

Oxygen Used by Sprouting Seeds, and Energy per Gram of Food: Two Datasets

Learning target: I can graph and calculate from data to show that living seeds use oxygen faster when warmer, and use real energy-per-gram values to explain why fat is the body's long-term energy store.

Data and graphing

About 45 min

Individual

MS-LS1-7 · practice

MS-LS1-6 · supports

data analysis

independent practice

Standards connections

MS-LS1-7 (practice): Measuring the oxygen that sprouting seeds consume gives quantitative evidence that food is reacting with oxygen to release energy, and comparing energy per gram of carbohydrate, fat and protein supports the idea that different food molecules store different amounts of energy. The sheet builds the data-analysis practice behind the model without building the model.

MS-LS1-6 (supports): The seeds are kept in the dark so that photosynthesis cannot be the cause of any gas change, which makes the comparison with the previous lesson explicit.

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

Answers with reasoning

Part A: How fast do sprouting seeds use oxygen?

A class placed 25 sprouting pea seeds in a sealed glass tube with a thin side tube marked in milliliters. A small packet inside the tube soaked up any carbon dioxide the seeds released, so the only gas change left to measure was the oxygen the seeds used. As the seeds used oxygen, a drop of colored water in the side tube moved inward, and the class read how many milliliters of oxygen had been used every five minutes. They ran the test in the dark in water baths at three temperatures, and they ran one more tube with boiled (killed) seeds as a comparison.

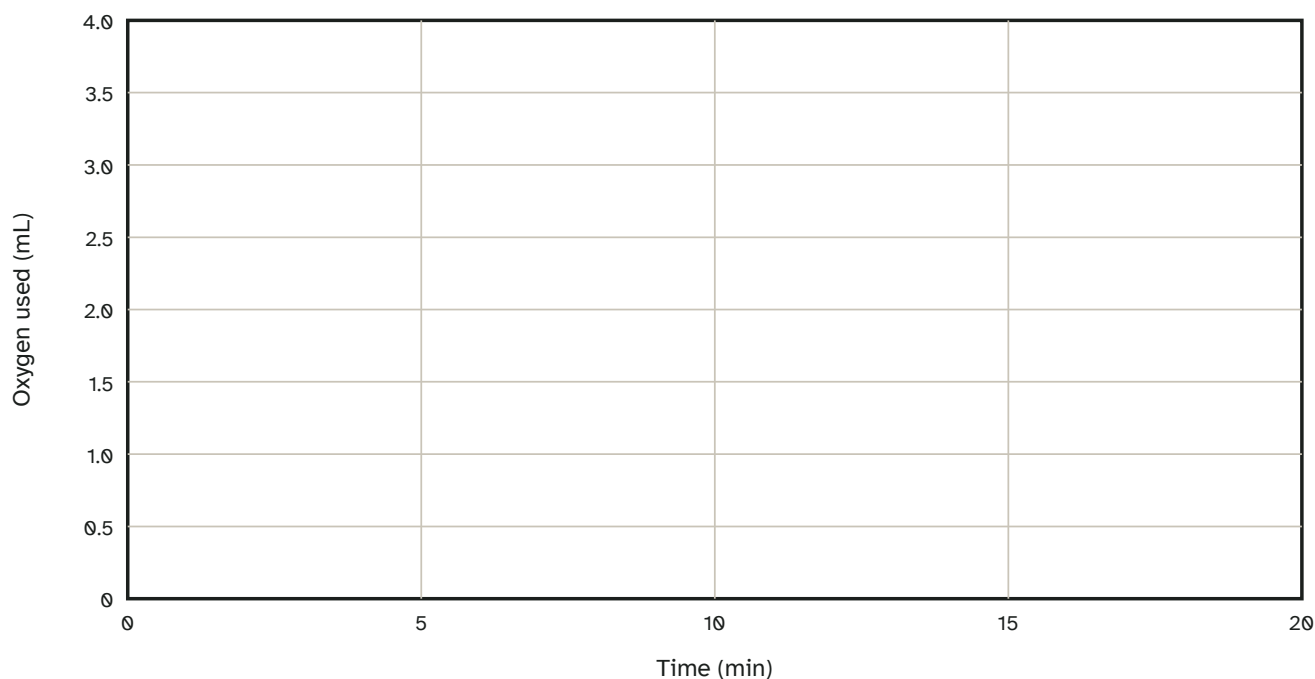
Oxygen used by 25 pea seeds in a sealed tube (teaching dataset)

