Developing Improved Curricula and Instructional Methods based on Physics Education Research

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Outline

Research-Based Curriculum Development

- Overview

Investigation of Students' Reasoning

- Students' reasoning in thermodynamics
- Students' reasoning in calorimetry
- Diverse representational modes in student learning

Curriculum Development

- Curricular materials for thermodynamics
- Curricular materials for calorimetry

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Curriculum-Development Process

- Carefully investigate students' reasoning when learning with standard instruction
- Identify principal learning difficulties
  - *due to preconceptions, or that arise **during** instruction*
- Develop instructional strategies
- Test, assess, and revise new instructional materials

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Previous Work

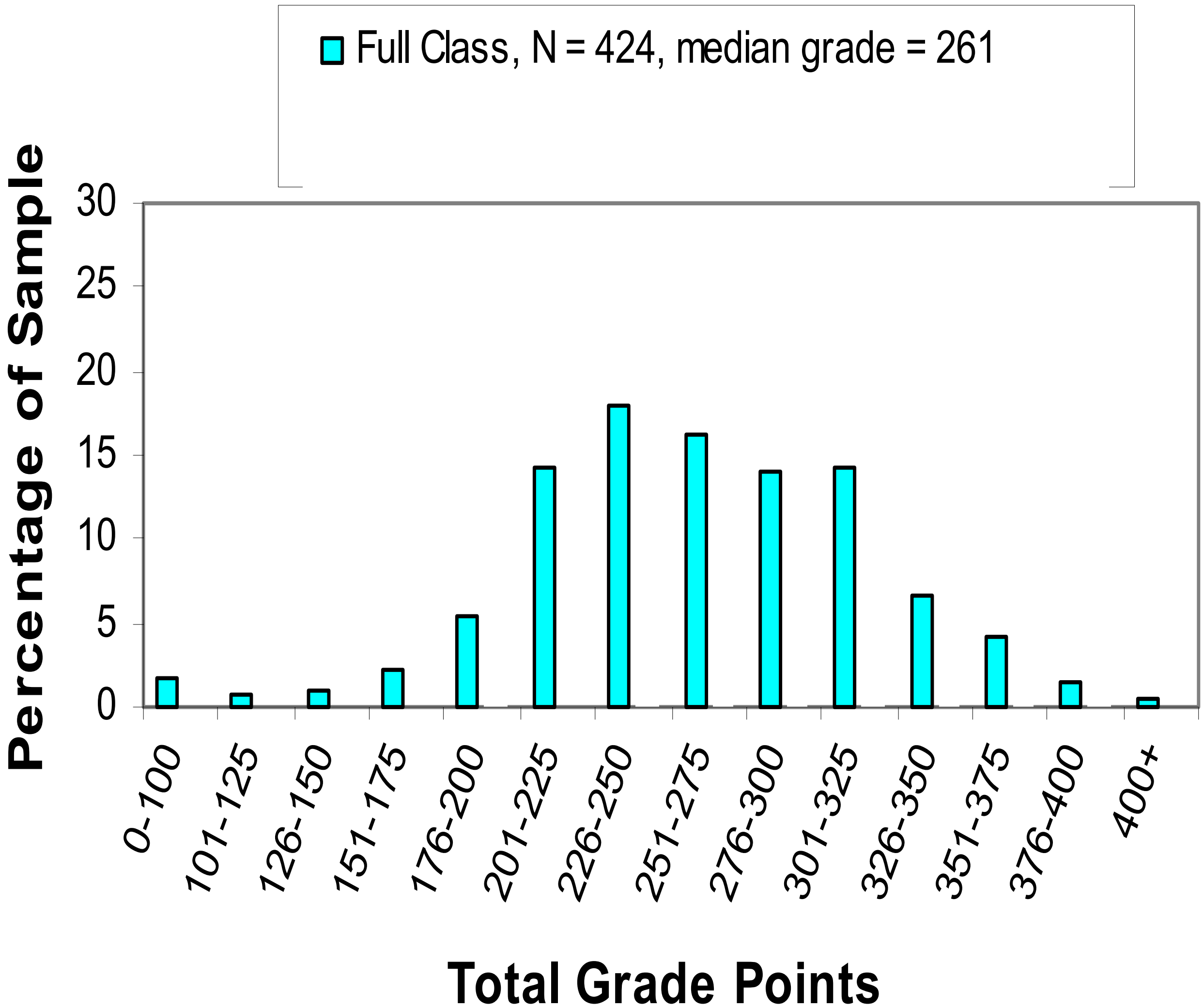
- There have been more than 200 investigations of pre-college students' learning of thermodynamics concepts, all showing serious conceptual difficulties.
- Recently published study of university students showed substantial difficulty with work concept and with the first law of thermodynamics. *M.E. Loverude, C.H. Kautz, and P.R.L. Heron, Am. J. Phys.* ***70****, 137 (2002).*
- Until now there has been only limited study of thermodynamics knowledge of students in introductory (first-year) calculus-based general physics course.

Research Basis for Curriculum Development *(NSF CCLI Project with T. Greenbowe)*

- Investigation of second-semester calculus-based physics course (mostly engineering students).
- Written diagnostic questions administered last week of class in 1999, 2000, and 2001 (N_{total} = 653).
- Detailed interviews (avg. duration ≥ one hour) carried out with 32 volunteers during 2002 (total class enrollment: 424).
  - *interviews carried out after all thermodynamics instruction completed*
  - *final grades of interview sample far above class average*

[two course instructors, ≈ 20 recitation instructors]

Grade Distributions: Interview Sample vs. Full Class



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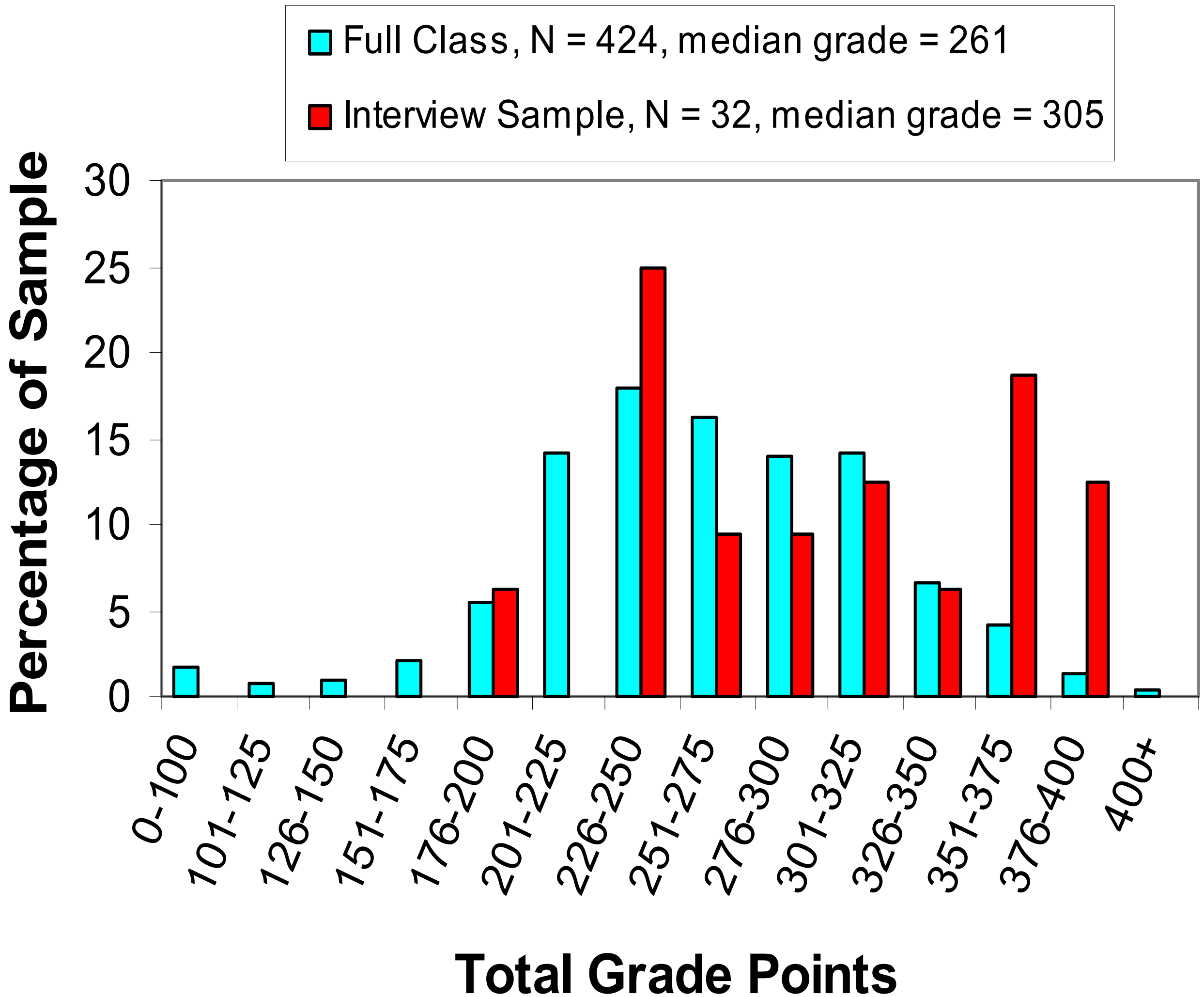

***Interview Sample*:**

34% above 91st percentile; 50% above 81st percentile

Predominant Themes of Students' Reasoning

1. Understanding of concept of state function in the context of energy.
2. Belief that work is a state function.
3. Belief that heat is a state function.
4. Belief that net work done and net heat transferred during a cyclic process are zero.
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Understanding of Concept of State Function in the Context of Energy

- Diagnostic question: two different processes connecting identical initial and final states.
- Do students realize that only initial and final states determine change in a state function?

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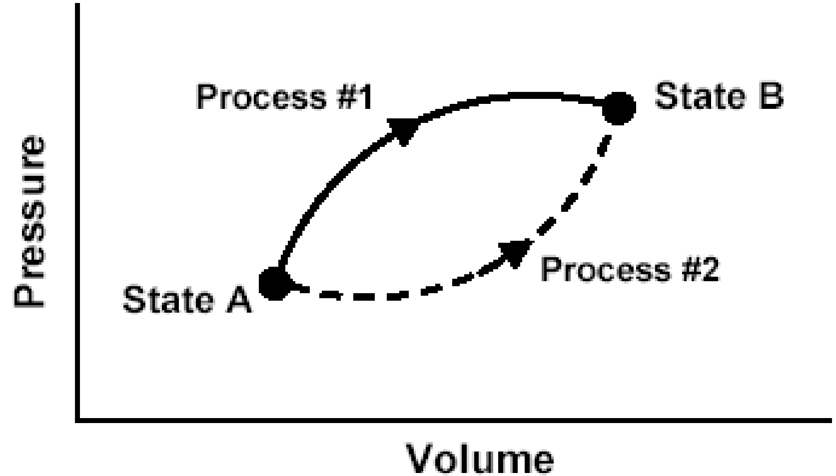

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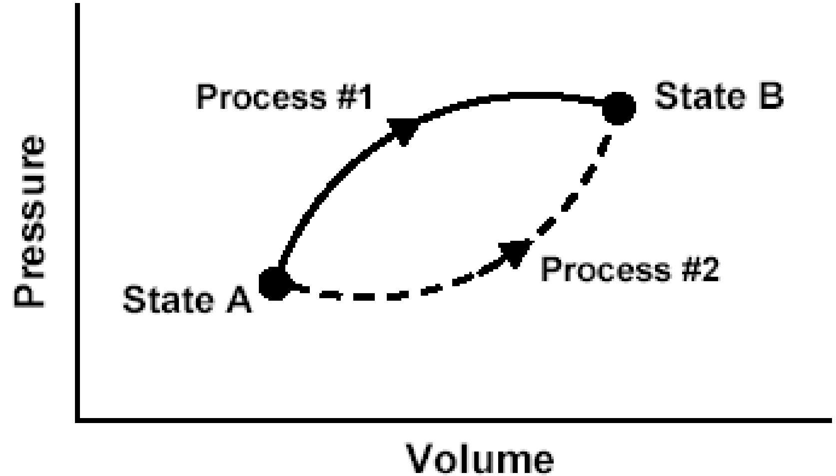

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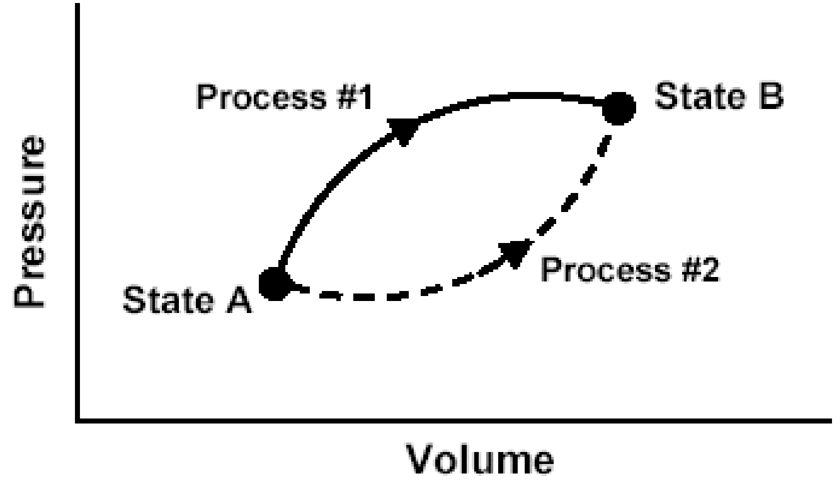

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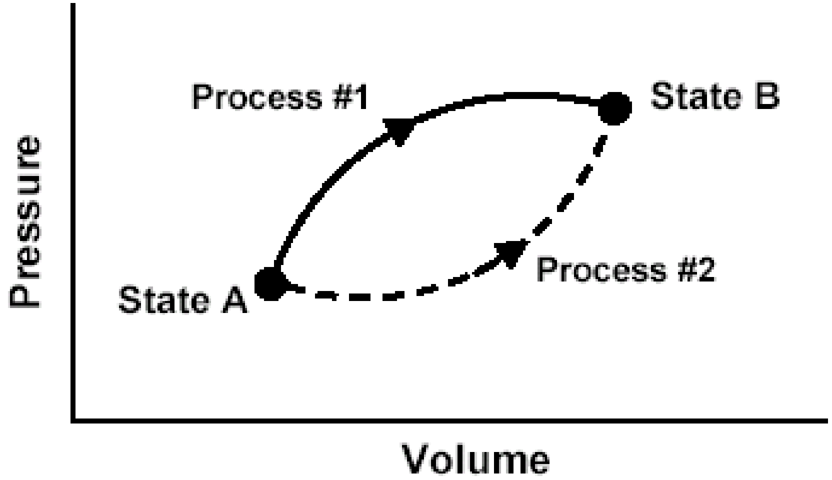

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Students seem to have adequate grasp of state-function concept

- Consistently high percentage (70-90%) of correct responses on relevant questions, with good explanations.

- Interview subjects displayed good understanding of state-function idea.

➡ Students' major conceptual difficulties stemmed from ***overgeneralization*** of state-function concept. **Details to follow . . .**

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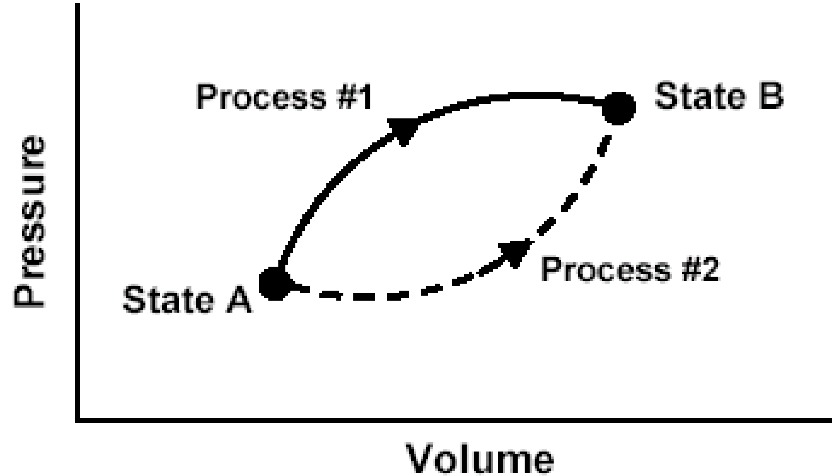

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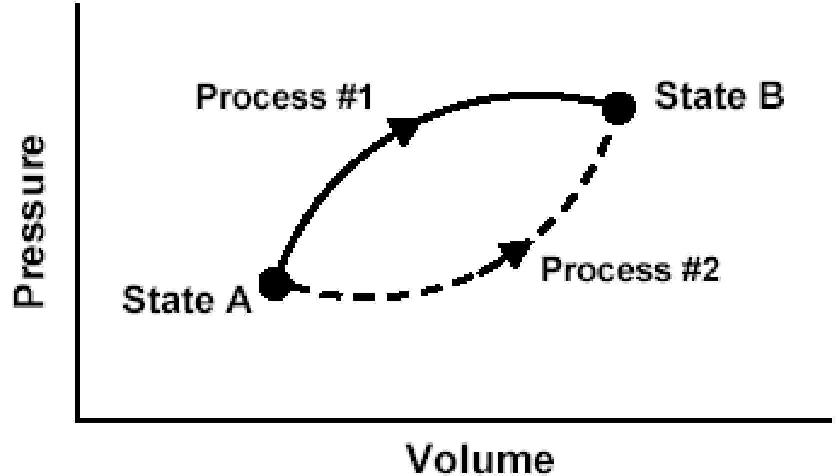

