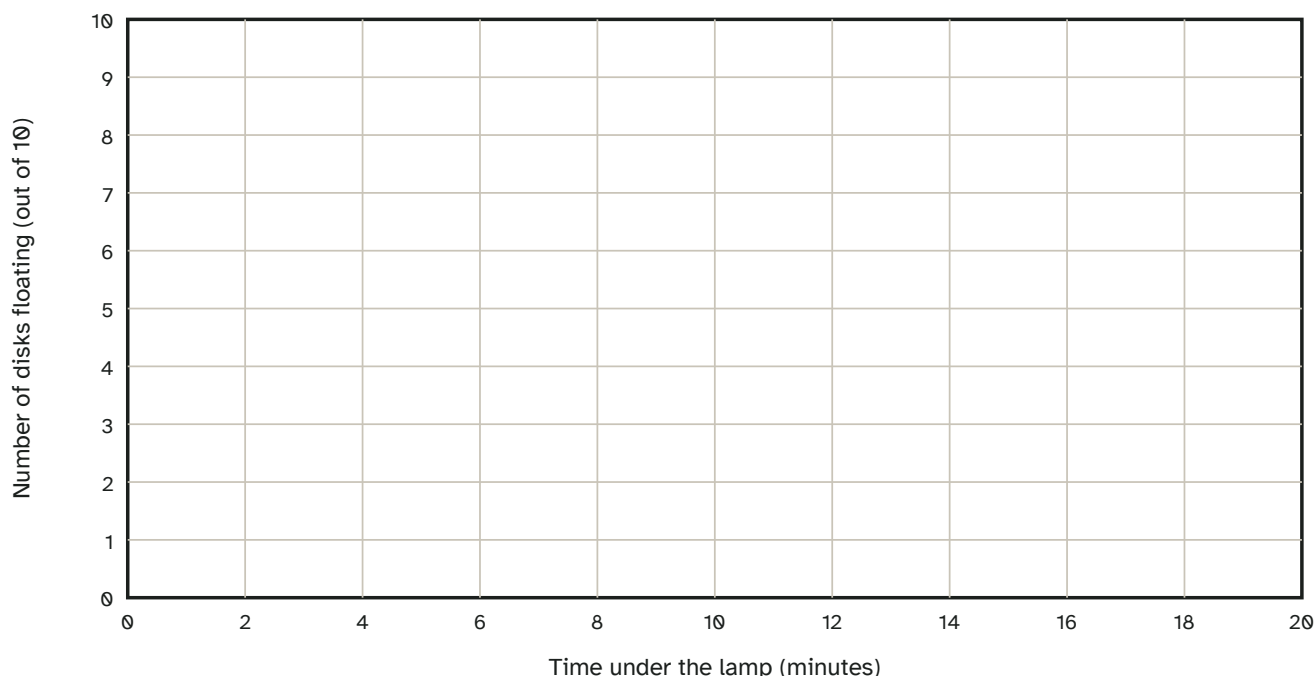
Minute	Cup A: light + baking soda	Cup B: dark + baking soda	Cup C: light + plain water	Notes
0				
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
11				
12				
13				

Minute	Cup A: light + baking soda	Cup B: dark + baking soda	Cup C: light + plain water	Notes
14				
15				
16				
17				
18				
19				
20				

After 20 minutes: cup A moved into the dark

Minutes in the dark	Disks still floating in cup A	What you see
0		
2		
4		
6		
8		
10		

Floating disks over time in cups A, B and C



-  Draw one leaf disk at minute 0 (on the bottom) and the same disk when it is floating. Show where the gas is and label where you think it came from.

Answer: Minute 0: a flat disk on the bottom, its inside spaces filled with liquid, no gas. Floating: the same disk at the surface with small gas pockets inside the leaf (and often tiny bubbles on its edge), with an arrow or label saying the gas was made inside the leaf from carbon dioxide and water using light.

Why: The key move is locating the gas inside the leaf rather than drawing bubbles stuck to the outside, because that is where photosynthesis happens.

