Identifying and Addressing Student Learning Difficulties in Calorimetry and Thermodynamics

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Project Overview

- Initial testing and interviews to explore students' conceptions regarding calorimetry
- Creation of diagnostic questions and curricular material
- Intervention and assessment in a small population

Project Strategy

- Earlier research into students' understanding had found much confusion about heat, temperature, and related fundamental concepts.
- Our objective: probe further to uncover students' "base-line" understanding in order to work from that.
- Investigate student reasoning about one of the most basic topics in thermal physics: calorimetry

Pretest Question #1

Written pretest given after all instruction on calorimetry completed

The specific heat of water is ***greater*** than that of copper.

A piece of copper metal is put into an insulated calorimeter which is nearly filled with water. The mass of the copper is the ***same*** as the mass of the water, but the initial temperature of the copper is *higher* than the initial temperature of the water. The calorimeter is left alone for several hours.

During the time it takes for the system to reach equilibrium, will the temperature change (number of degrees Celsius) of the copper be *more than, less than,* or *equal to* the temperature change of the water? Please explain your answer.

Answer: **The temperature change for copper is larger.**

Pretest Question #1 Solution

$$Q = mc\Delta T$$

$$\left|Q_{Cu}\right| = \left|Q_W\right| \quad \text{and} \quad m_{Cu} = m_W$$

$$\Rightarrow c_{Cu}\Delta T_{Cu} = c_W \Delta T_W$$

Pretest Question #1 Solution

$$Q = mc\Delta T$$

$$|Q_{Cu}| = |Q_W| \quad \text{and} \quad m_{Cu} = m_W$$

$$\Rightarrow c_{Cu}\Delta T_{Cu} = c_W \Delta T_W$$

$$\Delta T_{Cu} = \frac{c_W}{c_{Cu}} \Delta T_W$$

$$c_W > c_{Cu} \Rightarrow \Delta T_{Cu} > \Delta T_W$$

Notation: $\Delta T \equiv$ ***absolute value*** *of temperature change*

Pretest Question #1 Results (N = 32)

second-semester calculus-based course

Correct:

$\Delta T_{Cu} > \Delta T_W$	72%
with correct explanation	*53%*

Incorrect:

$\Delta T_{Cu} = \Delta T_W$	22%
$\Delta T_{Cu} < \Delta T_W$	6%

Responses from interview sample (N = 9) consistent with these results

Example of Acceptable Student Explanation

"*More than, A higher specific heat means it takes more heat to increase the temp. To increase the temp. of the water 1 degree the temp. of copper will have to decrease more than 1 degree. i.e. water resists change in temp. more than copper does*."

Example of Incorrect Student Explanation

"*Equal, to reach thermal equilibrium, the change in heat must be the same, heat can't be lost, they reach a sort of "middle ground" so copper decreases the same amount of temp that water increases*."

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"Equal, to reach thermal equilibrium, the change in heat must be the same, heat can't be lost, they reach a sort of "middle ground" so copper decreases the same amount of temp that water increases."

"Equal energy transfer" is assumed to imply "equal temperature change"