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

Time (min)	Sprouting seeds, 10 °C (mL)	Sprouting seeds, 20 °C (mL)	Sprouting seeds, 30 °C (mL)	Boiled seeds, 20 °C (mL)
0	0.0	0.0	0.0	0.0
5	0.2	0.5	0.9	0.0
10	0.4	1.1	1.9	0.1
15	0.7	1.5	2.8	0.1
20	0.8	2.0	3.8	0.1

Simulated data for teaching. The tubes were kept in the dark. Values are the total milliliters of oxygen used since the start.

Oxygen used versus time



1. Calculate the rate at which the sprouting seeds used oxygen at 20 °C, in milliliters per minute, using the total after 20 minutes. Show the division.

Answer: $2.0 \text{ mL} \div 20 \text{ min} = 0.10 \text{ mL per minute.}$

Why: Rate is the total oxygen used divided by the total time. Using the 20-minute total smooths out the small jitter in the five-minute readings.

Also acceptable: Accept 0.1 mL/min.

2. Complete the table for all four tubes. Round rates to the nearest hundredth.

Answer: Sprouting, 10 °C: 0.8 mL; $0.8 \div 20 = 0.04 \text{ mL/min.}$ Sprouting, 20 °C: 2.0 mL; 0.10 mL/min. Sprouting, 30 °C: 3.8 mL; $3.8 \div 20 = 0.19 \text{ mL/min.}$ Boiled, 20 °C: 0.1 mL; $0.1 \div 20 = 0.005$, which rounds to 0.01 mL/min (effectively zero).

Why: All four divisions use the 20-minute totals. The boiled seeds give a tiny value that should be recognized as 'about zero.'

Also acceptable: Accept 0.00 or 0.005 for the boiled seeds with a note that it is essentially zero.

3. Describe the pattern in the rates for the sprouting seeds as temperature rises from 10 °C to 20 °C to 30 °C. Use the numbers.

Answer: The rate rises with temperature: 0.04 mL/min at 10 °C, 0.10 at 20 °C and 0.19 at 30 °C. Each 10 °C rise roughly doubles the rate (0.04 to 0.10 is 2.5 times; 0.10 to 0.19 is about 1.9 times).

Why: A roughly doubling rate per 10 °C is typical for living processes near room temperature; students need only the direction and a numerical comparison.

Also acceptable: Accept 'about double for every 10 degrees' or 'the warmer tube used almost five times as much oxygen as the coldest.'

- States that the rate increases with temperature
- Uses at least two of the rates as evidence

4. Why did the class include the tube of boiled seeds? What would it have meant if that tube had also used 2.0 mL of oxygen?

Answer: The boiled seeds are the comparison (control). They are the same seeds in the same tube at the same temperature, but dead. Because they used almost no oxygen, the oxygen use in the other tubes must be caused by the seeds being alive. If the boiled tube had also used 2.0 mL, the oxygen loss would have to come from something other than living seeds, such as a leak, the packet, or the tube itself, and the whole experiment would be in doubt.

Why: Students should name the control's purpose and reason about the counterfactual.

Also acceptable: Accept 'it shows the oxygen loss is from living seeds, not the equipment.'

- Identifies the boiled tube as a comparison with everything the same except being alive
- Explains what a 2.0 mL reading would have meant

5. Predict how much oxygen the 30 °C seeds would have used after 40 minutes if the pattern continued. Show the calculation. Then give one reason the real reading might be lower.