- Shows the disk in two positions
- Places gas inside the leaf
- Labels a source (made inside the leaf, or from carbon dioxide and water with light)

1. Which cup had the first floating disk, and at what minute? At what minute (if ever) were five disks floating in each cup?

Answer: Group-specific. Typically cup A has the first floating disk at minute 3 to 8 and reaches five floating at minute 6 to 15; cups B and C never reach five in 20 minutes (C may have one to three late risers).

Why: The half-float time is the standard way to compare runs; the answer should come straight from the table and name both the cup and the minute.

- Names cup A and the correct minute for its first disk
- Reports the five-disk minute for A and 'never' for B and C, matching the table

2. Before you read any explanation: what do you think the disks are filling with, and why do you think that?

Answer: Any honest prediction with a reason. Common: 'air,' 'bubbles,' 'oxygen because plants give off oxygen,' 'carbon dioxide from the baking soda.'

Why: This is a prior-knowledge probe. A student who says carbon dioxide from the baking soda has a reasonable idea that the B cup will overturn; note it and revisit at q4.

- Gives a specific gas or 'a gas' and a reason tied to something observed or known

Analysis questions: answer key

3. Compare cup A with cup B. The only difference was light. What does that comparison tell you about what the leaf needs to make the gas?

Answer: Light is needed. Both cups had the carbon dioxide source, and only the lit cup made enough gas to lift the disks, so the leaf cannot make the gas without light.

Why: A versus B is the controlled comparison for light. Full credit requires naming the single difference and the conclusion.

- Identifies light as the only difference
- Concludes that light is required for gas production

4. Compare cup A with cup C. The only difference was the baking soda, which supplies carbon dioxide to the water. What does that comparison tell you?

Answer: Carbon dioxide is needed. Both cups were lit, and the cup with the carbon dioxide source rose much sooner and higher than the cup without it, so the leaf needs carbon dioxide to make the gas. The slow risers in C show tap water and the leaf itself supply only a little.

Why: A versus C is the controlled comparison for carbon dioxide. Accept 'C rose slowly' explanations that still conclude carbon dioxide is required.

Also acceptable: If a group's cup C rose almost as fast as A (warm room, high-CO₂ tap water), accept an answer that says the comparison was inconclusive for that group and cites the class data.

- Identifies the carbon dioxide source as the only difference
- Concludes that carbon dioxide is required

5. The photosynthesis equation is carbon dioxide + water + light energy → sugar + oxygen. Which product could be the gas that lifted the disks, and why can it not be the sugar?

Answer: Oxygen. It is a gas, so it can fill the leaf's air spaces and make the disk buoyant. Sugar is not a gas; it is a solid dissolved in the cell's water and stays inside the leaf, so it cannot lift anything.

Why: Students should match the observed gas to the gas product in the equation and rule out sugar by its state.

- Names oxygen
- Explains that sugar is not a gas and cannot provide buoyancy

6. When cup A was moved into the dark, what happened to the floating disks over the next 10 minutes? Explain it using the fact that plant cells use oxygen to break down sugar at all times.

Answer: The floating disks began to sink again (some within the 10 minutes, the rest soon after). In the dark no new oxygen is made, but the leaf's cells keep using oxygen to break down sugar for energy, so the oxygen in the air spaces is used up and the disk loses its buoyancy. This shows the plant uses oxygen all the time; in the light, photosynthesis simply makes more than it uses.

Why: This is the day-and-night correction made visible. Full credit requires both parts: no production in the dark and continued use at all times.

Also acceptable: If the class skipped the extension, accept a prediction with the same reasoning.

- Reports that disks sank
- States that photosynthesis stopped in the dark
- States that the leaf keeps using oxygen to break down sugar, so the gas was used up

7. Van Helmont's willow gained about 74 kg while its soil lost about 60 g. Using your results, write a three-sentence explanation of where the willow's matter came from and what the Sun contributed.