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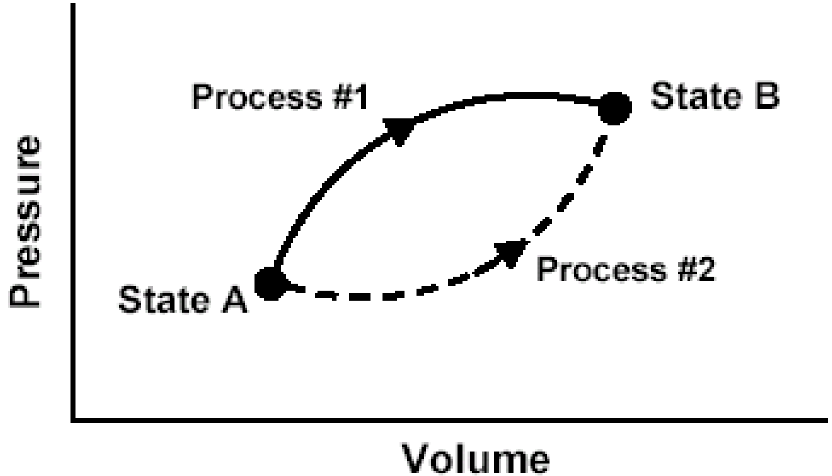

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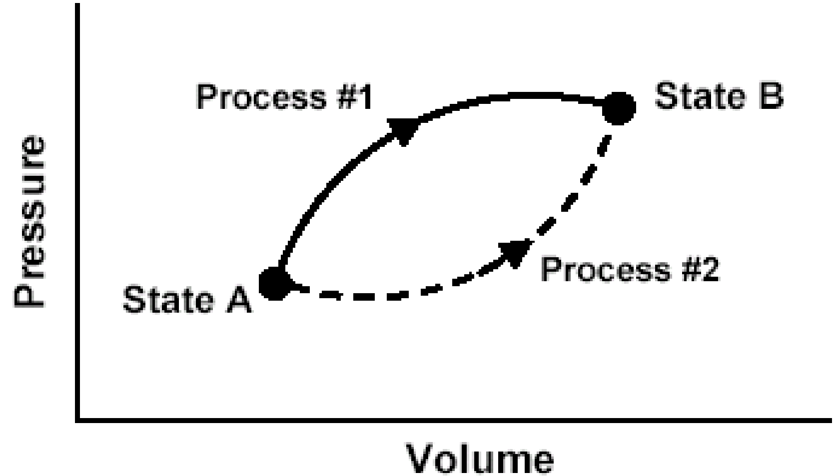

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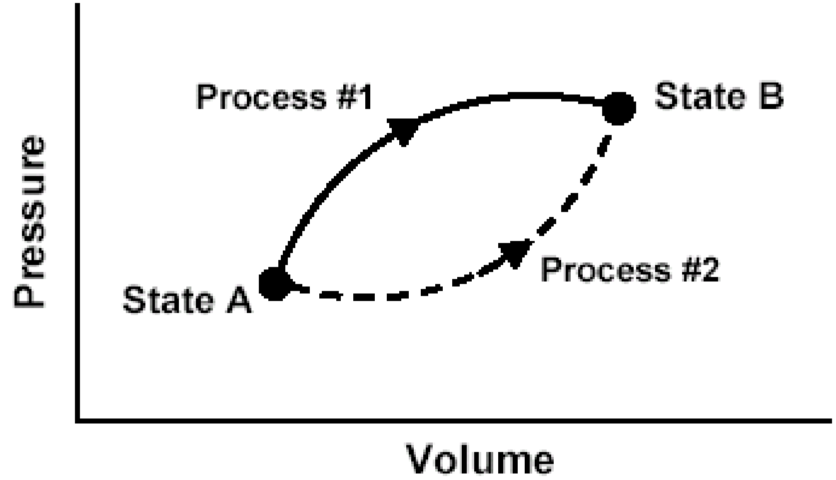

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Responses to Diagnostic Question #1
(Work question)

	1999 (***N***=**186**)	**2000** (***N***=**188**)	**2001** (***N***=**279**)	**2002 Interview Sample** (***N***=**32**)
$W_1 > W_2$				
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	1999 (*N*=186)	**2000** (*N*=188)	**2001** (*N*=279)	**2002** Interview Sample (*N*=32)
$W_1 = W_2$	**25%**	**26%**	**35%**	**22%**
Because work is independent of path	*	**14%**	**23%**	**22%**
Other reason, or none	*	**12%**	**13%**	**0%**

*explanations not required in 1999

Explanations Given by Interview Subjects to Justify $W_1 = W_2$

- "*Work is a state function*."
- "*No matter what route you take to get to state B from A, it's still the same amount of work*."
- "*For work done take state A minus state B; the process to get there doesn't matter*."

Many students come to associate work with properties (and descriptive phrases) only used by instructors in connection with state functions.

Confusion with mechanical work done by conservative forces?

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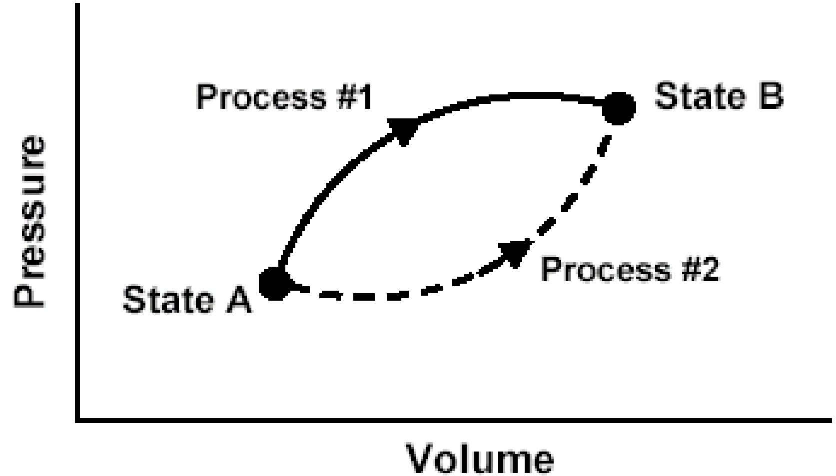

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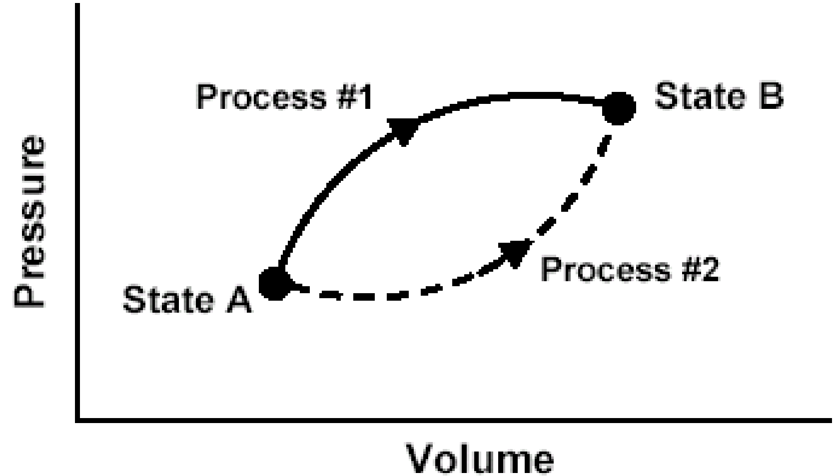

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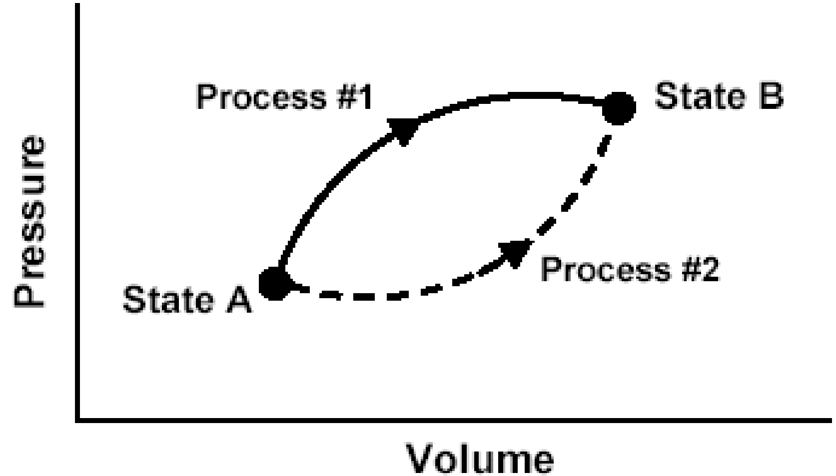
Change in internal energy is the same for Process #1 and Process #2.



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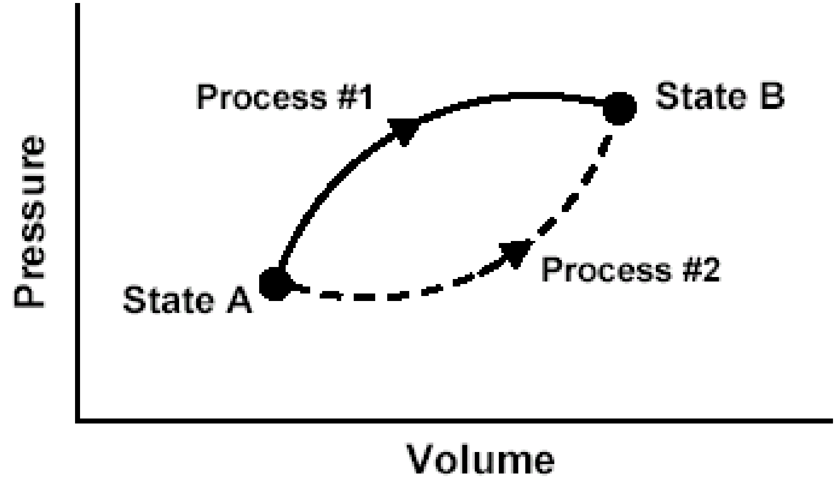

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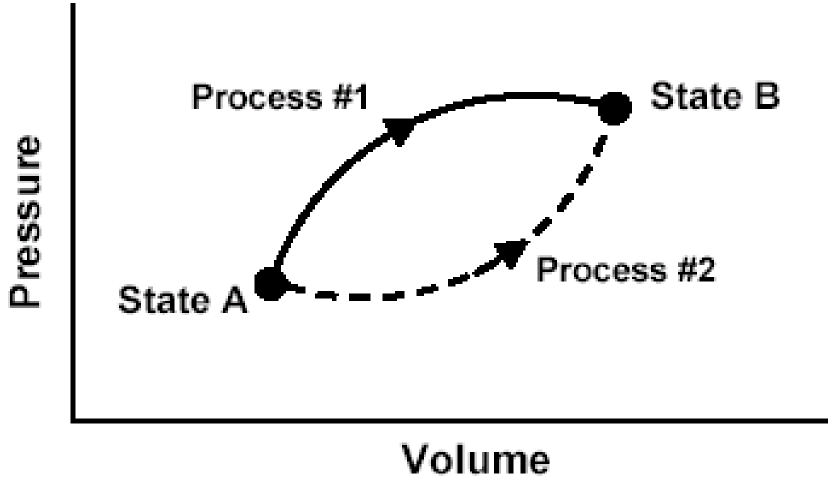

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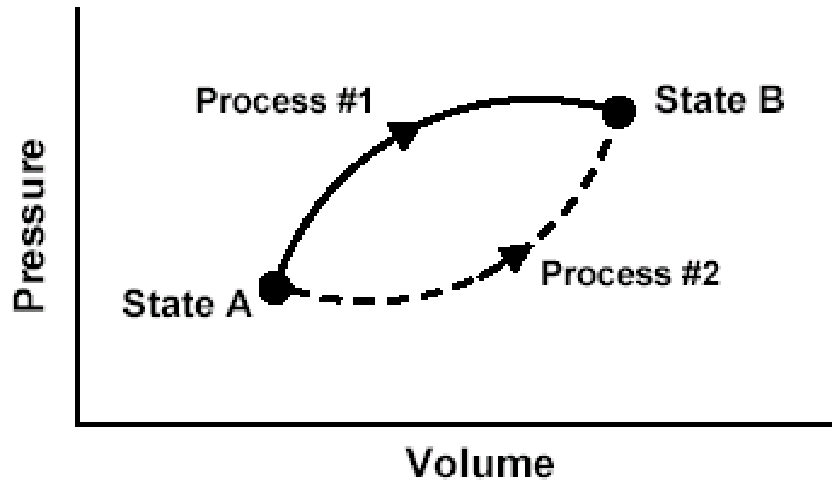

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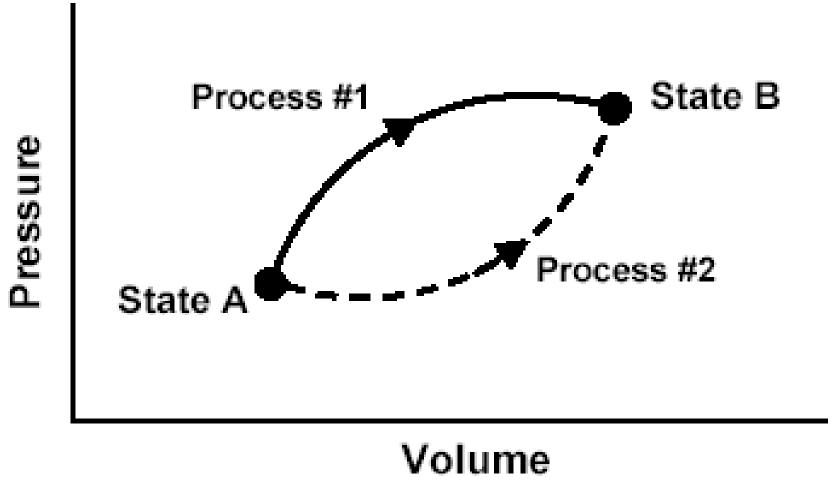

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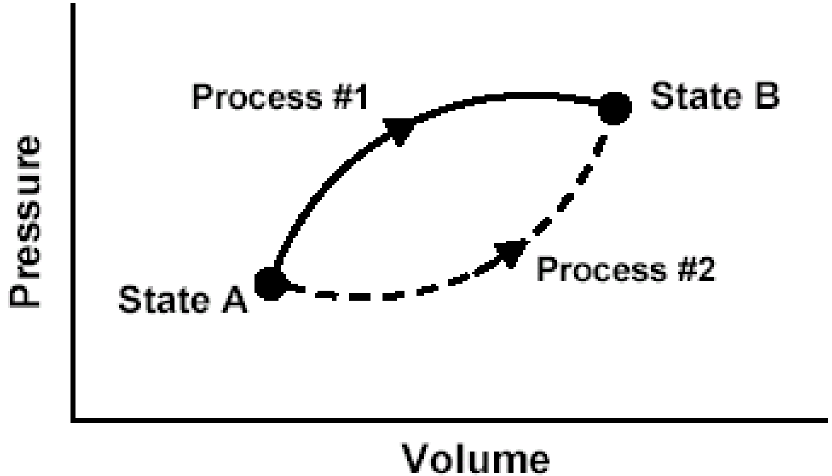

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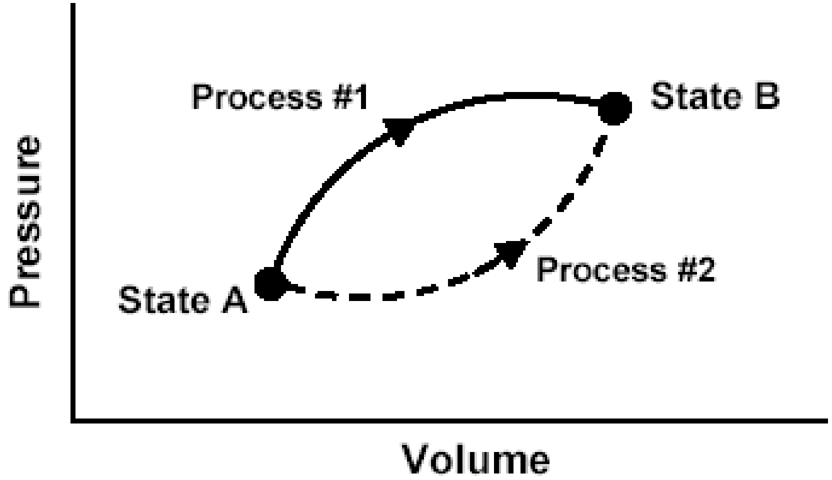
$$W_1 > W_2 \Rightarrow Q_1 > Q_2$$



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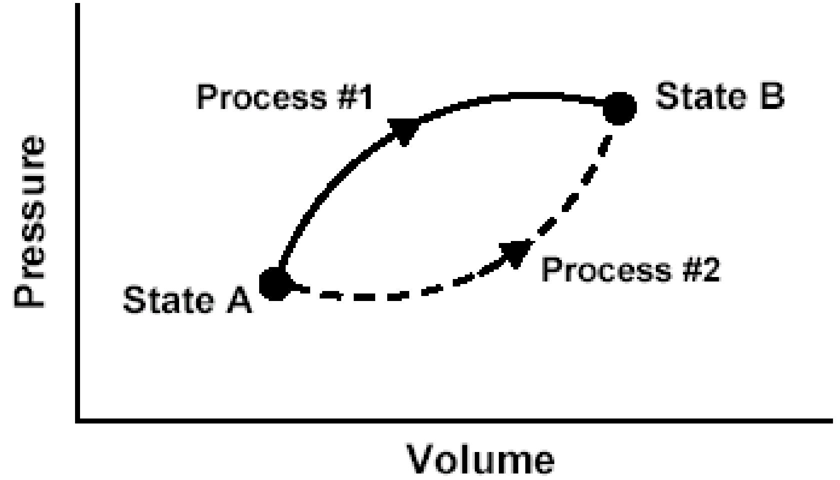

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Responses to Diagnostic Question #2
(Heat question)

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(Heat question)

	1999 (*N*=186)	**2000** (*N*=188)	**2001** (*N*=279)	**2002** Interview Sample (*N*=32)
$Q_1 = Q_2$	**31%**	**43%**	**41%**	**47%**
Because heat is independent of path	**21%**	**23%**	**20%**	**44%**
Other explanation, or none	**10%**	**18%**	**20%**	**3%**

Explanations Given by Interview Subjects to Justify $Q_1 = Q_2$

- "*I believe that heat transfer is like energy in the fact that it is a state function and doesn't matter the path since they end at the same point*."

