

Keep It Between 2 and 8: Choosing a Melting Pack for a Vaccine Cooler

Learning target: I can use a particle model of melting to predict how a pure substance will behave as it gains energy, and use that prediction with test data to choose and justify a design that meets criteria and constraints.

Transfer and design

About 55 min

Pairs

MS-PS1-4 · assesses

MS-ETS1-2 · practice

engineering design

data analysis

writing

Name _____

Date _____

Period _____

Directions

Read the problem, the criteria and constraints, and the facts about four pack materials. In Part A, use your particle model to predict how each pack will behave before you look at the test results. In Part B, evaluate the options against every criterion and constraint. In Part C, make and defend a recommendation. Work with a partner, but write your own Part C.

You will need: This worksheet, Pencil, Calculator (optional)

The problem

A county health clinic runs a mobile van that carries vaccines to rural schools and farmworker communities. On summer days the air outside can reach 35 °C or more. The vaccines ride in insulated coolers for up to 10 hours. Most vaccines must stay between **2 °C and 8 °C**: too warm and they slowly lose strength, and some are ruined if they get close to freezing. The clinic wants a reusable cold pack, a sealed pouch filled with one pure substance, that will hold the coolers in that range. Engineers often call these *phase-change packs*, because they work by changing state.

Criteria and constraints — Criteria (what success looks like): (1) the vaccines stay between 2 °C and 8 °C for at least 10 hours on a 35 °C day; (2) the vaccines never fall below 2 °C. **Constraints (limits on the design):** (3) the packs must be safe to ride in a closed van with people; (4) the packs must be made solid again overnight using only the clinic's refrigerator, which runs at 3 °C, or its freezer, which runs at −18 °C; (5) the clinic has \$250 for packs for its six coolers.

Four pack materials (real reference values at 101 kPa)

Option	Material	What it is	Melting point
A	Water (ice)	The familiar pure substance	0 °C
B	Tetradecane	A colorless, waxy compound made from petroleum	about 6 °C
C	Hexadecane	A similar waxy compound with longer molecules	about 18 °C
D	Dry ice (solid carbon dioxide)	Turns straight from solid to gas	−78.5 °C (sublimes)

Melting points are real reference values, rounded. Tetradecane and hexadecane are pure compounds of carbon and hydrogen; they have low toxicity but are harmful if swallowed, so the pouches must stay sealed and away from flames.

Part A: Predict with the model

- For each option, predict the temperature the pack will hold near while it is changing state inside the cooler, and say whether that is too cold, in range, or too warm for vaccines.

Option	Temperature it holds near while changing state	Too cold, in range or too warm?
A: water ice		
B: tetradecane		
C: hexadecane		
D: dry ice		

- Explain, using particles, why a pack of solid tetradecane can keep the inside of a cooler near 6 °C for hours even though energy keeps leaking in from the 35 °C air outside.

- Which of the four packs can be made solid again overnight using the clinic's 3 °C refrigerator or −18 °C freezer? For each pack, name the appliance or explain why neither works.

Part B: Evaluate the options

An engineer tested each option in identical coolers on a 35 °C day, with a temperature logger beside the vaccine boxes. She then tested different numbers of tetradecane packs.

Cooler test results and pack costs (teaching dataset)

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

Option	Packs per cooler, and where they were stored overnight	Coldest reading at the vaccines (°C)	Hours with vaccines between 2 °C and 8 °C	Cost per pack	Notes
A	2 packs, from the -18 °C freezer	-5	4	\$4	Vaccines below 0 °C for the first 2 hours, then about 1-3 °C
B	2 packs, from the 3 °C refrigerator	4	11	\$18	Held near 6 °C until about hour 11, then rose above 8 °C
C	2 packs, from the 3 °C refrigerator	4	1	\$20	Rose above 8 °C within the first hour, then held near 18 °C
D	1 kg, bought that morning	-40	0	\$3 per kg, each trip	Vaccines frozen; gas pushed the cooler lid open

A teaching dataset: test results and prices are invented to be realistic and were not measured. Each test lasted 12 hours.

Number of tetradecane packs per cooler (teaching dataset)

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

Tetradecane packs per cooler	Hours with vaccines between 2 °C and 8 °C
1	6
2	11
3	16

A teaching dataset from the same kind of 12-hour test on a 35 °C day.

4. Water ice melts at 0 °C, only 2 °C below the safe range, yet option A failed badly. Use the test data and the particle model to explain why.

5. Complete the decision matrix. Write **yes** or **no** in each box, and in the last column say whether the option is still allowed.

Option	At least 10 h in range? (1)	Never below 2 °C? (2)	Safe in a closed van? (3)	Re-solidified with clinic equipment? (4)	Still allowed?
A: water ice					
B: tetradecane					
C: hexadecane					
D: dry ice					

6. What would 2 tetradecane packs per cooler cost for all six coolers? What would 3 packs per cooler cost? Which plan fits the \$250 budget, and how much money would be left over?

7. Going from 1 pack to 2 packs nearly doubled the hours in range. Explain why more pack material holds the temperature longer, using particles. No calculation is needed.

Part C: Decide and justify (write your own)

8. Write your recommendation to the clinic. Name the material and the number of packs per cooler. Justify it with every criterion and constraint, at least two numbers from the test data, and the particle model. Name one trade-off or risk of your plan and one way to reduce it.

9. Predict what will happen to the vaccines' temperature after the packs have completely melted, and describe what the particles in the packs are doing then.

10. Propose one more test the clinic should run before using your plan all summer, and describe a result that would make you change your recommendation.

The flat step is the design

Think of the heating curve from class. While a pure solid melts at a steady pressure, its temperature stays flat at the melting point even though energy keeps flowing in. A phase-change pack is that flat step put to work. For each option ask: where is its flat step, and is that temperature between 2 °C and 8 °C? Then ask: can the clinic make it solid again (is the fridge or freezer colder than its melting point)?

Design for a colder job

Some vaccines must be shipped frozen, far below the 2-8 °C range, and some lab samples must stay below −60 °C. Explain which of the four materials could serve a shipment that must stay below −60 °C, what new safety constraints the clinic would have to add, and why that material cannot simply be refrozen in an ordinary freezer. Then explain why a pack that sublimates instead of melting is a problem in a closed van, using the particle model of a gas.