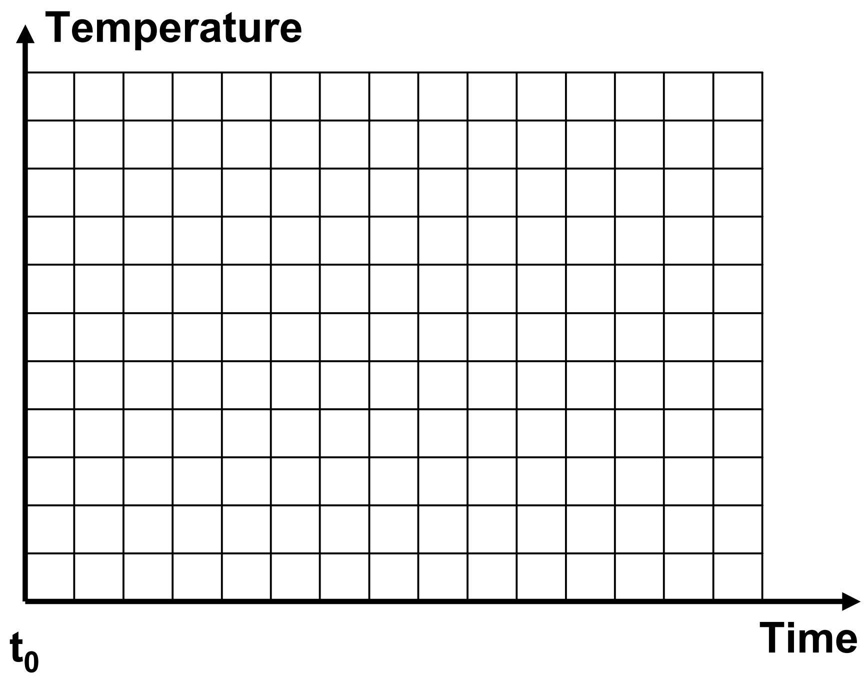
Pretest Question #2

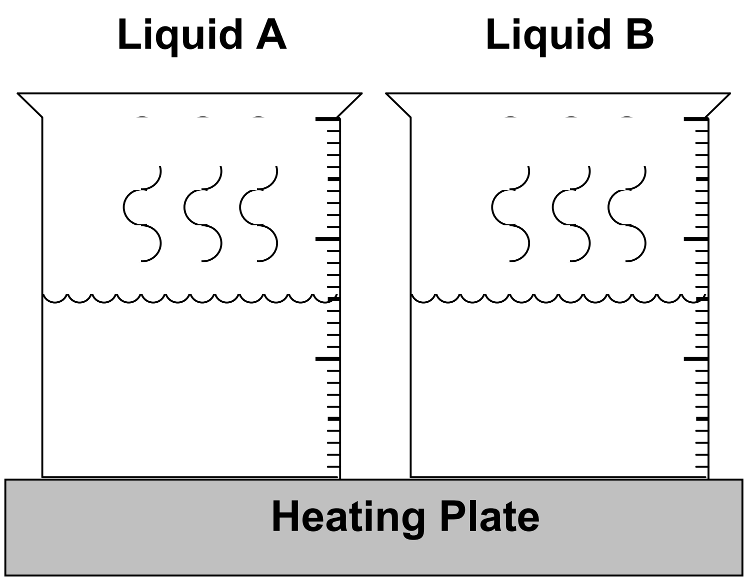
Suppose we have two ***separate*** containers: One container holds Liquid A, and another contains Liquid B. The mass and initial temperature of the two liquids are the same, but the ***specific heat*** of Liquid A is ***greater than*** Liquid B.

Each container is placed on a heating plate that delivers the ***same rate of heating*** in joules per second to each liquid beginning at initial time $\mathbf{t_0}$.

Pretest Question #2 Graph

$[c_A > c_B]$





The specific heat of A is greater than the specific heat of B.

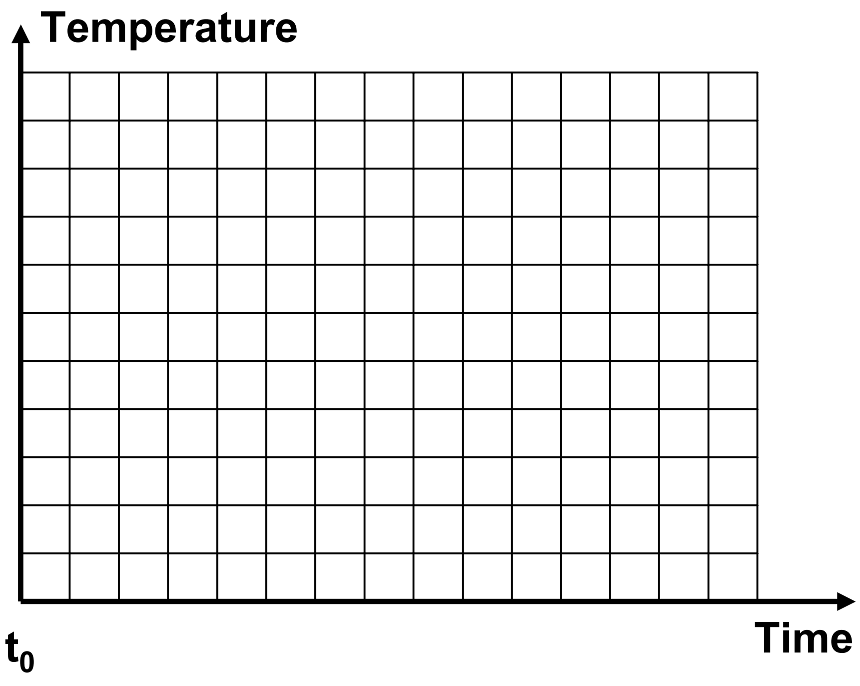
Pretest Question #2 (cont'd)