- "*Transfer of heat doesn't matter on the path you take*."

- "*They both end up at the same PV value so . . . They both have the same Q or heat transfer*."

➢ **Almost 150 students offered arguments similar to these either in their written responses or during the interviews. Confusion with "$Q = mc\Delta T$" ?**

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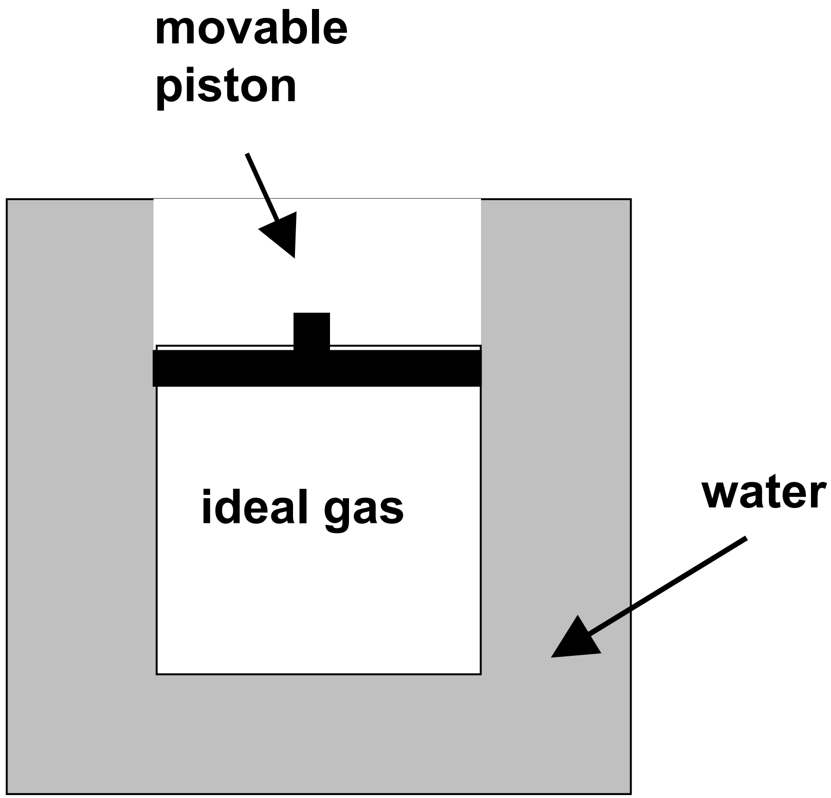
Interview Questions

A fixed quantity of ideal gas is contained within a metal cylinder that is sealed with a movable, frictionless, insulating piston.

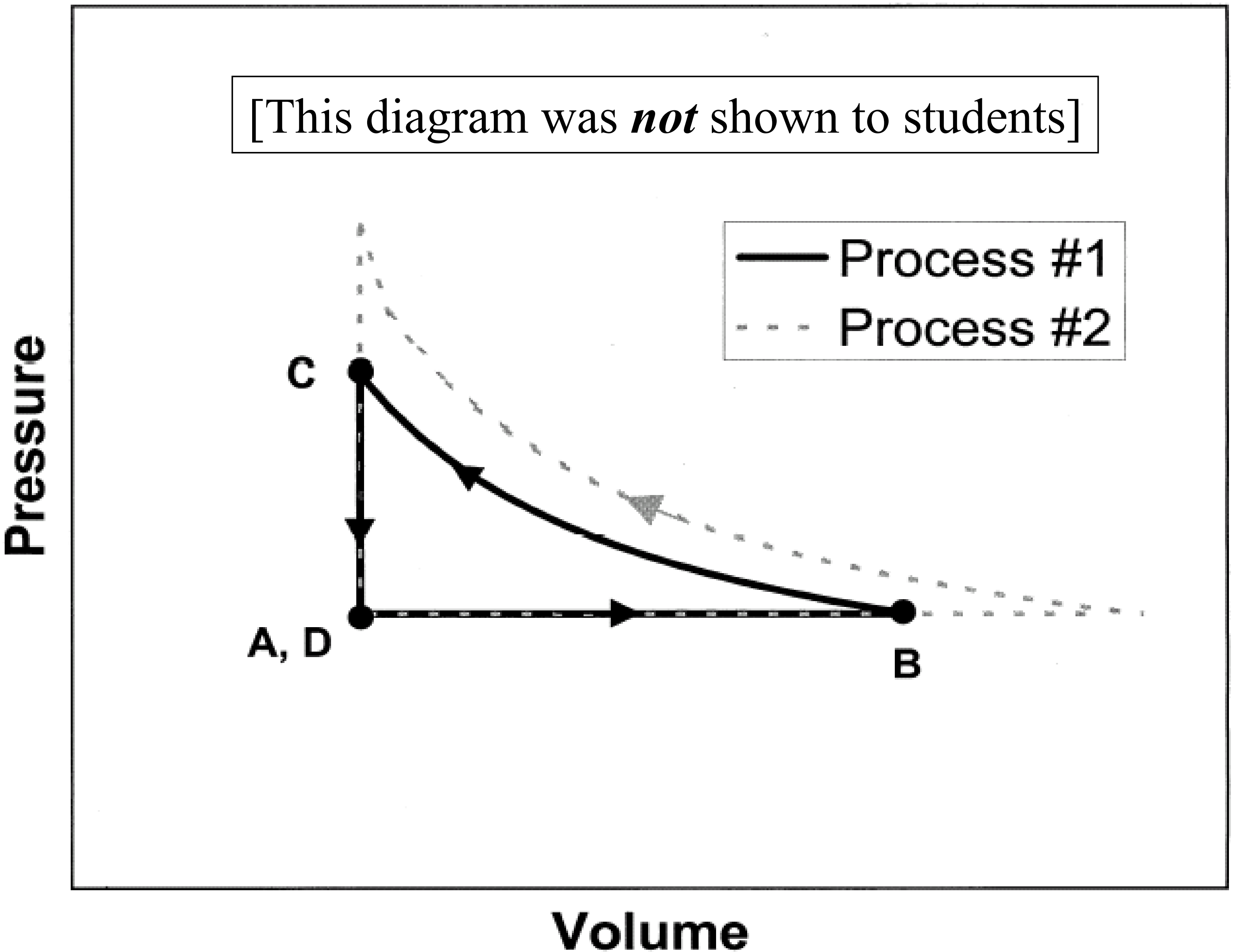
The cylinder is surrounded by a large container of water with high walls as shown. We are going to describe two separate processes, Process #1 and Process #2.

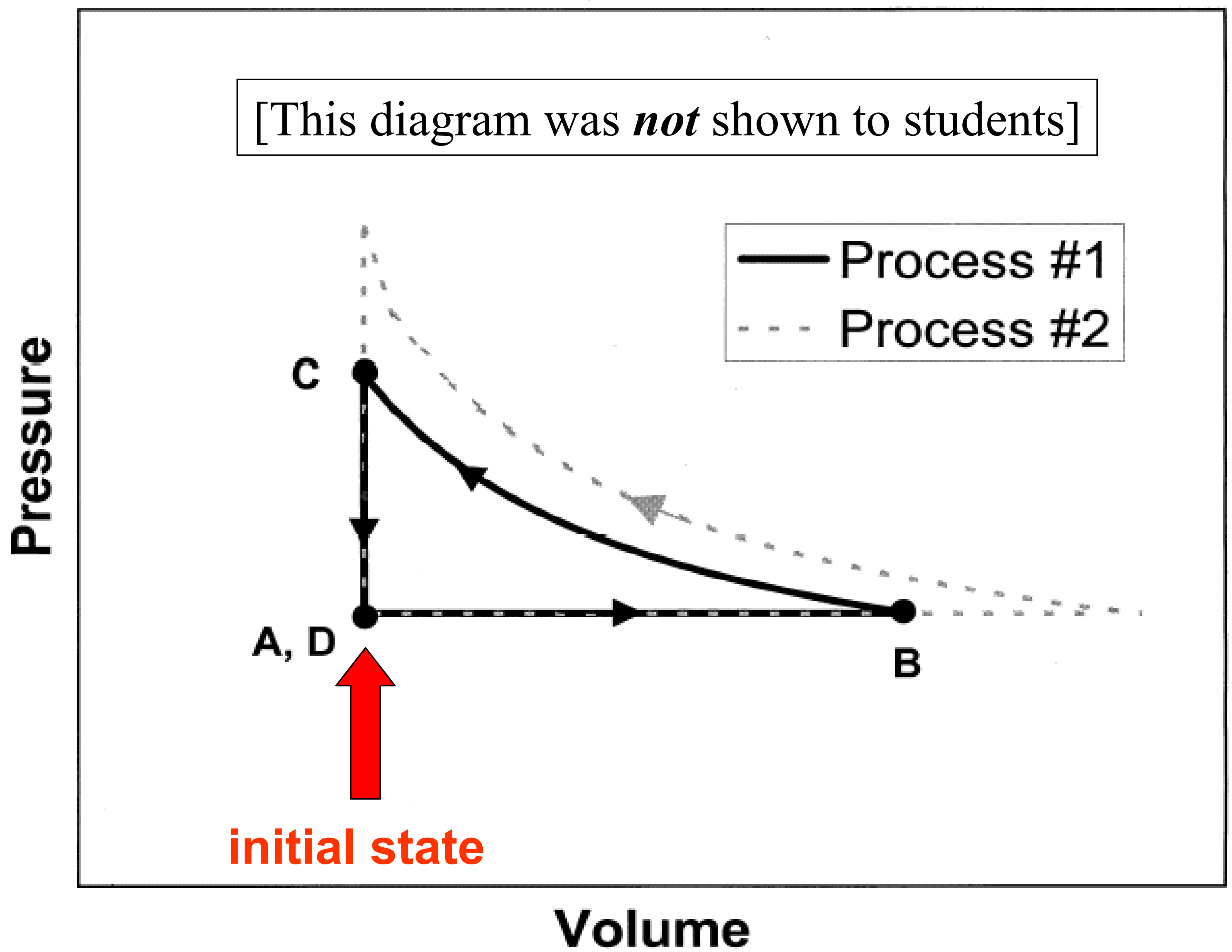
At initial time *A*, the gas, cylinder, and water have all been sitting in a room for a long period of time, and all of them are at room temperature



Time *A*

Entire system at room temperature.


[This diagram was *not* shown to students]
Process #1
Process #2
C
A, D
B
Pressure
Volume


[This diagram was not shown to students]
Process #1
Process #2
C
A, D
B
initial state
Pressure
Volume

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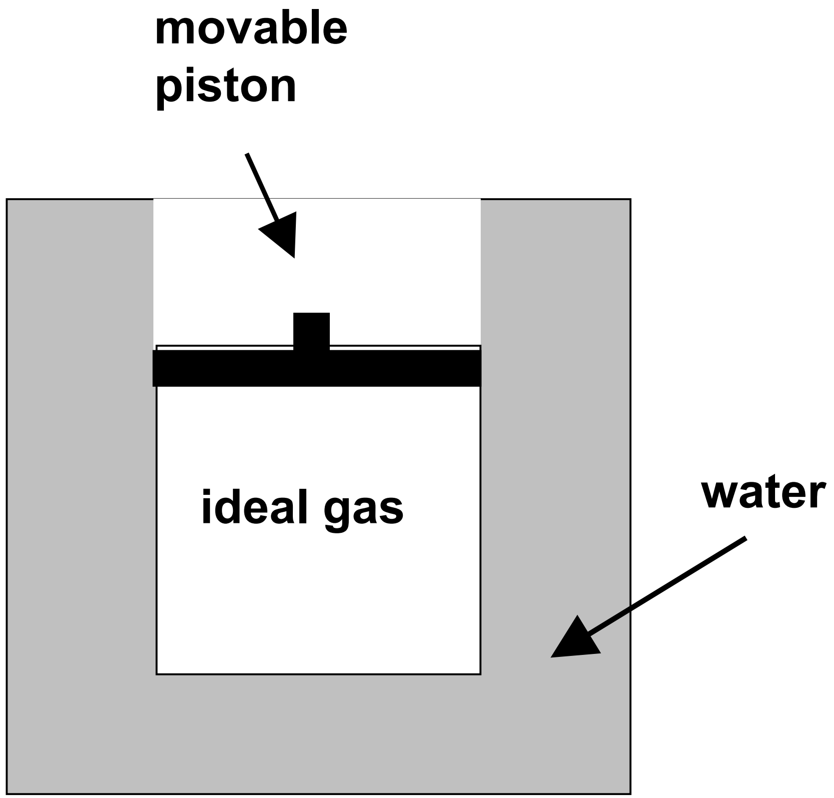
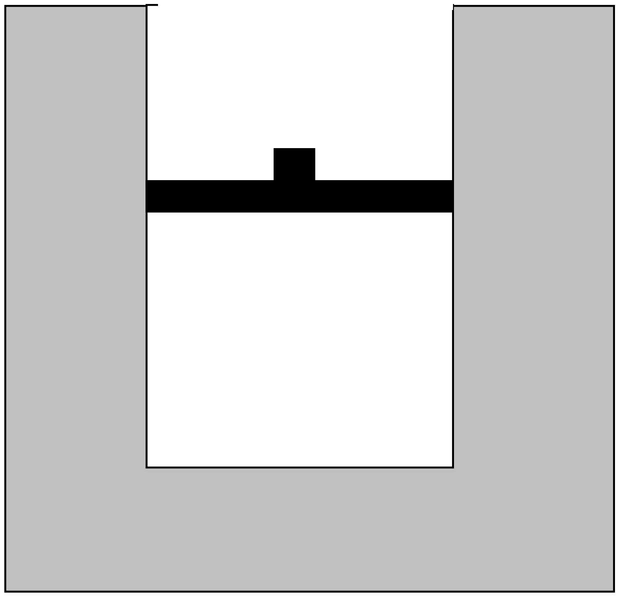


Time *A*

Entire system at room temperature.

Step 1. We now begin Process #1: The water container is gradually heated, and the piston *very slowly* moves upward. At time *B* the heating of the water stops, and the piston stops moving when it is in the position shown in the diagram below:



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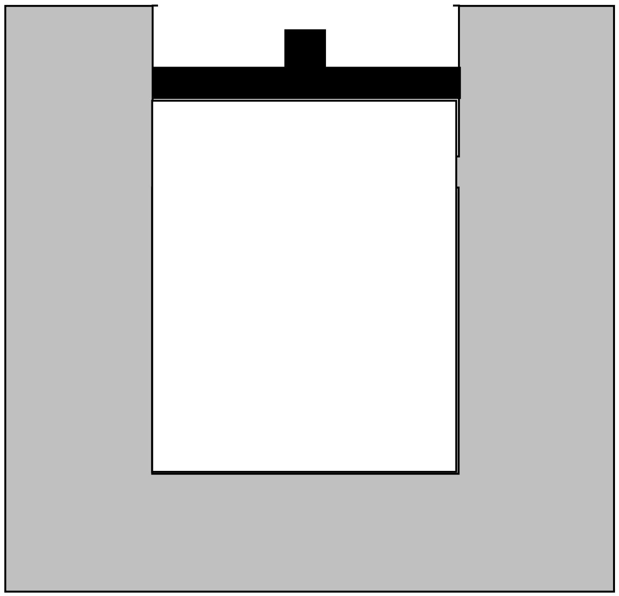