Answer: $0.19 \text{ mL/min} \times 40 \text{ min} = 7.6 \text{ mL}$. The real reading might be lower because the sealed tube holds a limited amount of oxygen, so the seeds could begin to run short of it; or because the seeds use up their stored food; or because the water drop reaches the end of the side tube's scale.

Why: The prediction extends the linear pattern; the second part checks that students know a pattern can bend outside the measured range.

Also acceptable: Accept 7.6 mL or 7.5 mL if the student used an unrounded rate; any physically sensible limit earns credit.

6. The seeds were in the dark the whole time. Using the words **reactant**, **product** and **energy**, explain where the oxygen went, what the seeds gave off (even though the packet hid it), and why the seeds needed to do this at all.

Answer: The oxygen was a reactant: it entered the seeds' cells and reacted with sugar (made from the seeds' stored starch) in their mitochondria. The products were carbon dioxide, which the packet absorbed, and water. The reaction released energy, which the sprouting seeds need to grow roots and shoots and to stay alive. They had to do this because, in the dark, a seed cannot capture light energy; its only source of usable energy is the food stored inside it, and cellular respiration is the way to release it.

Why: Full credit uses all three words correctly, names carbon dioxide as the hidden product, and explains the need for energy in the dark.

Also acceptable: A student who adds that the seeds would warm slightly is making a correct connection to Worksheet 1.

- Oxygen identified as a reactant that reacts with sugar
- Carbon dioxide (and water) named as products
- Energy release connected to growth and staying alive
- Explains that the dark rules out light as the energy source

Part B: How much energy is in each kind of food molecule?

Scientists measure the energy a food can release by burning a weighed sample and measuring the heat, much as Lavoisier did. The table gives real, rounded values. A kilocalorie (kcal) is the unit printed as 'Calories' on food labels in the United States; 1 kcal is about 4.2 kilojoules (kJ).

Energy released per gram of food molecule (real rounded values)

Food molecule	Energy per gram (kcal)	Energy per gram (kJ)	Main role in the body
Carbohydrate (sugar, starch)	4	17	quick fuel; short-term storage as glycogen
Fat	9	37	long-term energy storage; part of cell membranes
Protein	4	17	building material for muscle and other structures; can be used as fuel

A trail-mix serving contains 18 g of carbohydrate, 8 g of fat and 5 g of protein (these amounts are typical for a small handful; treat them as the serving for the questions below).

7. Calculate the total energy in the trail-mix serving in kilocalories. Show the three multiplications and the sum.

Answer: Carbohydrate: $18 \text{ g} \times 4 \text{ kcal/g} = 72 \text{ kcal}$. Fat: $8 \text{ g} \times 9 \text{ kcal/g} = 72 \text{ kcal}$. Protein: $5 \text{ g} \times 4 \text{ kcal/g} = 20 \text{ kcal}$. Total: $72 + 72 + 20 = 164 \text{ kcal}$.

Why: Each food molecule's mass is multiplied by its energy per gram; the three results are added. Notice that 8 g of fat supplies as much energy as 18 g of carbohydrate.

Also acceptable: Accept the same calculation in kilojoules: $18 \times 17 + 8 \times 37 + 5 \times 17 = 306 + 296 + 85 = 687 \text{ kJ}$.

8. What percentage of the serving's energy comes from fat? Show the calculation and round to the nearest whole percent.

Answer: $72 \text{ kcal} \div 164 \text{ kcal} \times 100 = 43.9\%$, which rounds to 44%.

Why: The part is the fat energy (72 kcal) and the whole is the total (164 kcal). Even though fat is the smallest mass in the serving (8 g of 31 g), it supplies nearly half the energy.

Also acceptable: Accept 44% or 43.9%; if the student worked in kilojoules, $296 \div 687 = 43\%$.