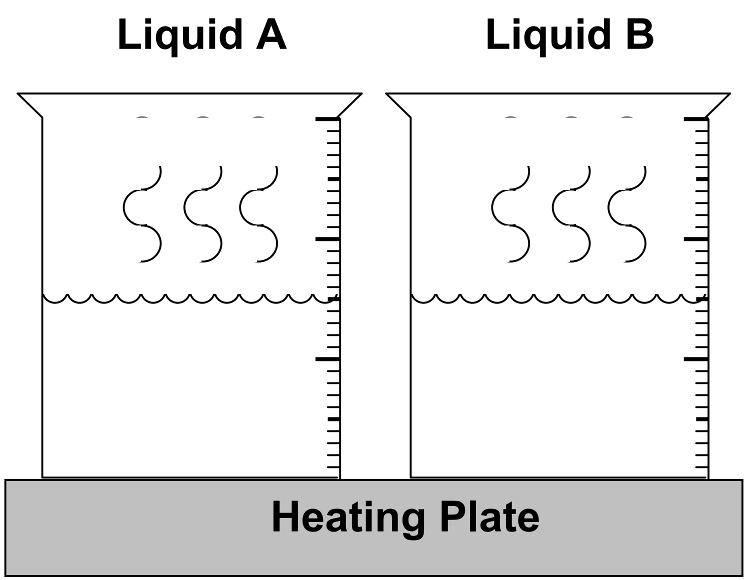
On the grid below, graph the temperature as a function of time for *each* liquid, A and B. Use a separate line for each liquid, even if they overlap. Make sure to clearly label your lines, and use proper graphing techniques.

Please **explain** the reasoning that you used in drawing your graph.

Pretest Question #2 Graph

$[c_A > c_B]$





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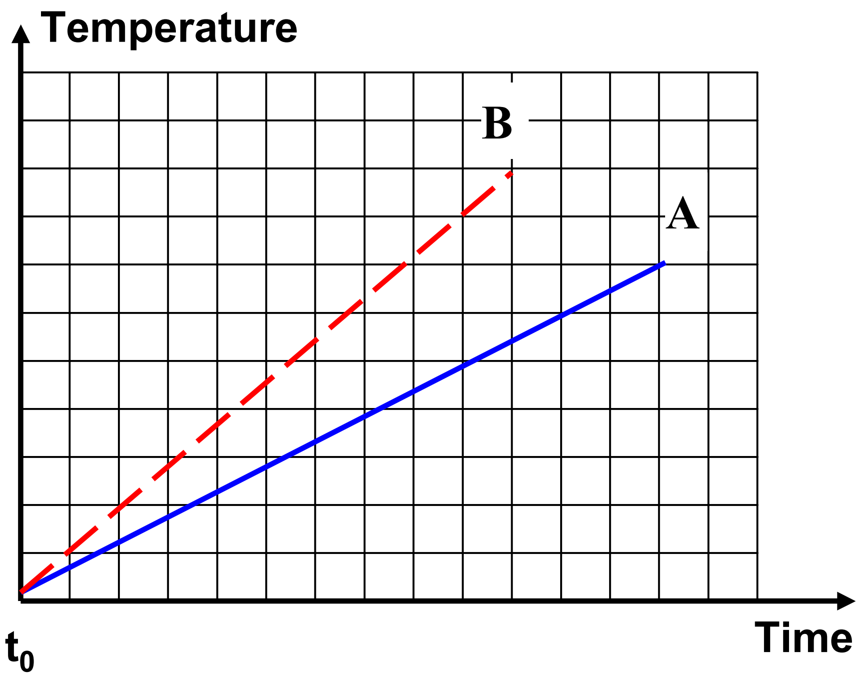
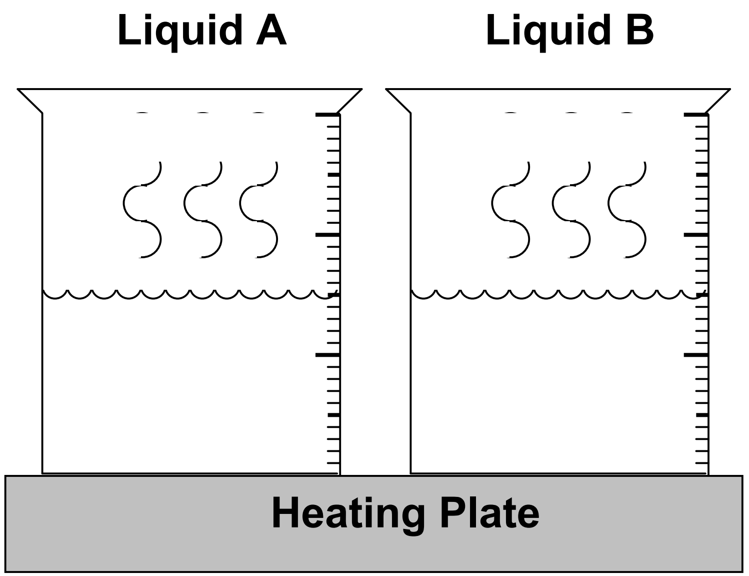
Pretest Question #2 Graph

$[c_A > c_B]$





The specific heat of A is greater than the specific heat of B.

Example of Acceptable Student Explanation

"*Liquid B will experience a higher dT/dt because its specific heat is lower, so it doesn't require as much energy as liquid A to go up 1^{o} C, and since the heat is the same for both, liquid B will rise higher and faster*."