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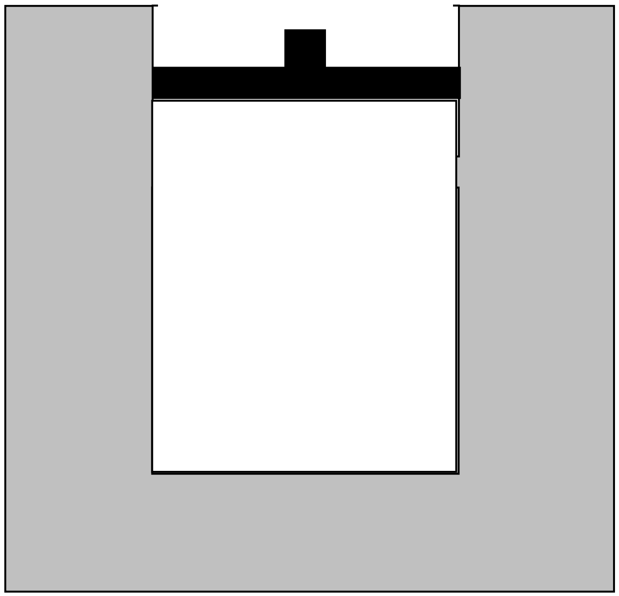
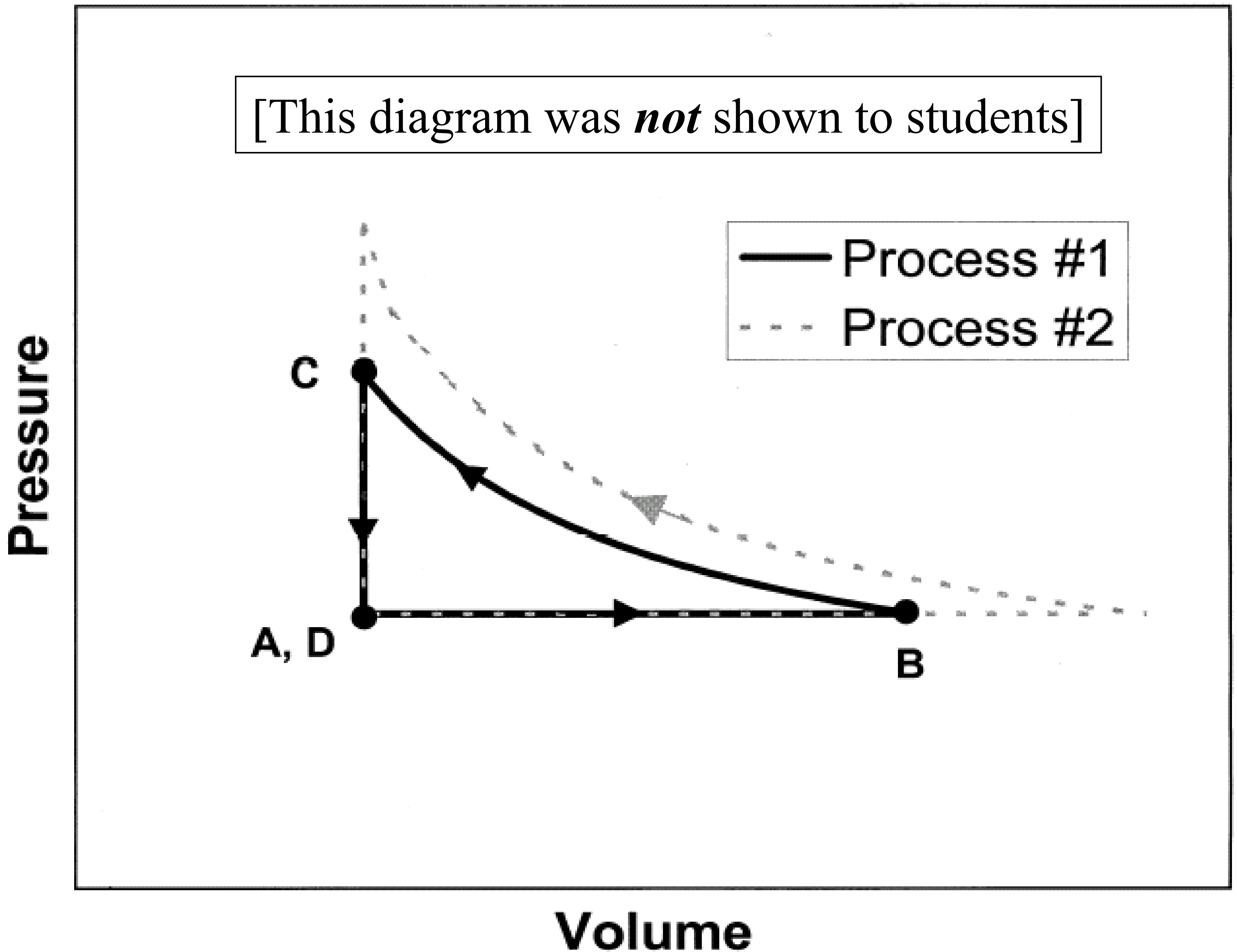
Time *B*

Piston in new position.

Temperature of system has changed.





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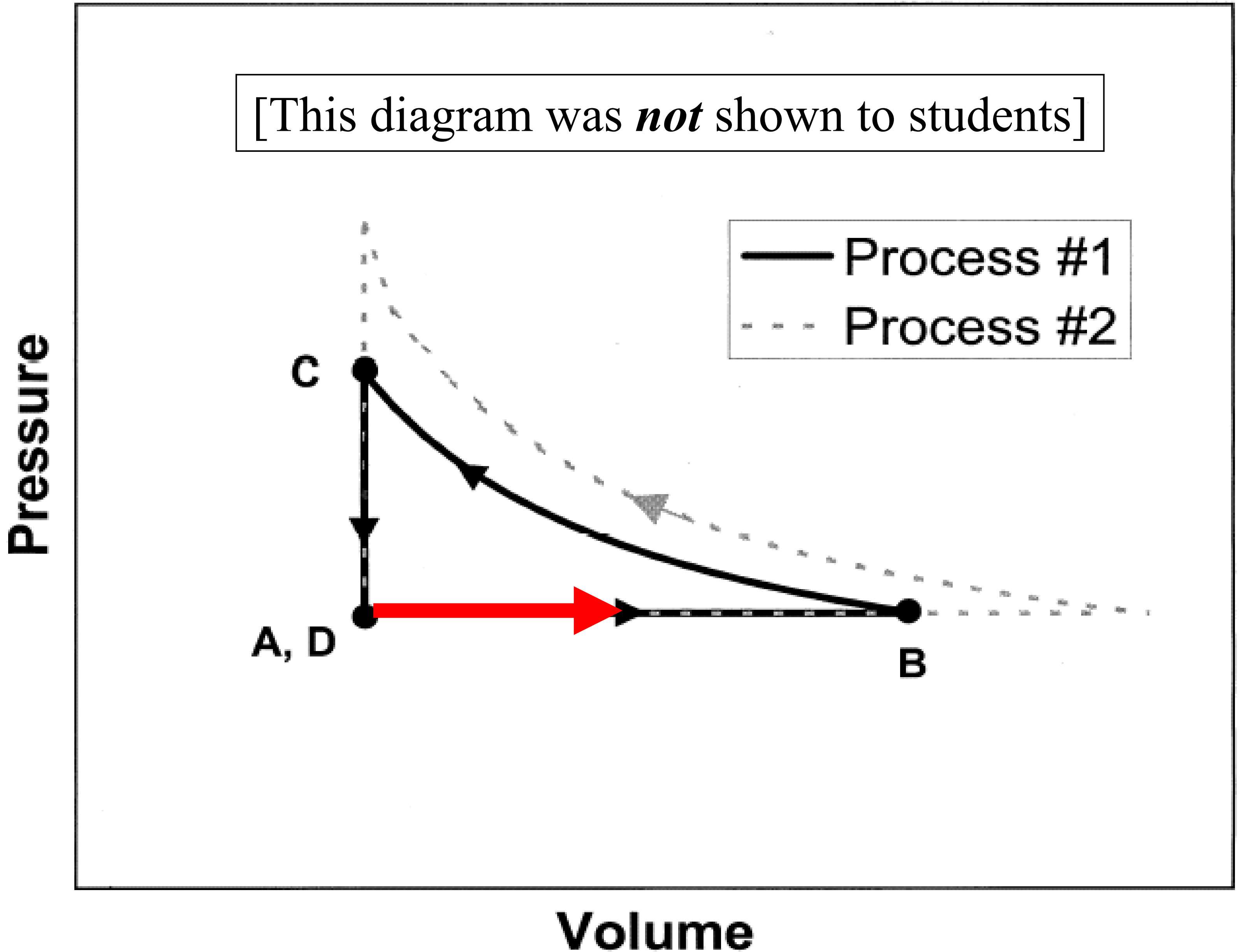
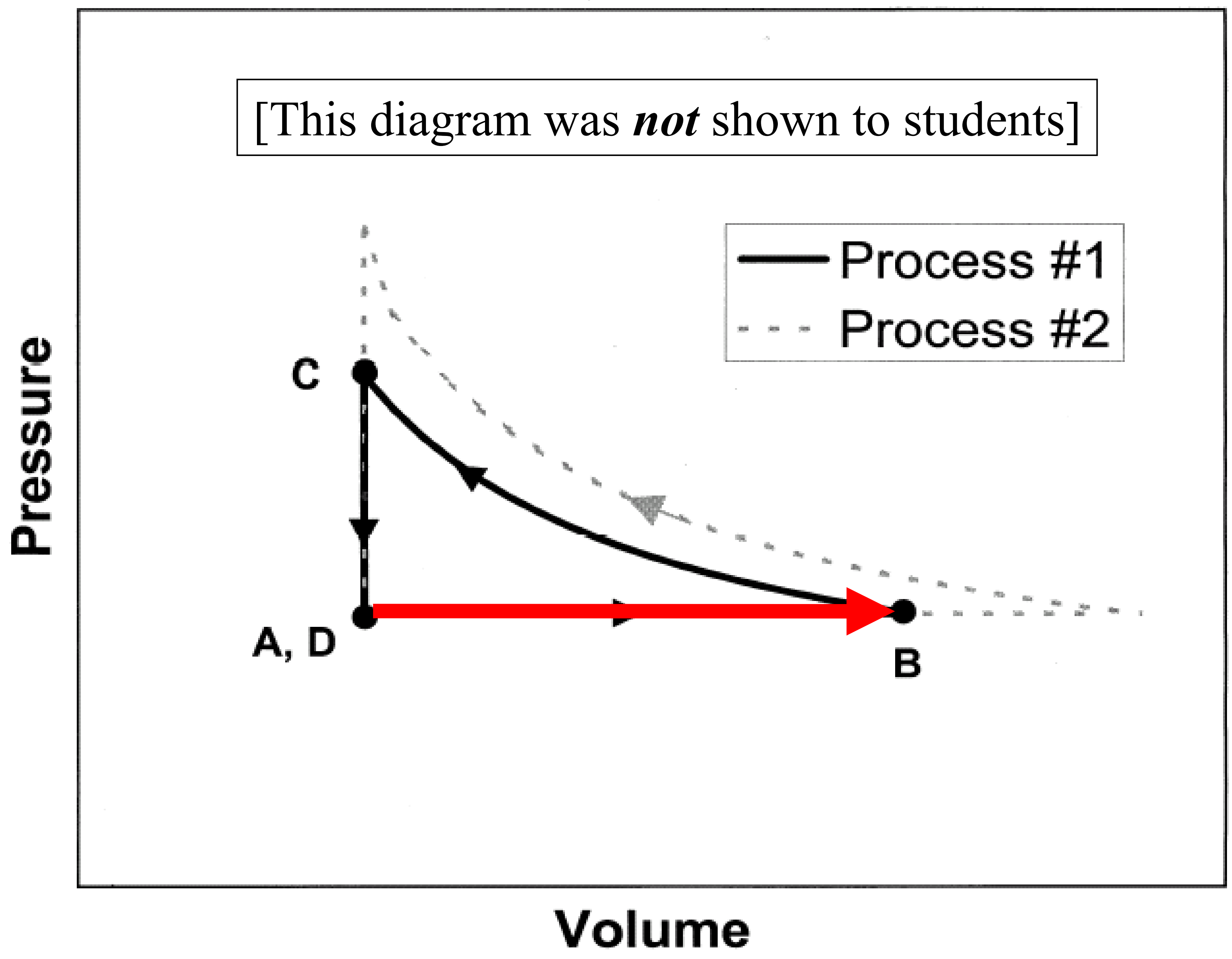

[This diagram was *not* shown to students]
Process #1
Process #2
C
A, D
B
Pressure
Volume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Process #1
Process #2
C
A, D
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Pressure
Volume

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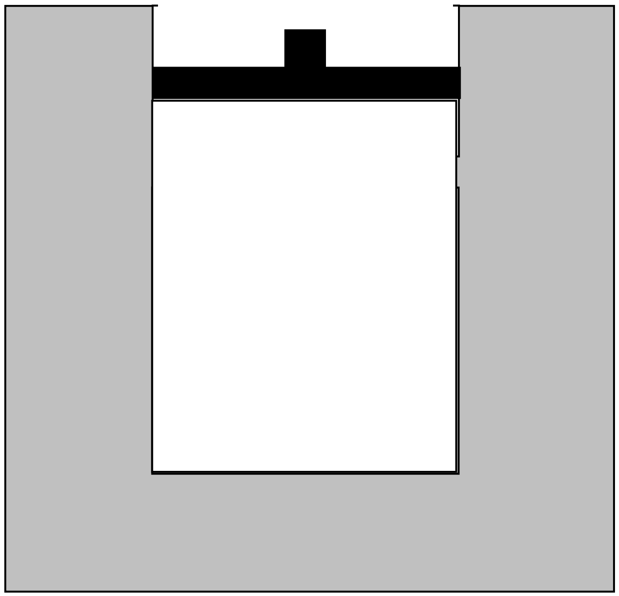
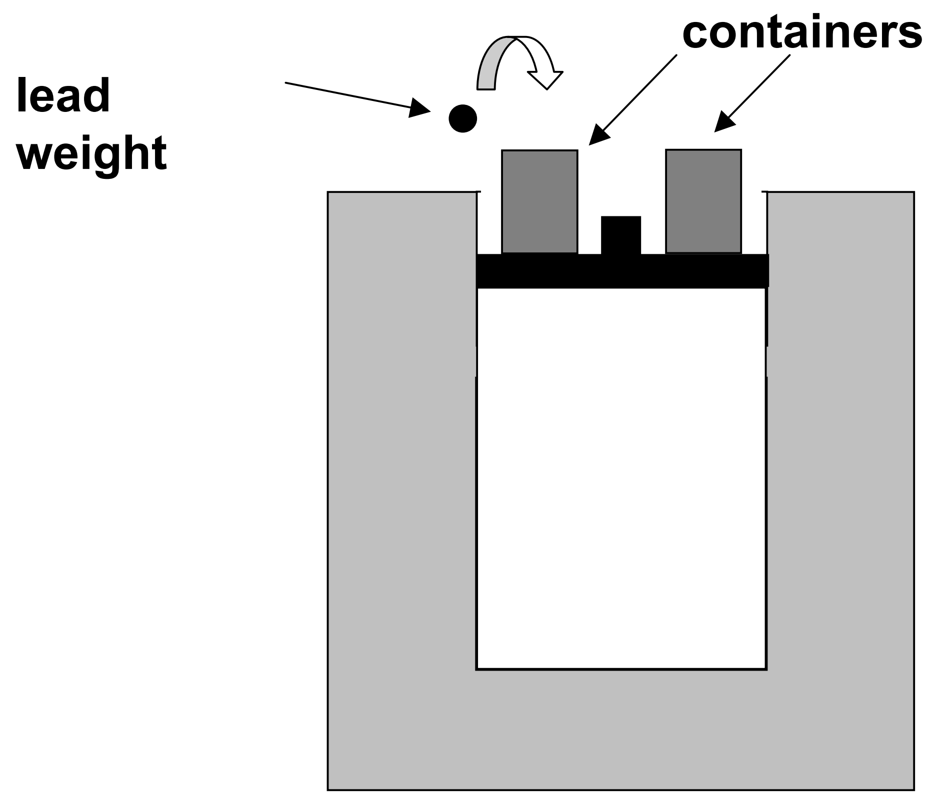
Time *B*

Piston in new position.

Temperature of system has changed.



Step 2. Now, empty containers are placed on top of the piston as shown. Small lead weights are gradually placed in the containers, one by one, and the piston is observed to move down slowly. While this happens, the temperature of the water is nearly unchanged, and the gas temperature remains practically *constant*. (That is, it remains at the temperature it reached at time *B*, after the water had been heated up.)



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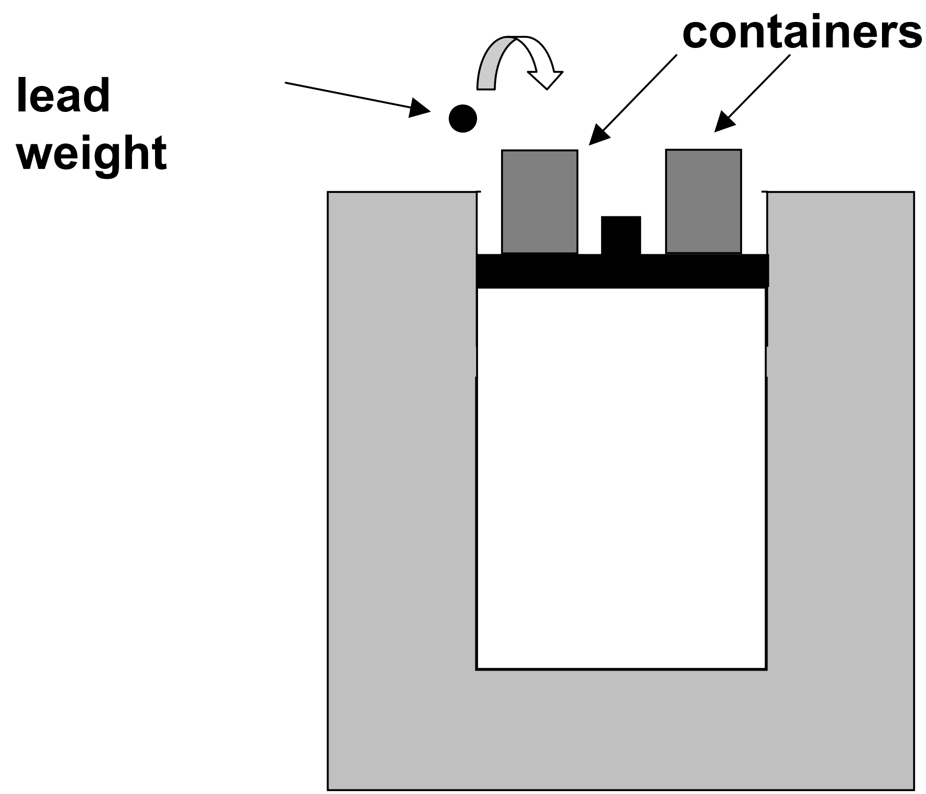

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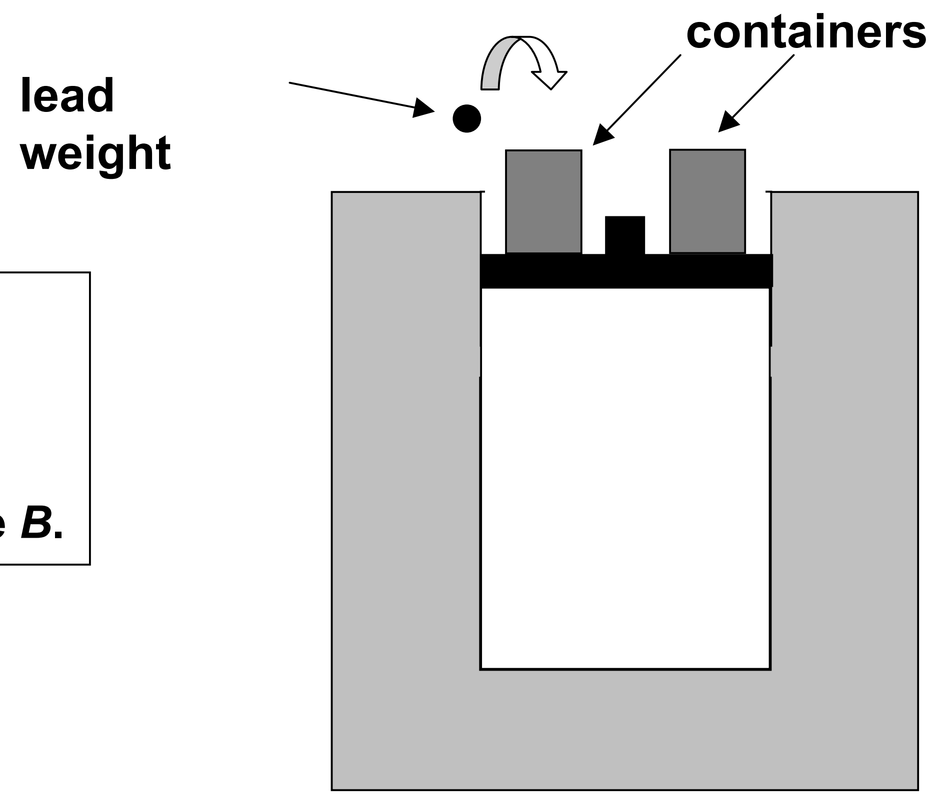

weights being added

Piston moves down slowly.