Answer: Example: The willow's matter did not come from the soil, because the soil lost only 60 g. Our disks showed that a leaf takes in carbon dioxide and, with light, makes sugar and gives off oxygen, so the tree's carbon came in through its leaves as carbon dioxide from the air, and its water came up through the roots; the atoms of those two were rearranged into sugar and then into wood. The Sun supplied the energy for the reaction, which is now stored as chemical energy in the wood, but it supplied no atoms.

Why: This is the MS-LS1-6 explanation. It must trace matter (carbon dioxide and water, not soil) and energy (light, stored as chemical energy) and keep them separate.

- Rules out soil with the 60 g evidence
- Names carbon dioxide (and water) as the matter source, citing the lab
- States that the Sun contributed energy, not matter

8. Describe one change to this investigation that would let you test whether the amount of light matters, and say what you would measure.

Answer: Example: Run three lit cups with baking soda at 10, 20 and 40 cm from the same lamp (or with one, two and three layers of tissue paper over the lamp), keep everything else the same, and measure the minute at which five disks float in each cup. Closer or brighter light should give a shorter half-float time.

Why: Students must change only light amount and keep the dependent variable (half-float time or disks floating per minute).

- Changes light amount in a controlled way
- Keeps carbon dioxide and other conditions the same
- Names the measurement (half-float time or floating count)

Individual evidence of learning

Each student submits their own data table, graph, drawing and written answers to q1 through q8. Question 7 is the primary evidence for the MS-LS1-6 explanation; q3, q4 and q5 show whether the student can reason from the controlled comparisons to the inputs and the product.

Assessment criteria

Criterion	Proficient looks like
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Data and graph	All three cups recorded at every minute, three series plotted with a legend, half-float minute marked for any cup that reached five.
Reasoning from comparisons	States that A versus B isolates light and A versus C isolates carbon dioxide, and draws the correct conclusion from each without confusing them.
Linking evidence to the equation	Identifies oxygen as the gas, explains why sugar cannot lift a disk, and uses the dark-cup extension to show the plant also uses oxygen.
Explanation of plant matter	Explains in q7 that most of the willow's matter came from carbon dioxide and water rearranged into sugar and then wood, with light supplying energy, not atoms.

Accessibility adaptations

- Use larger disks (a 1.5 cm craft punch) and a tall, narrow clear container so rising disks are obvious; place dark paper behind the cups and provide a hand lens.
- Let a partner operate the syringe while a student with limited hand strength times and counts; counting can be done aloud and recorded by another student.
- Provide the recording table with the time column filled in and the graph with axes already scaled; offer the sentence frame 'The disks in cup ___ rose because ___, which shows photosynthesis needs ___.'
- Offer a multilingual card for the terms float, sink, gas, light, dark and carbon dioxide, and allow q6 and q7 to be answered as a recorded spoken explanation.

Low-cost alternative

Skip the lamps and use a sunny windowsill, running all groups at the same time. If syringes are unavailable, the disks can be sunk by placing them in the solution inside a sealed zip bag, squeezing out the air and pressing the bag flat for a minute, though sinking is less reliable. One shared batch of solution and one hole punch per two groups keeps the cost near \$5.

Model limitations

The disks rise because oxygen accumulates in the leaf's internal air spaces, which were filled with liquid by the vacuum; the float time measures the rate of net oxygen production, not the total amount of photosynthesis, and it includes the oxygen the leaf uses up itself. Cup C is not a true zero-carbon-dioxide control, since tap water and the leaf's own cells supply a little carbon dioxide. The spinach disk is a cut piece of a plant, not a whole organism, and the baking soda provides carbon dioxide in a way no soil or air does. This activity has not been physically tested by the authors in this exact form; the timings given are typical for classroom leaf-disk work and should be checked in your own trial run.

Teacher notes

The half-float time (minute at which five disks float) is the number to compare across groups; absolute times depend on the leaf and lamp. If no group's cup A rose within 20 minutes, the usual causes are wilted leaves, a weak lamp, or disks that were not fully infiltrated; rerun with a brighter light and fresh spinach rather than extending the time. If cup C rises nearly as fast as A, the tap water was carbon-dioxide rich; using boiled-and-cooled water for C sharpens the contrast next time. Mark q7 against the three criteria rather than its length.