Example of Incorrect Student Explanation

"*Higher Specific heat means it absorbs more heat; raising temp quicker*.

$Q = mc\Delta T \quad c_A > c_B \quad Q_A > Q_B$ "

Example of Incorrect Student Explanation

"Higher Specific heat means it absorbs more heat; raising temp quicker.

$Q = mc\Delta T \quad c_A > c_B \quad Q_A > Q_B$ "

Confusion about meaning of "specific heat"

Pretest Question #2 Results (N=32)

second-semester calculus-based course

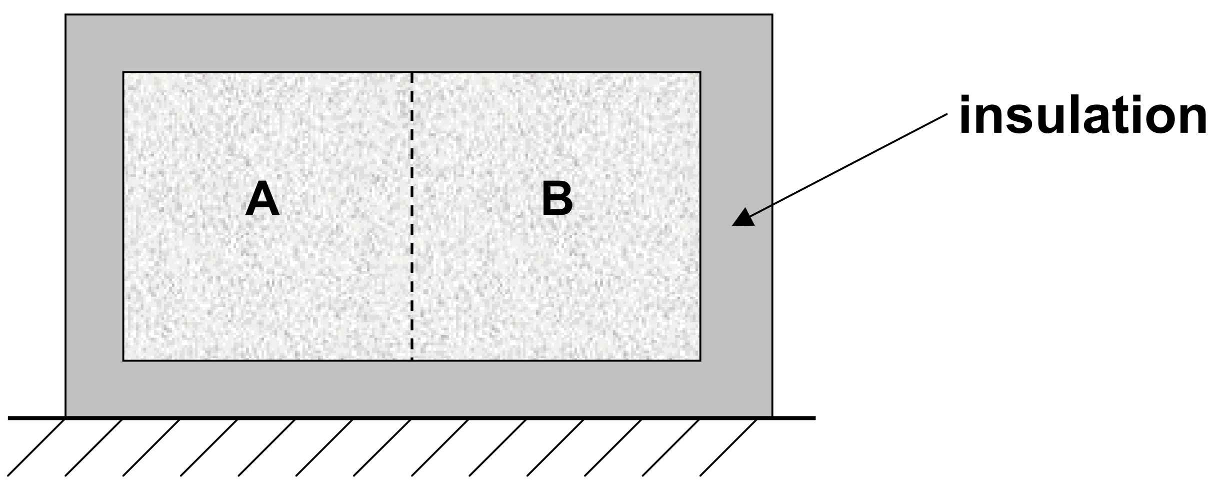
Correct *(Slope of B > A)*	66%
with correct explanation	56%
Incorrect	
Slope of B < A	22%
Negative slope	9%
Other	3%

Worksheet Strategy

- Draw out relationship and contrast meaning of internal energy, energy transfer, and temperature.
- Give students simple variations in temperature, mass, and specific heat to work through.
- Combine multiple variation types to make progressively more complex problems.