Temperature remains same as at time *B*.

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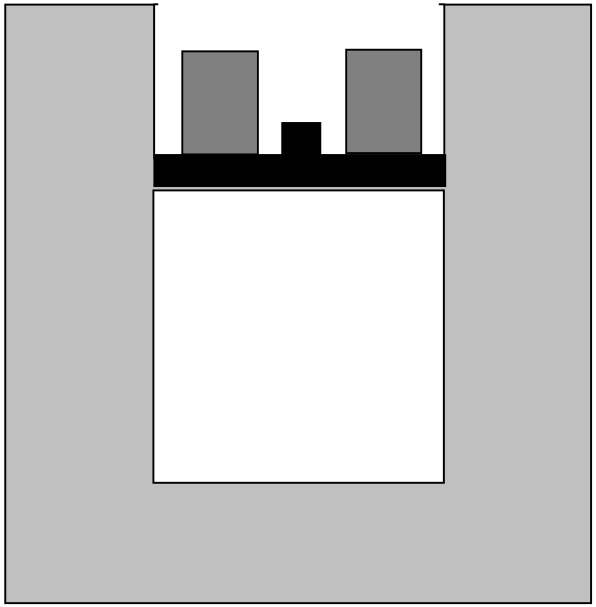
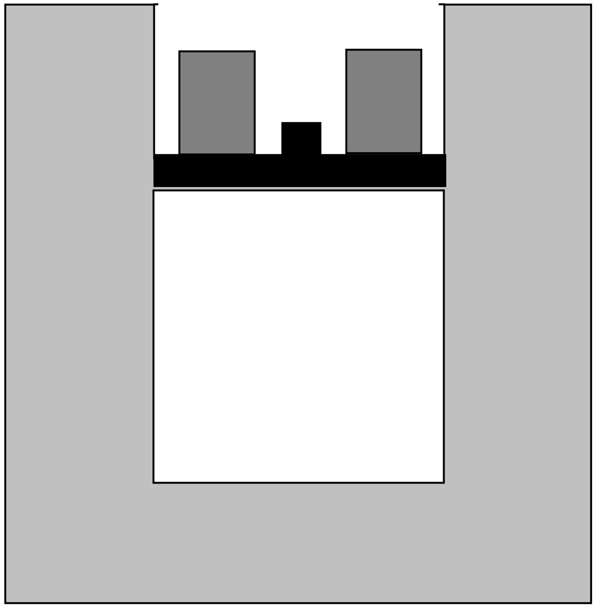


Step 3. At time *C* we stop adding lead weights to the container and the piston stops moving. (The weights that we have already added up until now are still in the containers.) The piston is now found to be at *exactly the same position it was at time **A*** .



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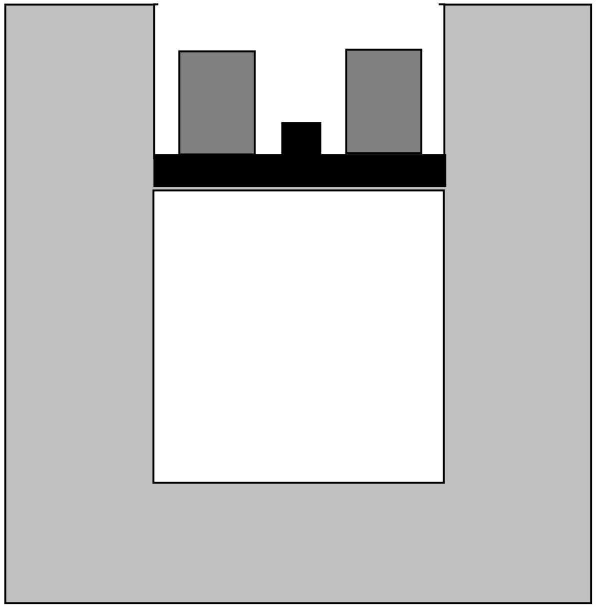
Time *C*

Weights in containers.

Piston in same position as at time *A*.

Temperature same as at time *B*.



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Time *C*

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Piston in same position as at time *A*.

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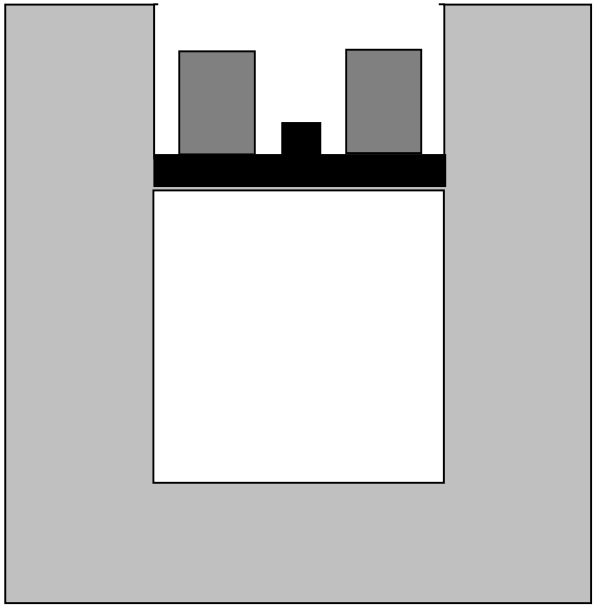
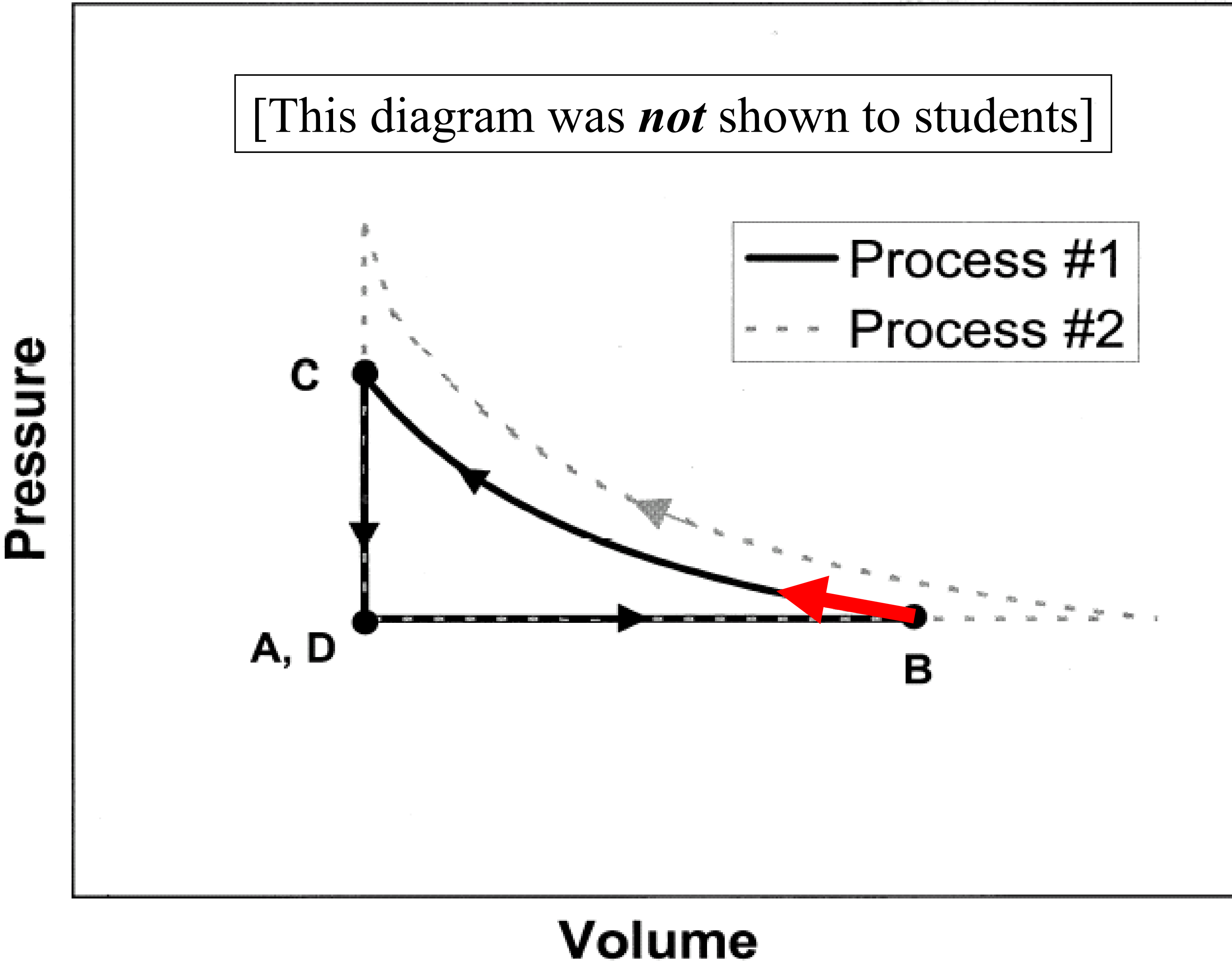
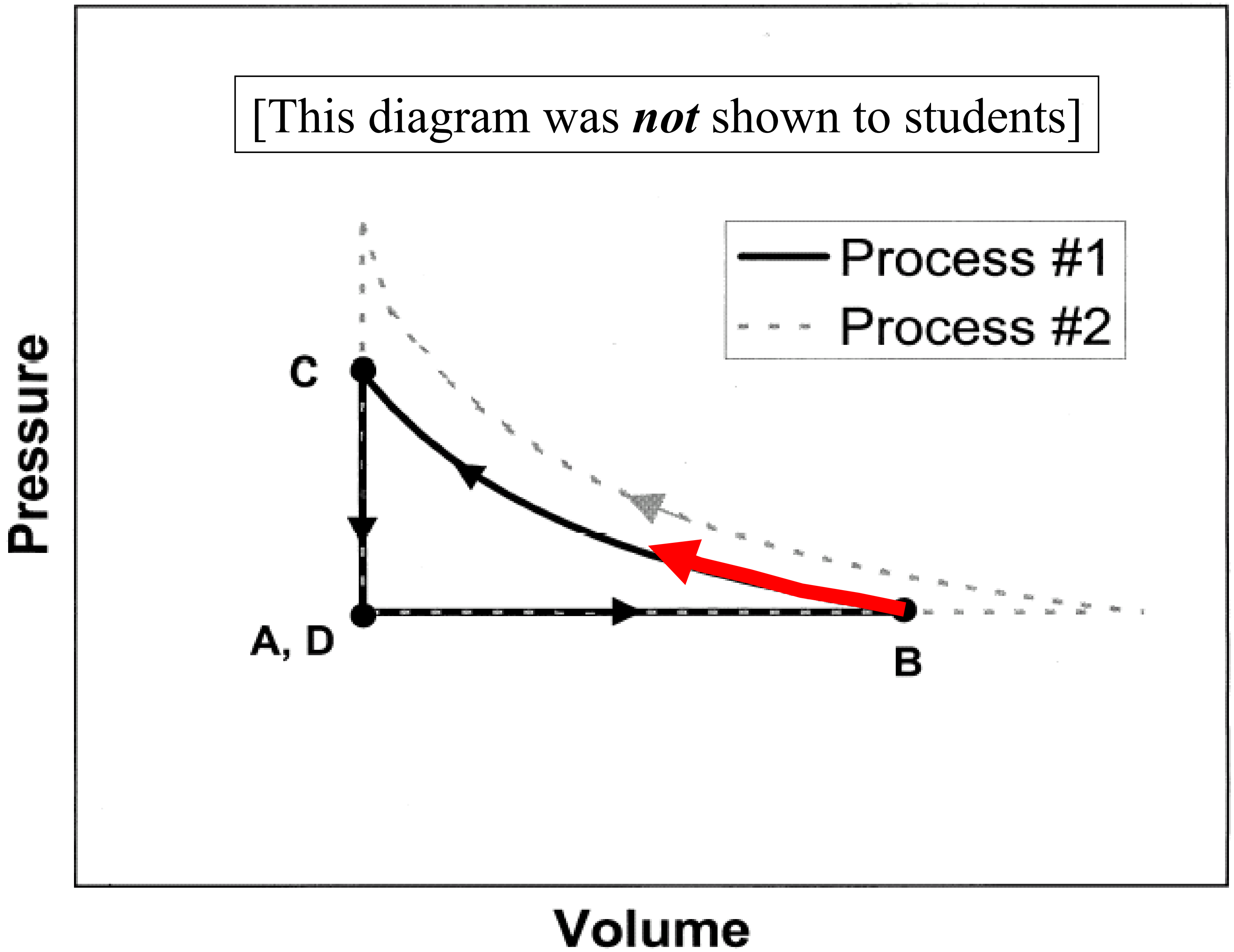



[This diagram was *not* shown to students]
Process #1
Process #2
C
A, D
B
Pressure
Volume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Process #1
Process #2
C
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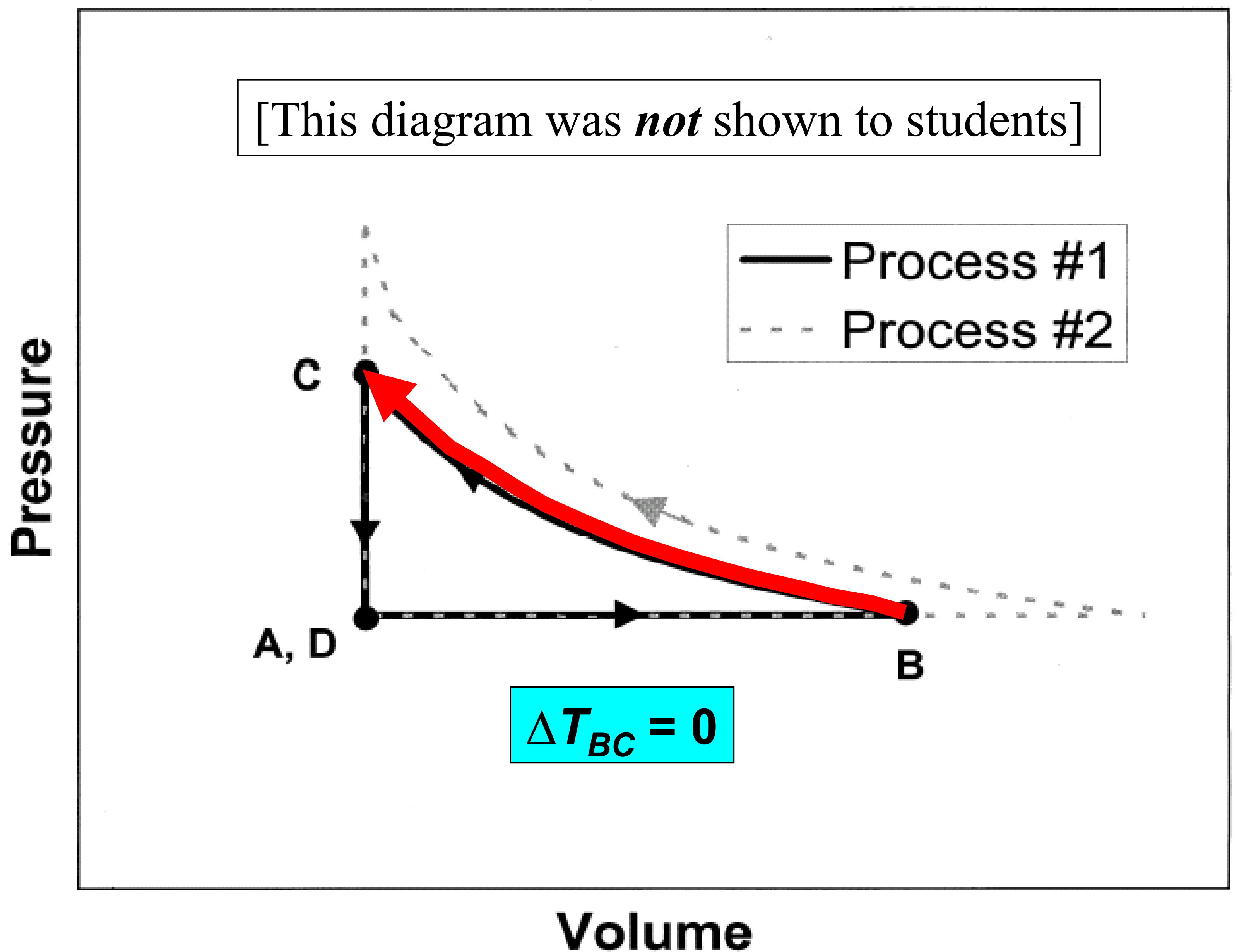
B
Pressure
Volume