9. A songbird stores energy for migration as fat, not as glycogen. Using the table, explain why fat is the better choice for an animal that has to carry its energy store while flying.

Answer: Fat releases 9 kcal per gram, more than twice the 4 kcal per gram of carbohydrate. A bird that stores a given amount of energy as fat carries less than half the mass it would need as glycogen, and lighter is better for flying. Fat is the most energy per gram, so it is the best store to carry.

Why: The table supports the argument directly; the key move is 'more energy per gram means less mass to carry.'

Also acceptable: A student who also notes that glycogen is stored with a lot of water, making it even heavier, is correct, though that fact is not on the sheet.

- Cites 9 versus 4 kcal per gram
- Connects energy per gram to carrying less mass in flight

10. Look at both parts of this sheet. The sprouting seeds in Part A were using up starch that the parent plant stored in them. If the class had dried and weighed the seeds before and after the test, what would have happened to the dry mass, and where did that mass go? Connect your answer to the oxygen the seeds used and to the energy values in Part B.

Answer: The dry mass of the sprouting seeds would go down. The seeds broke their stored starch into sugar and reacted the sugar with the oxygen they took in; the carbon and hydrogen atoms of the sugar left the seeds as carbon dioxide and water, so the solid matter that remained was lighter. The oxygen use in Part A is the sign that this reaction was happening: the more oxygen a tube used, the more sugar had been reacted and the more dry mass was lost. Part B shows that the starch being used up holds about 4 kcal of energy per gram, which is the energy the seeds released to grow. The boiled seeds, which used no oxygen, would have lost no dry mass.

Why: Full credit connects three things: lost dry mass, the atoms leaving as gases, and the energy values; it should also mention that atoms were conserved (the mass went into gases, it did not vanish).

Also acceptable: A student who estimates the mass loss as roughly proportional to oxygen used, or who notes that the 30 °C seeds would lose the most, is reasoning well.

- Dry mass decreases
- The lost mass left as carbon dioxide and water
- Links oxygen used to amount of sugar reacted
- Links the starch used to the energy released (about 4 kcal per gram)

Teacher notes

Part A is simulated and shaped like classroom respirometer results: 25 germinating peas near 20 °C typically use a few hundredths to about a tenth of a milliliter of oxygen per minute depending on the seeds and how far germination has gone, and the rate roughly doubles for each 10 °C rise over this range. The packet that absorbs carbon dioxide is usually a few pellets of a strong base inside cotton; if you run this live,

the teacher handles the pellets with gloves and goggles and the tubes are kept away from skin. Part B uses the standard rounded energy values (4, 9 and 4 kcal per gram; 17, 37 and 17 kJ per gram); real foods vary a little around these. If a student asks, 'Calories' on a US food label means kilocalories. The extension works out to about 5×10^{19} oxygen molecules, about 8×10^{18} sugar molecules, and roughly 2.5 mg of sugar, far below what a 0.01 g balance can detect; the point is that gas measurements can reveal reactions that mass measurements miss.

Scaffold offered to students: Rates are 'how much per how long'

A rate is an amount divided by a time. For q1 and q2, write the amount used in 20 minutes on top, the 20 minutes on the bottom, and divide: for example, $1.0 \text{ mL} \div 20 \text{ min} = 0.05 \text{ mL per minute}$. The unit of your answer is always 'mL per min.' For the percentage in q8, divide the part (energy from fat) by the whole (total energy) and multiply by 100.

Extension: How much sugar did the seeds use?

In the overall reaction, six oxygen molecules are used for every sugar molecule, and in gas form 1 mL of oxygen at room conditions holds about 2.5×10^{19} molecules. Use the 20 °C data to estimate how many oxygen molecules the seeds used in 20 minutes, then how many sugar molecules that corresponds to. One sugar molecule has a mass of about 3.0×10^{-22} g; estimate the mass of sugar used in 20 minutes and explain why a balance that reads to 0.01 g could not have detected this change.