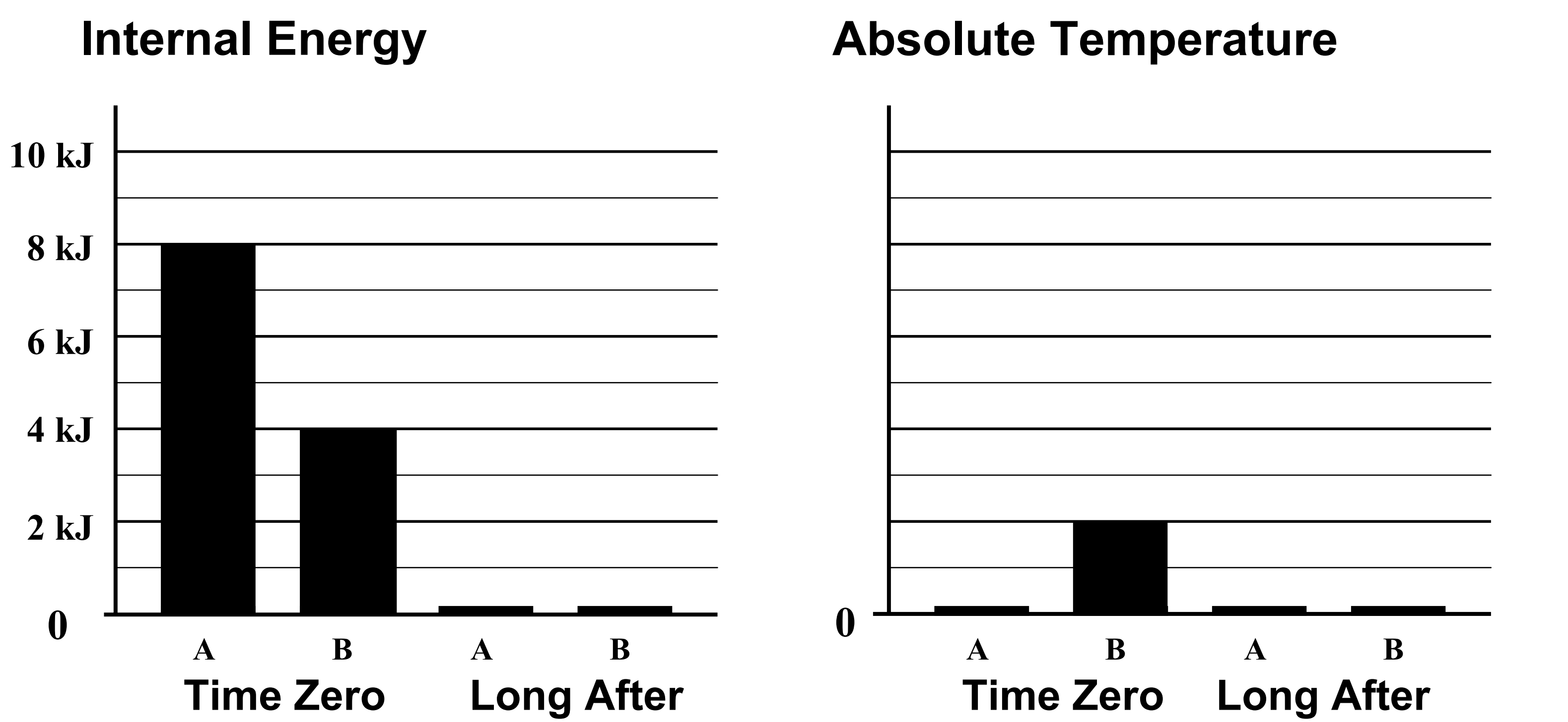
Ideal Gas Problem

Suppose we have two samples, **A** and **B**, of an **ideal gas** placed in a partitioned insulated container of negligible heat capacity. Sample **A** has the **same mass** as sample **B** and each side of the partition has the same volume**.** Energy but no material can pass through the conducting partition; the partition is rigid and cannot move.



Find the absolute temperature of sample A at time zero (the initial time), and plot it on the chart. *Hint:* If two equal masses of ideal gas have the same internal energy, will their temperature be the same, or different? If the ratio of internal energies is $\frac{U_A}{U_B}$, what can you say about $\frac{T_A}{T_B}$?

Complete the bar charts by finding the "Long After" values for temperature and internal energy. Explain your reasoning.