[This diagram was *not* shown to students]
Process #1
Process #2
C
A, D
B
$\Delta T_{BC} = 0$
Pressure
Volume

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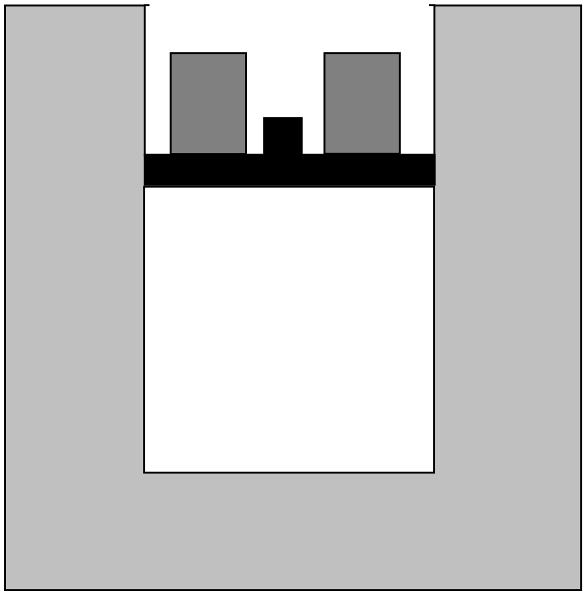
Time *C*

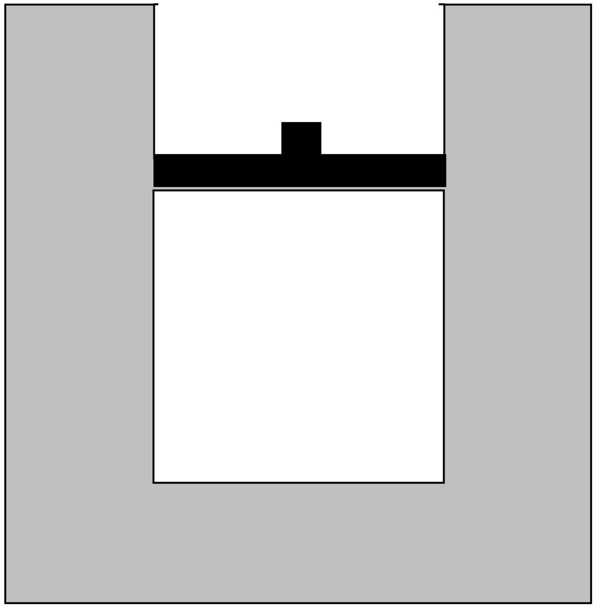
Weights in containers.

Piston in same position as at time *A*.

Temperature same as at time *B*.



Step 4. Now, the piston is locked into place so it *cannot move*; the weights are removed from the piston. The system is left to sit in the room for many hours, and eventually the entire system cools back down to the same room temperature it had at time *A*. When this finally happens, it is time *D*.



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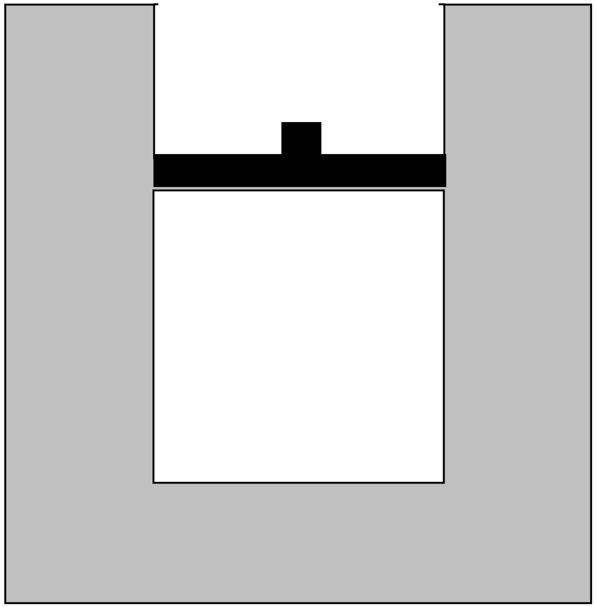

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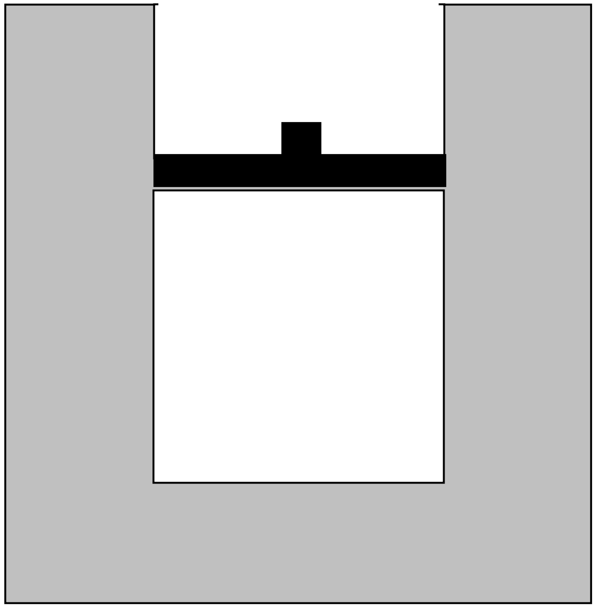
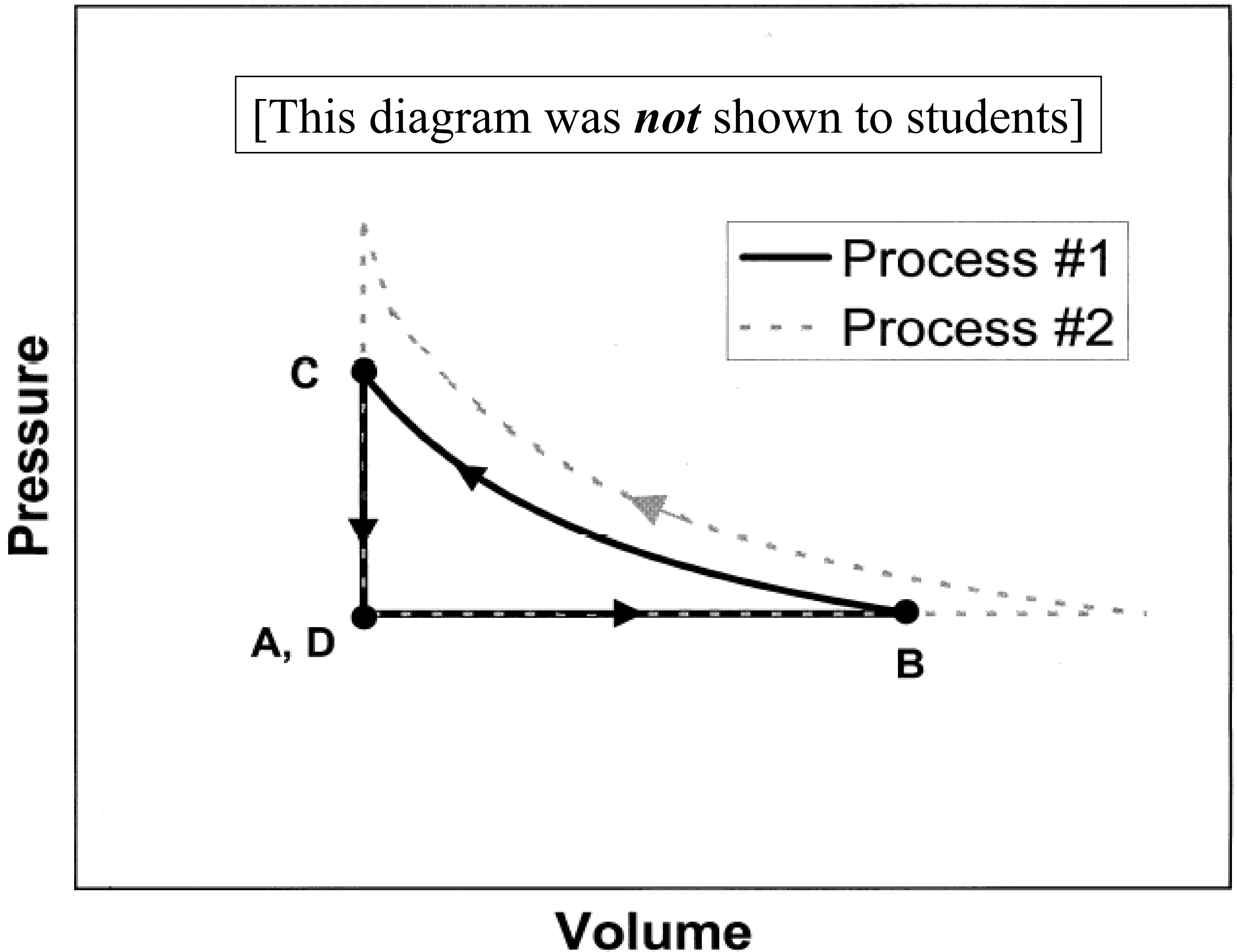
Time *D*

Piston in same position as at time *A*.

Temperature same as at time *A*.

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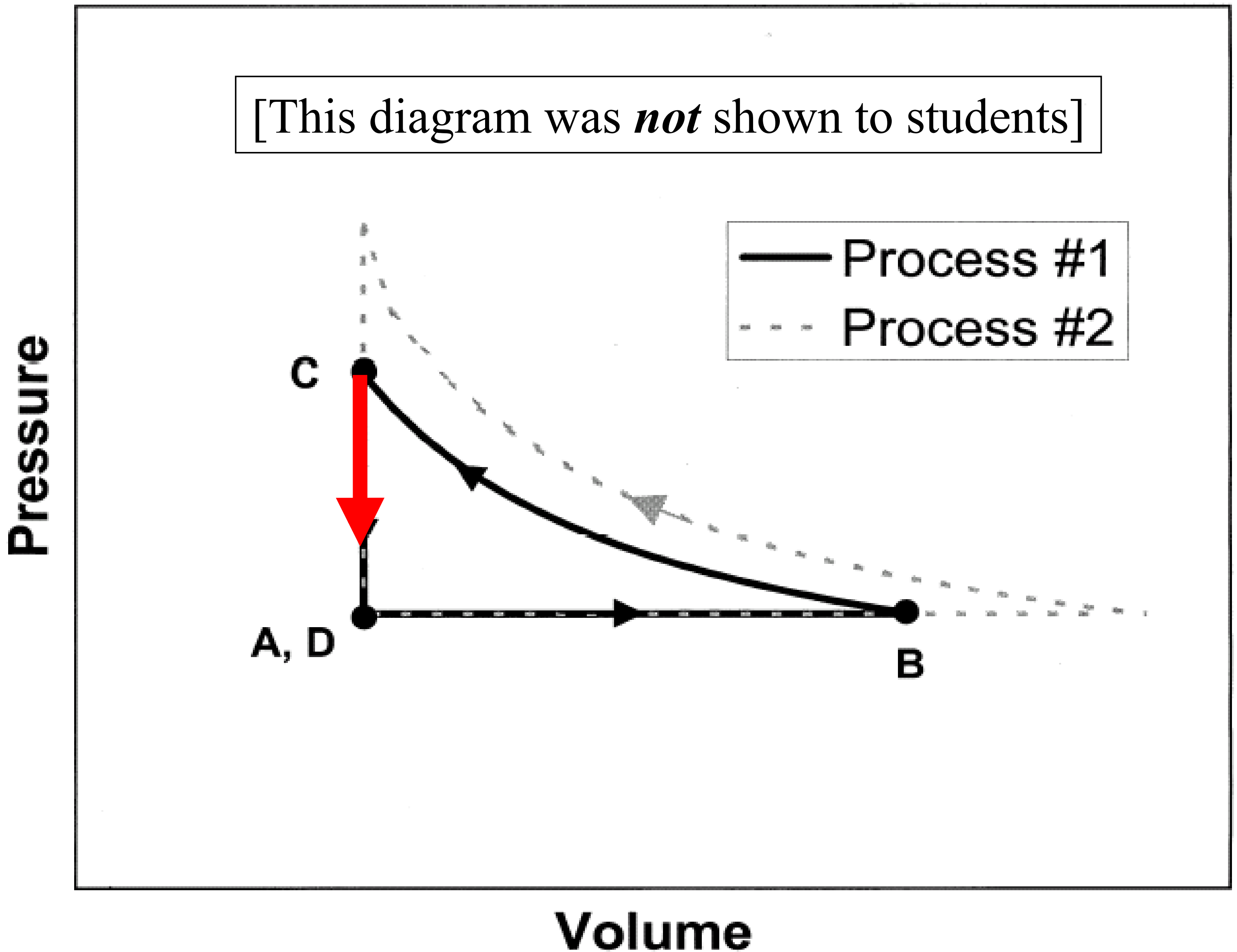
Process #1
Process #2
C
A, D
B
Pressure
Volume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Process #1
Process #2
C
A, D
B
Pressure
Volume

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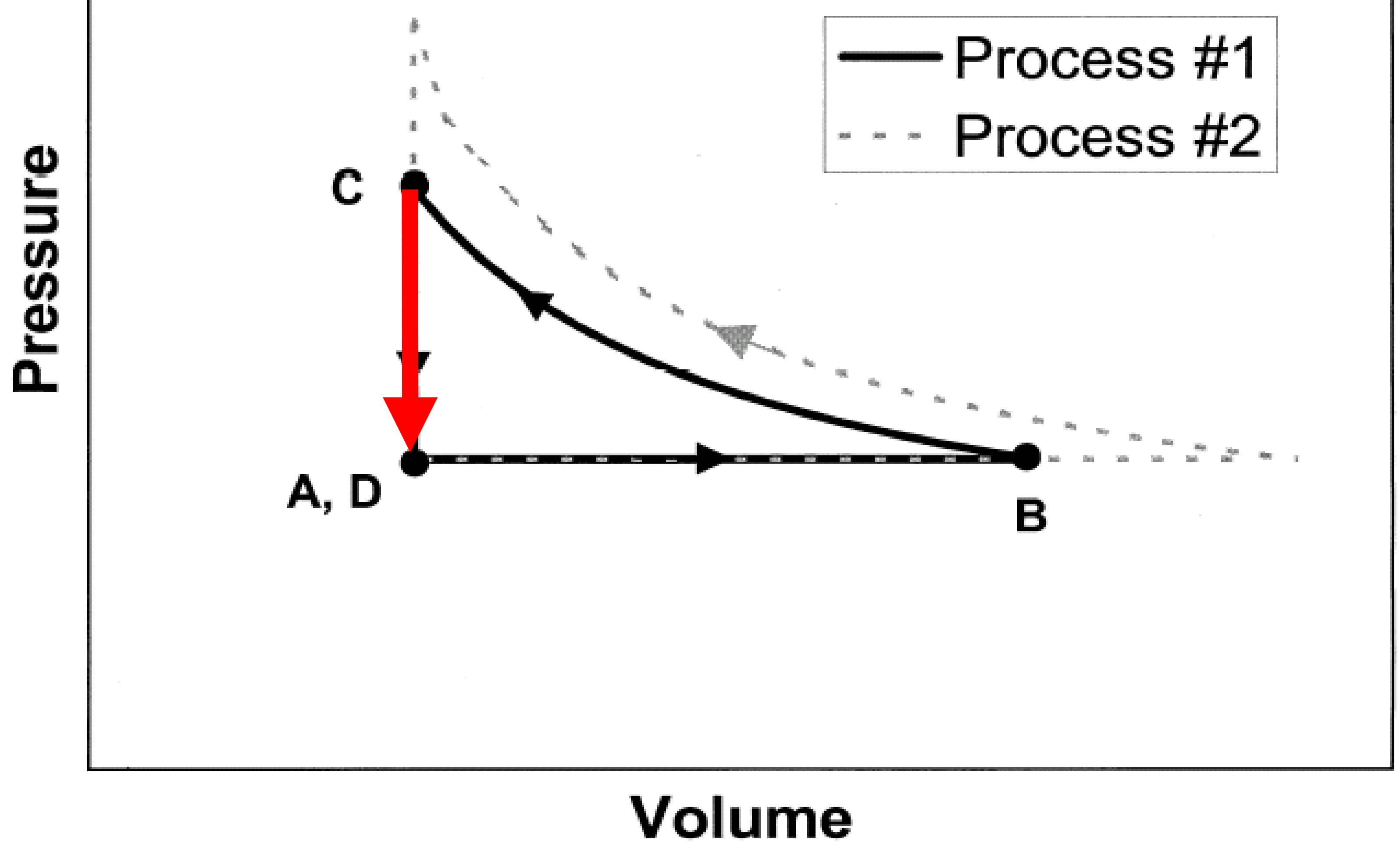
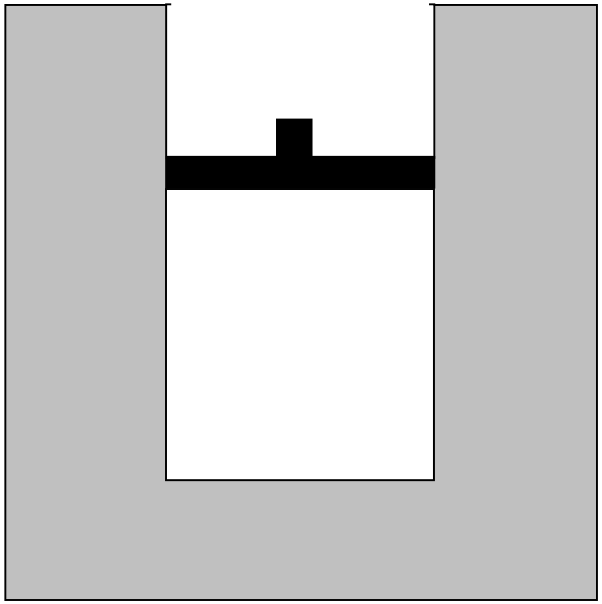




Time *D*

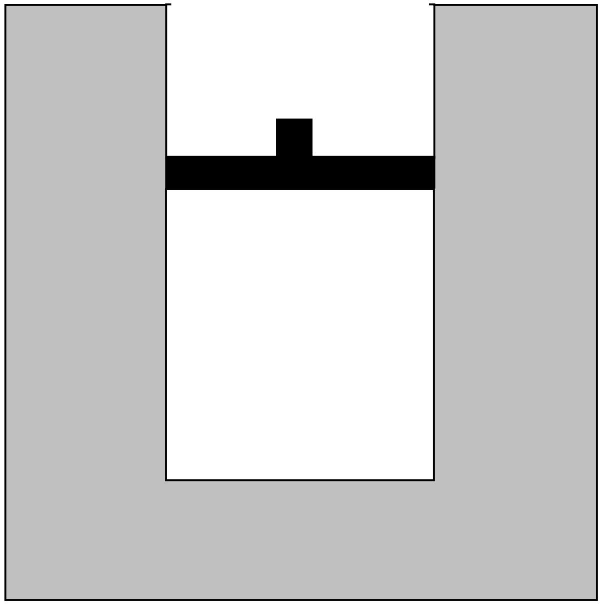
Piston in same position as at time *A*.