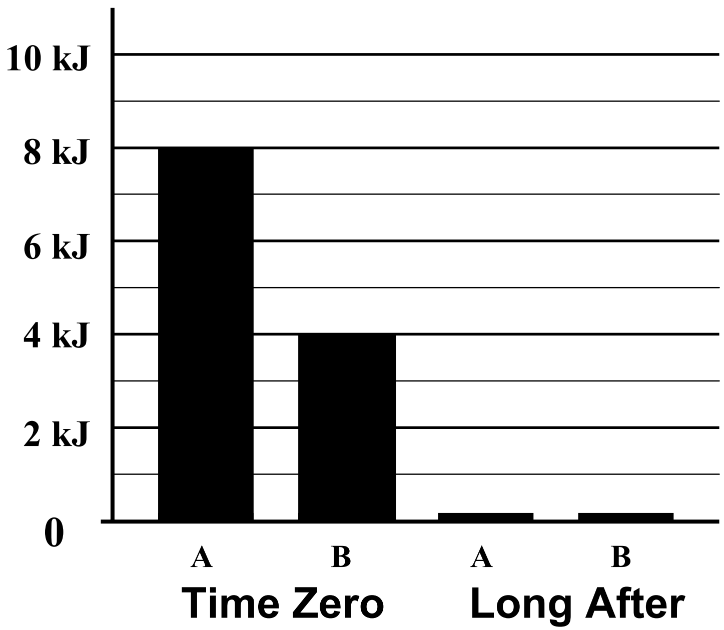


Ideal Gas Bar Graph Solution

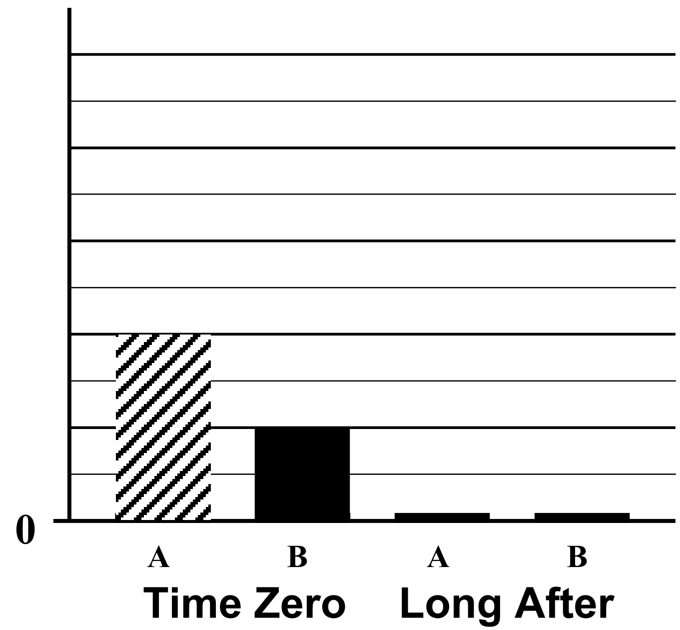
with same mass

$$U = \frac{3}{2}NkT; \quad \text{Equal masses of ideal gas} \Rightarrow \quad \frac{T_A}{T_B} = \frac{U_A}{U_B}$$