Temperature same as at time *A*.

Question #6: Consider ***<u>the entire process</u>*** from time *A* to time *D*.

(i) Is the net work done *by* the gas on the environment during that process (a) greater than zero, (b) equal to zero, or (c) less than zero?

(ii) Is the total heat transfer to the gas during that process (a) greater than zero, (b) equal to zero, or (c) less than zero?



Time *D*

Piston in same position as at time *A*.

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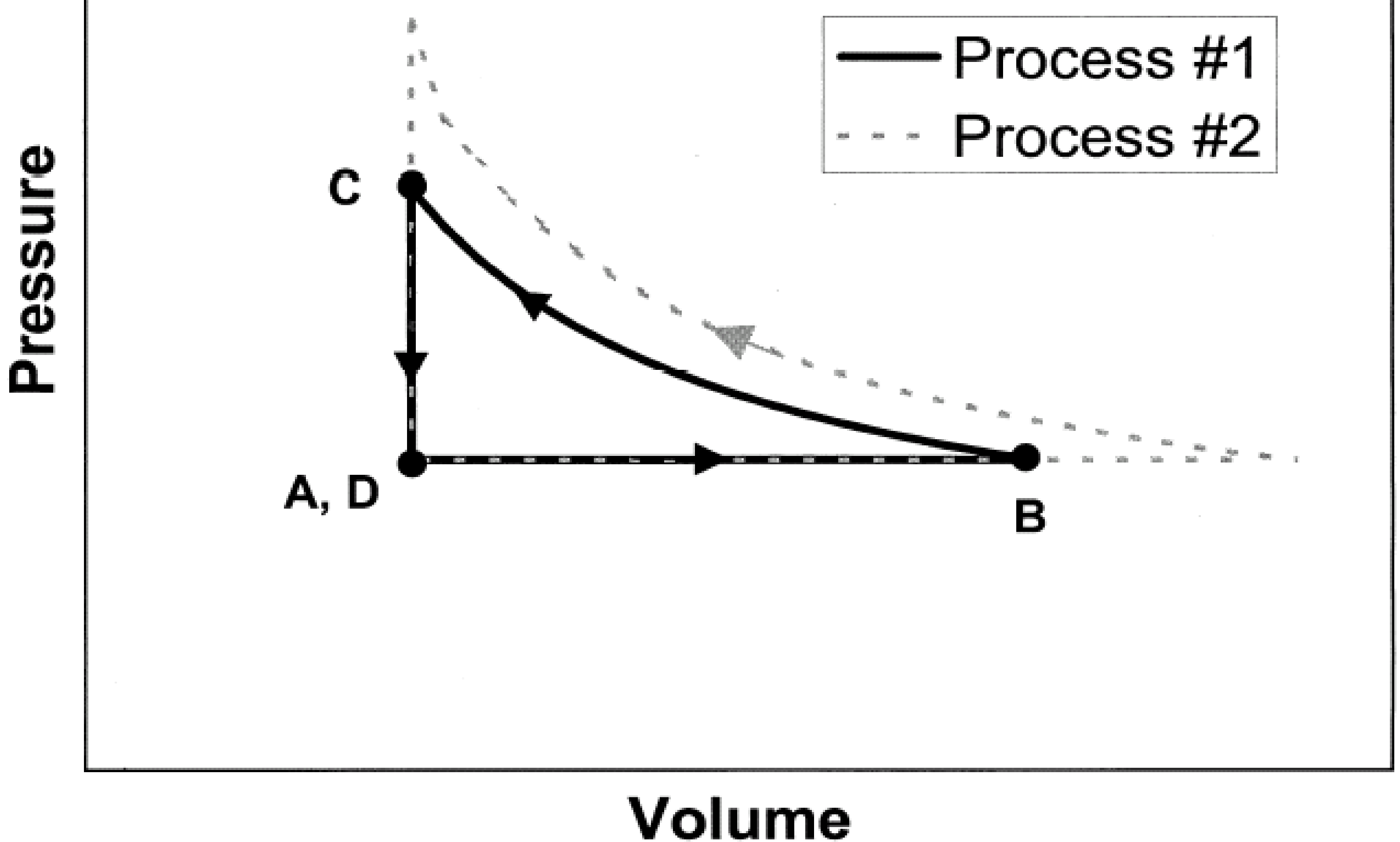
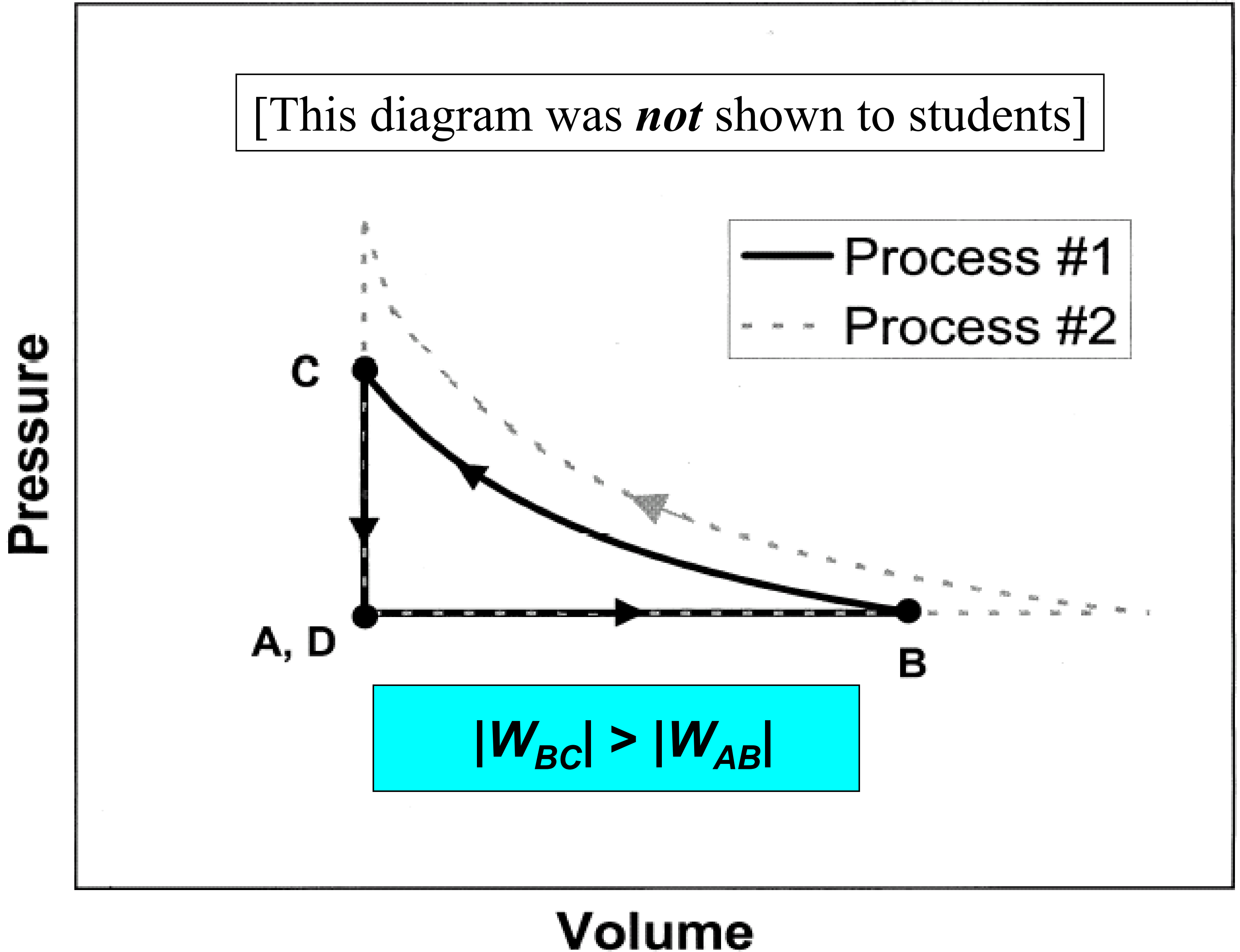
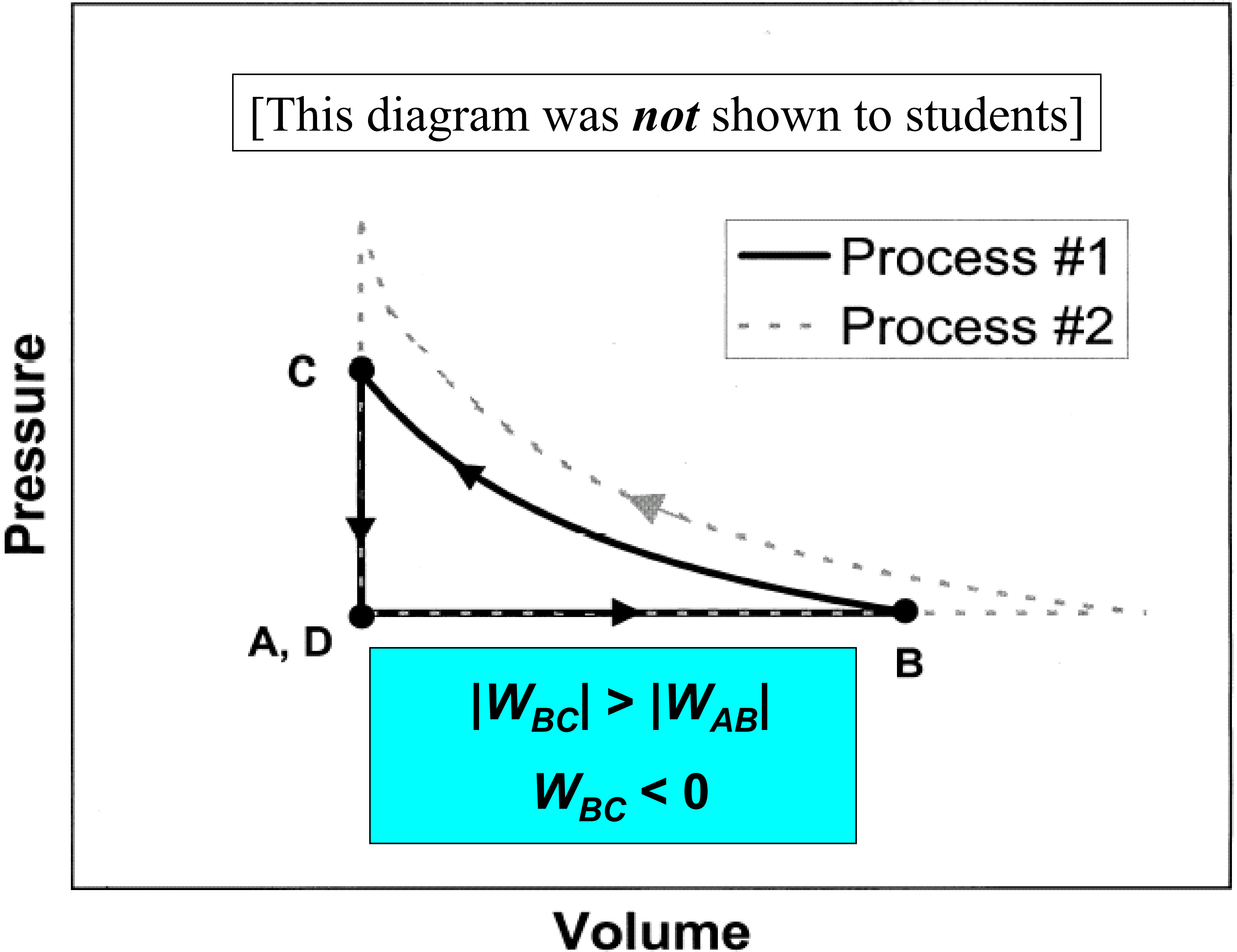
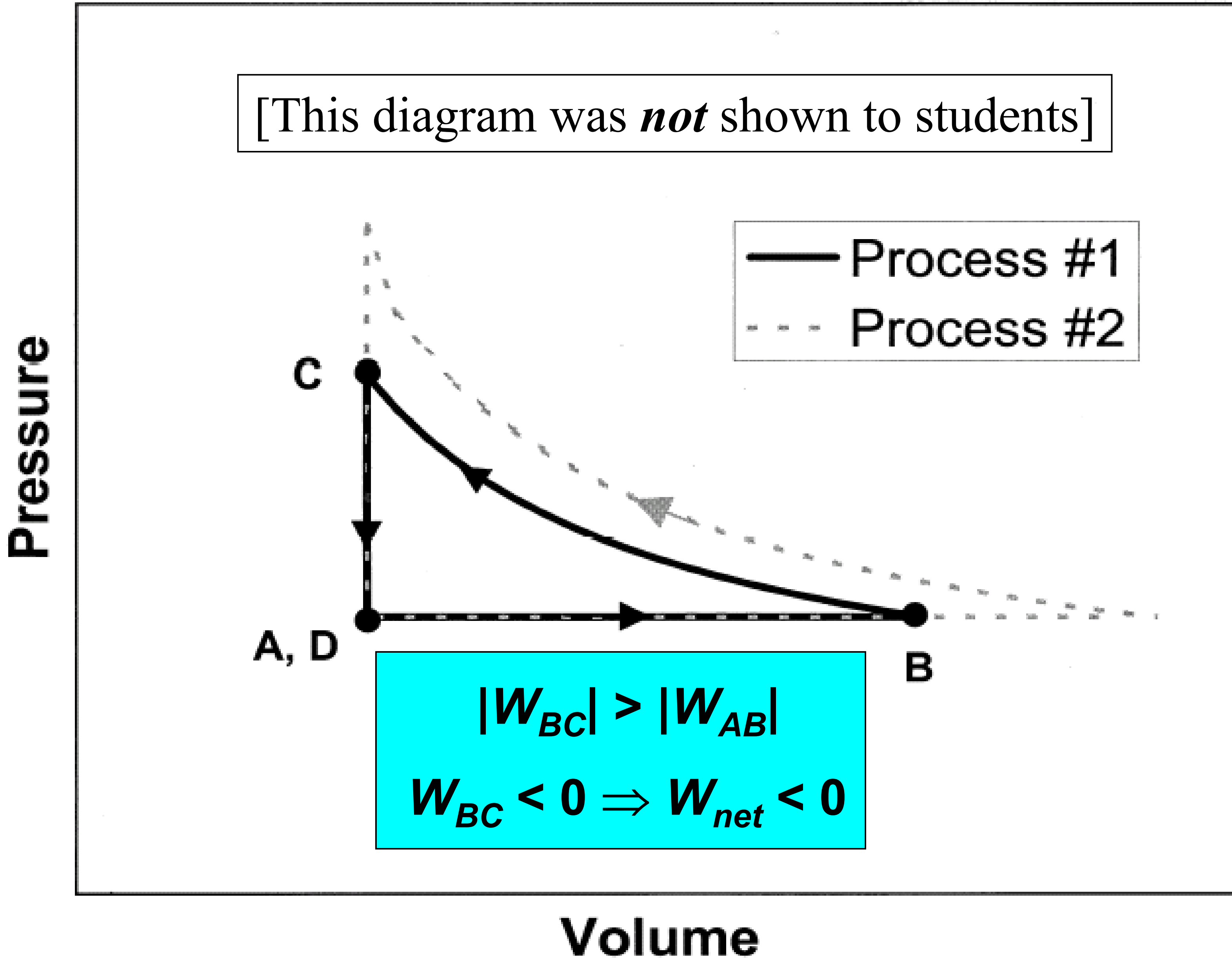




[This diagram was *not* shown to students]
Process #1
Process #2
Pressure
Volume
C
A, D
B
$|W_{BC}| > |W_{AB}|$

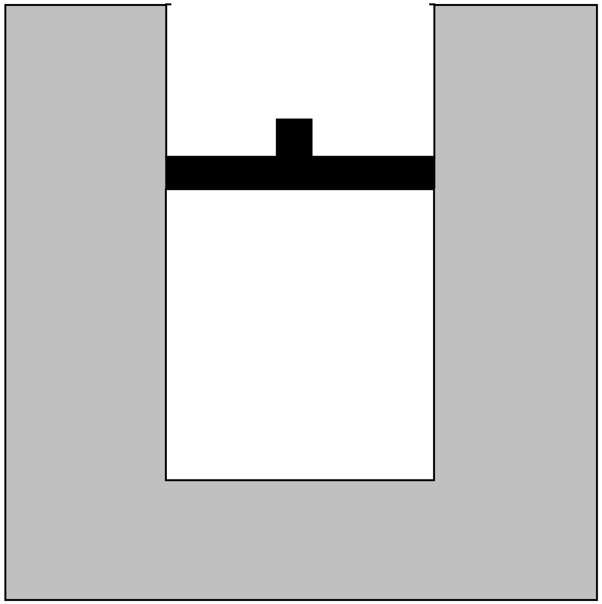

[This diagram was *not* shown to students]
Process #1
Process #2
C
A, D
B
$|W_{BC}| > |W_{AB}|$
$W_{BC} < 0$
Pressure
Volume

[This diagram was *not* shown to students]



$$|W_{BC}| > |W_{AB}|$$

$$W_{BC} < 0 \Rightarrow W_{net} < 0$$



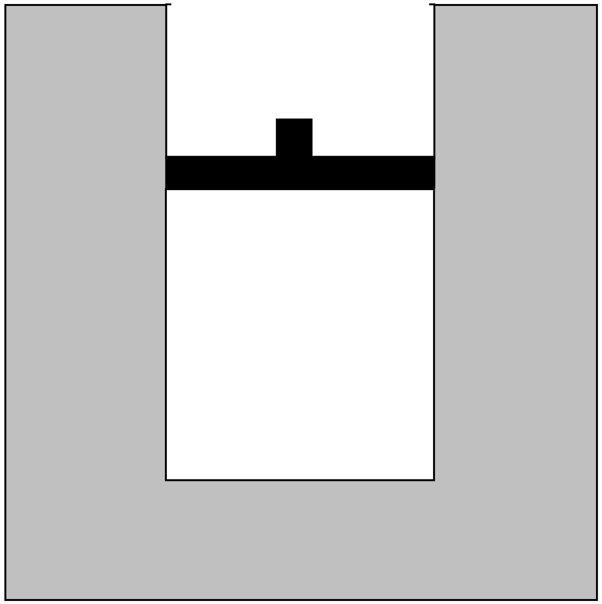
Time *D*

Piston in same position as at time *A*.