Internal Energy



Absolute Temperature

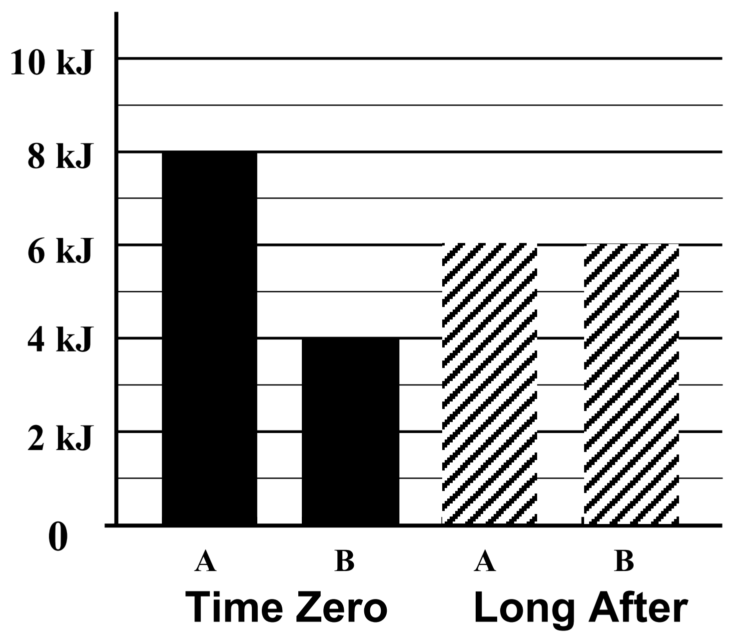


Ideal Gas Bar Graph Solution

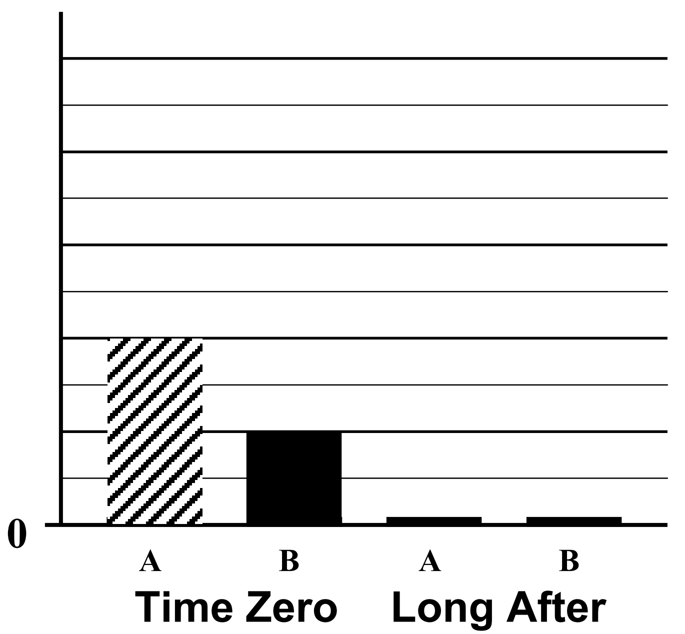
with same mass

energy lost by *A* = energy gained by *B*

Internal Energy



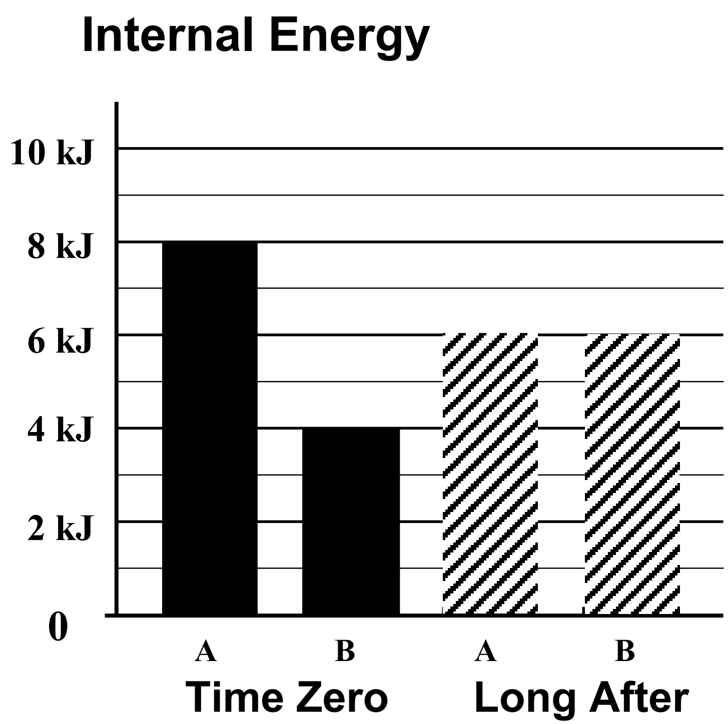
Absolute Temperature

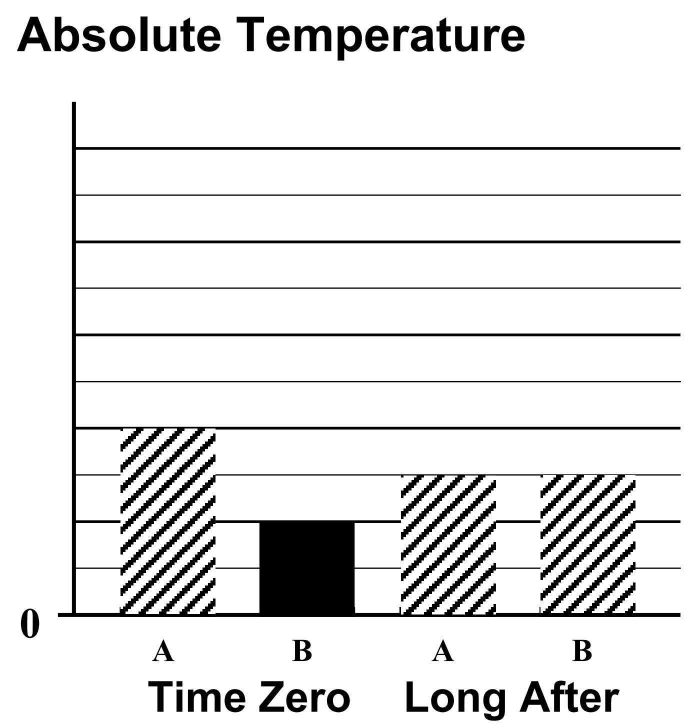


Ideal Gas Bar Graph Solution

with same mass

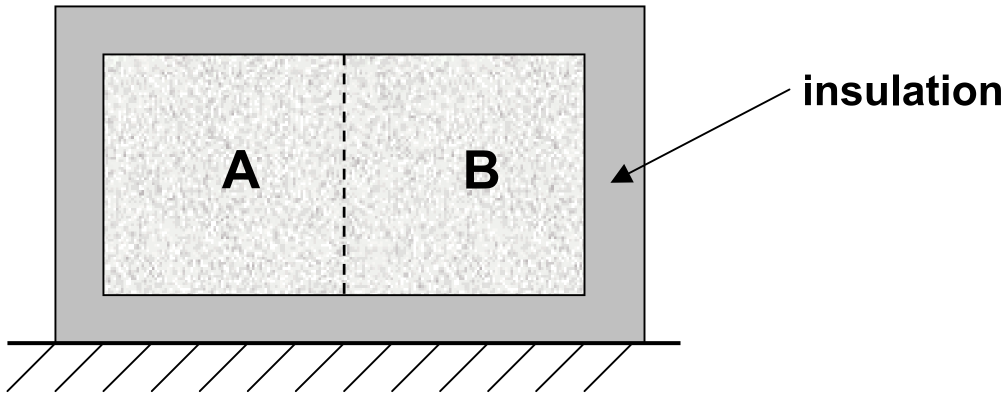
temperature decrease of A = temperature increase of B



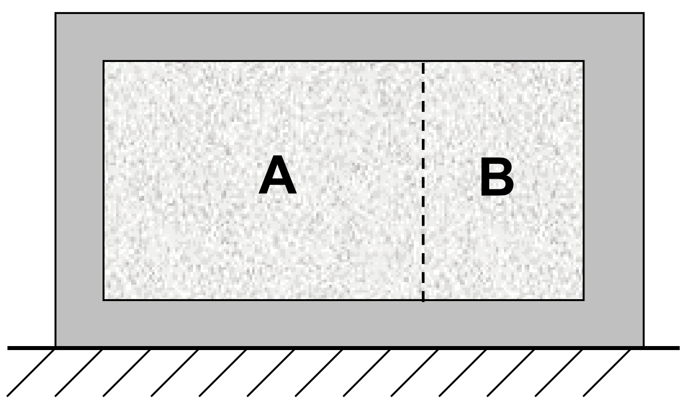


Progression

Ideal Gas with equal masses



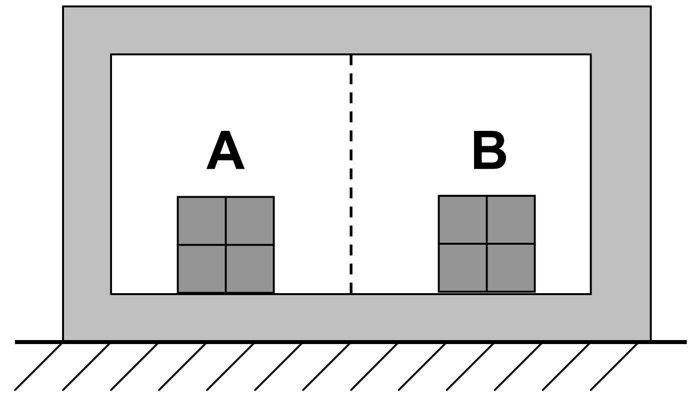
Ideal Gas, $m_A = 2m_B$



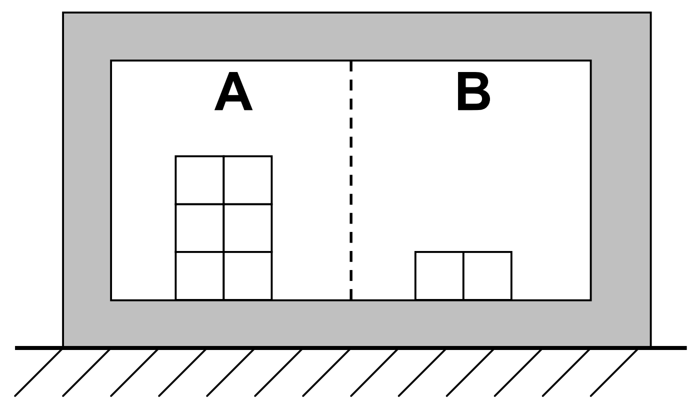
Further Progression

Problem: Given ΔT_A find ΔT_B.

A and B are same material and have same masses, but have different initial temperatures

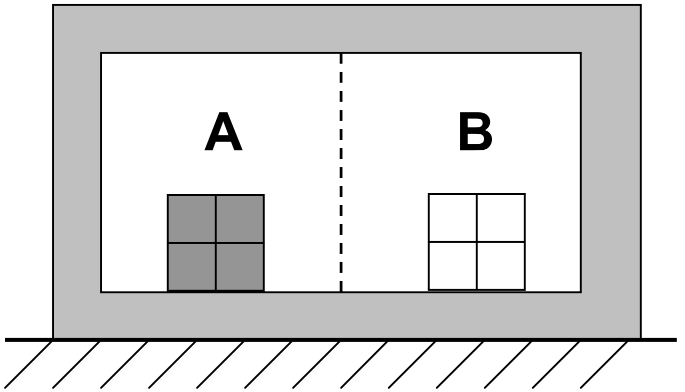


A and B are same material, have different initial temperatures, and $m_A = 3m_B$

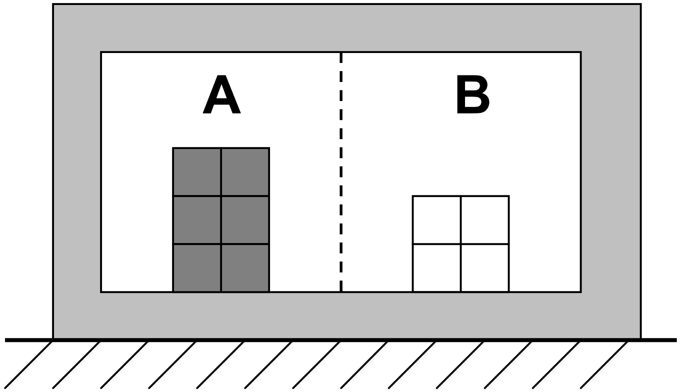


More examples

A and B are different materials with different initial temperatures, $c_A = 2c_B$ and $m_A = m_B$.



A and B are different materials with different initial temperatures, $c_A = 0.5c_B$ and $m_A = 1.5m_B$



Preliminary Assessment

- Pre-test and Post-test administered to entire class (matched sample, $N = 31$)
- Intervention group ($N = 6$) used worksheets during one recitation period (other students did ordinary recitation)
- No statistically significant difference in performance (population too small to tell?)

Conclusions

- Most students capable of doing elementary calorimetry problems despite some confusion.
- Most interview subjects and members of intervention group were eventually able to solve worksheet problems (given assistance and sufficient time).
- Further assessment of worksheet's usefulness is needed.
- Next step is to investigate harder topics for future study