Temperature same as at time *A*.

Question #6: Consider ***<u>the entire process</u>*** from time *A* to time *D*.

> ***(i)*** Is the net work done *by* the gas on the environment during that process (a) greater than zero, (b) equal to zero, or (c) less than zero?
>
> ***(ii)*** Is the total heat transfer to the gas during that process (a) greater than zero, (b) equal to zero, or (c) less than zero?



Time *D*

Piston in same position as at time *A*.

Temperature same as at time *A*.

Question #6: Consider ***<u>the entire process</u>*** from time *A* to time *D*.

(i) Is the net work done *by* the gas on the environment during that process (a) greater than zero, (b) equal to zero, or **(c) less than zero?**

(ii) Is the total heat transfer to the gas during that process (a) greater than zero, (b) equal to zero, or (c) less than zero?

Results on Interview Question #6 (i)

$N = 32$

(a) $W_{net} > 0$: 16%

(b) $W_{net} = 0$: 63%

(c) $W_{net} < 0$: 19% *[correct]*

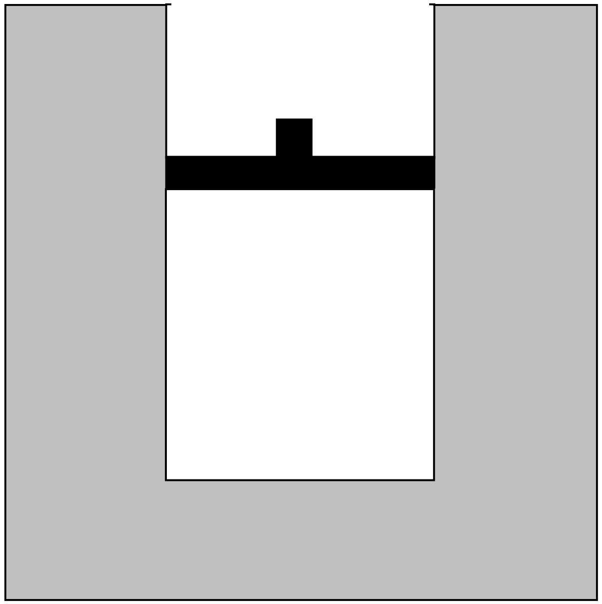
No response: 3%

Even after being asked to draw a *P-V* diagram for Process #1, nearly two thirds of the interview sample believed that net work done was equal to zero.

Explanations offered for $W_{net} = 0$

"[Student #1:] *The physics definition of work is like force times distance. And basically if you use the same force and you just travel around in a circle and come back to your original spot, technically you did zero work*."

"[Student #2:] *At one point the volume increased and then the pressure increased, but it was returned back to that state . . . The piston went up so far and then it's returned back to its original position, retracing that exact same distance*."



Time *D*

Piston in same position as at time *A*.

Temperature same as at time *A*.

Question #6: Consider ***<u>the entire process</u>*** from time *A* to time *D*.

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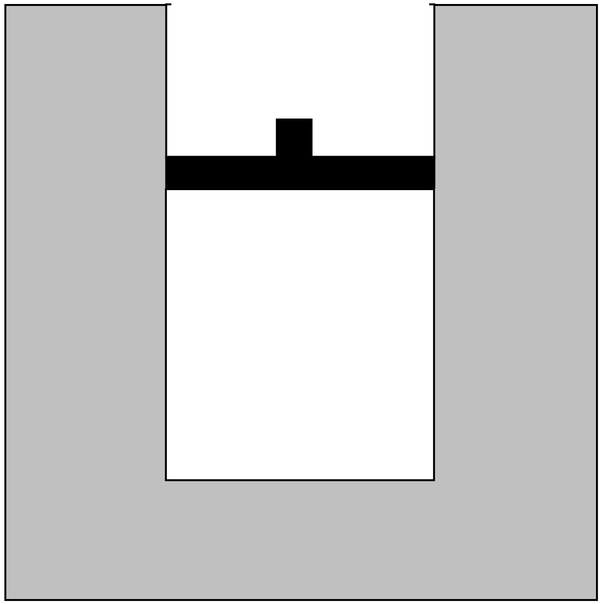

Time *D*

Piston in same position as at time *A*.

Temperature same as at time *A*.

Question #6: Consider ***<u>the entire process</u>*** from time *A* to time *D*.

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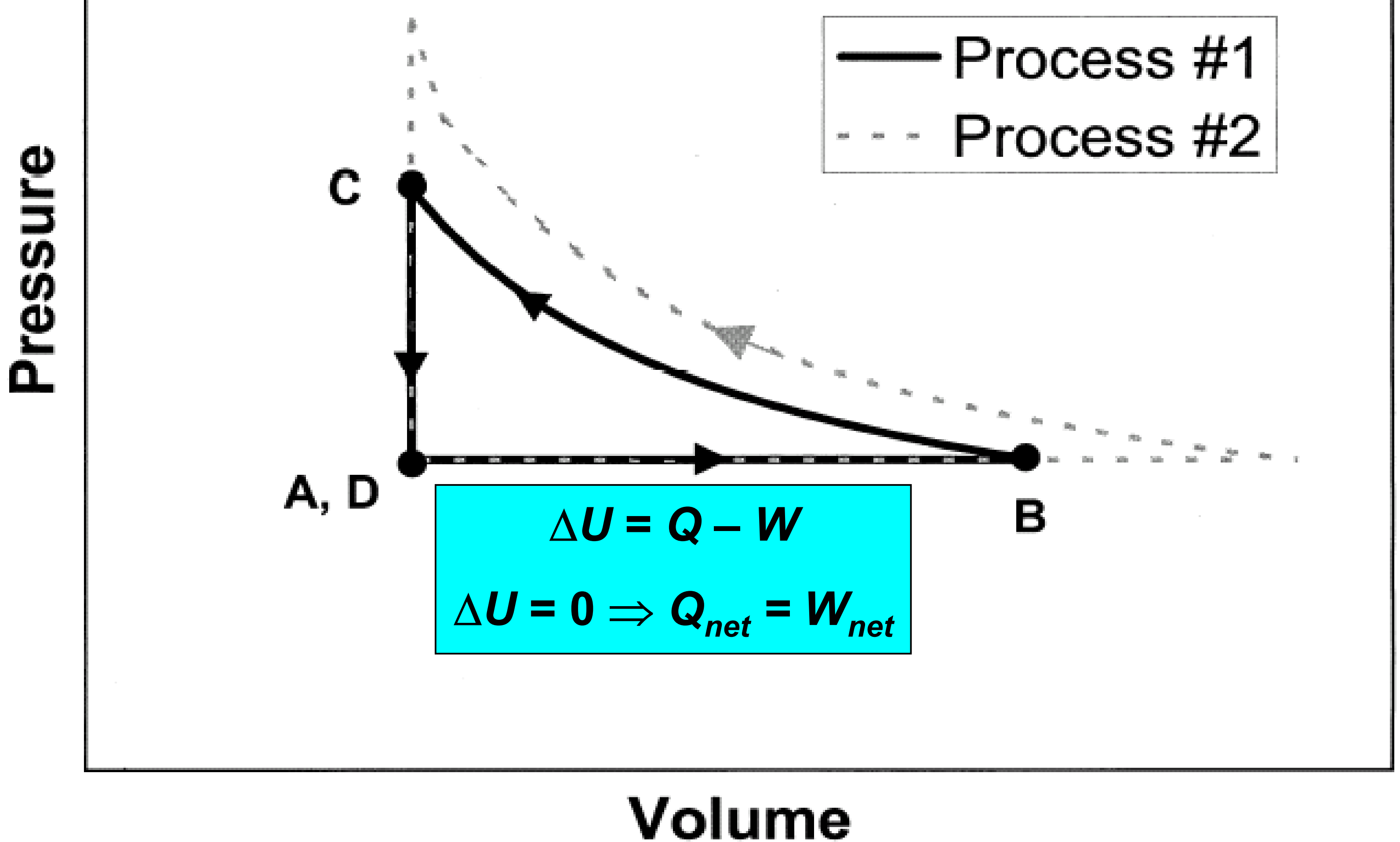
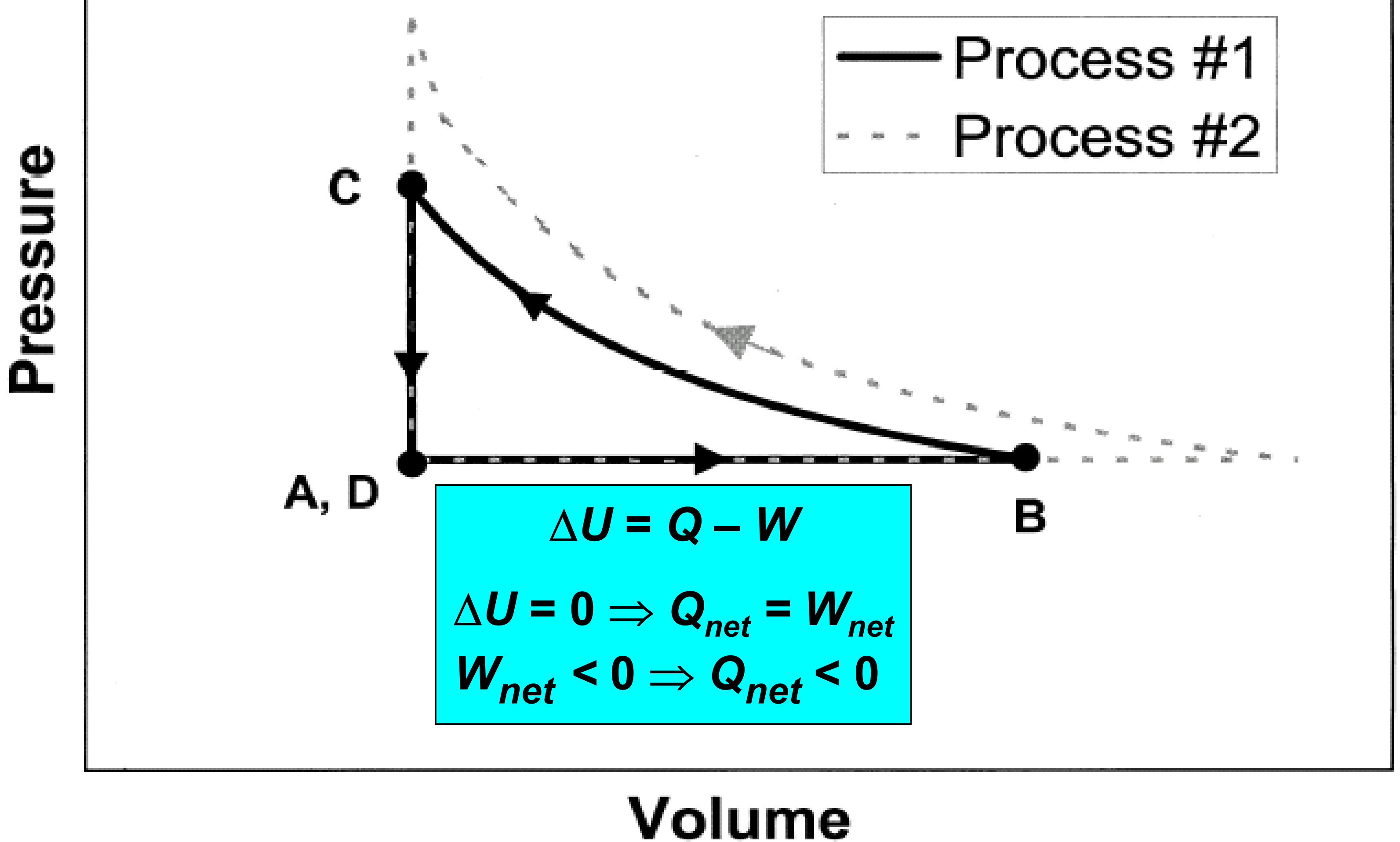
[This diagram was *not* shown to students]



$$\Delta U = Q - W$$

$$\Delta U = 0 \Rightarrow Q_{net} = W_{net}$$

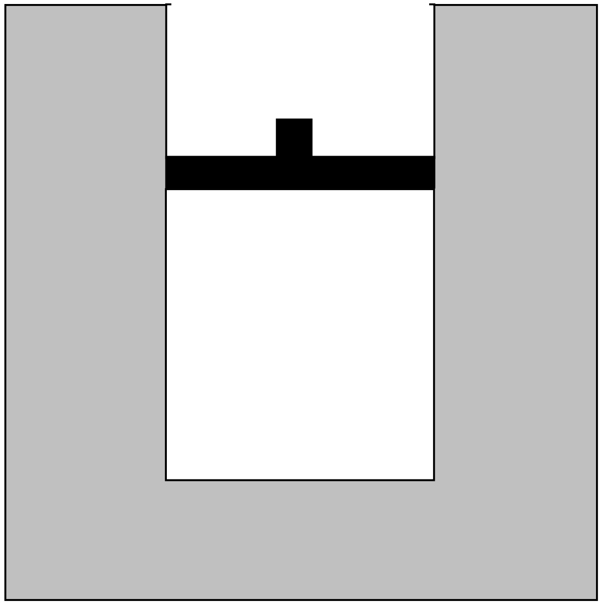
[This diagram was ***not*** shown to students]



$$\Delta U = Q - W$$

$$\Delta U = 0 \Rightarrow Q_{net} = W_{net}$$

$$W_{net} < 0 \Rightarrow Q_{net} < 0$$



Time *D*

Piston in same position as at time *A*.

Temperature same as at time *A*.

Question #6: Consider ***the entire process*** from time *A* to time *D*.

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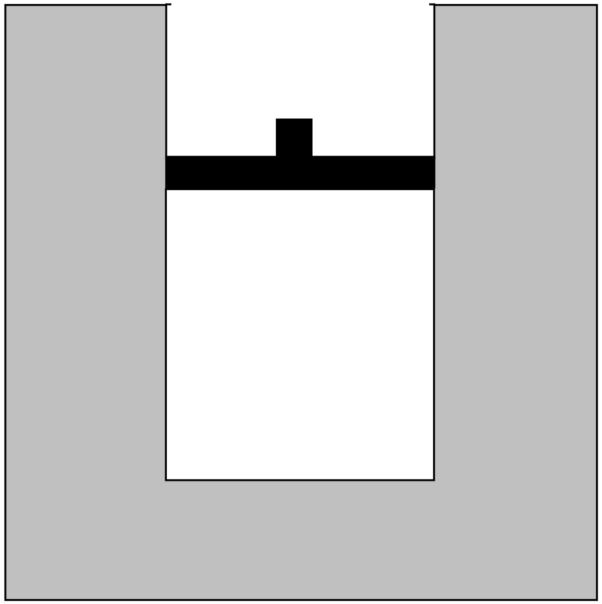


Time *D*

Piston in same position as at time *A*.

Temperature same as at time *A*.

Question #6: Consider ***<u>the entire process</u>*** from time *A* to time *D*.

(i) Is the net work done *by* the gas on the environment during that process (a) greater than zero, (b) equal to zero, or **(c) less than zero?**

(ii) Is the total heat transfer to the gas during that process (a) greater than zero, (b) equal to zero, or **(c) less than zero?**

Results on Interview Question #6 (ii)

$N = 32$

(a) $Q_{net} > 0$	**9%**	
(b) $Q_{net} = 0$	**69%**	
(c) $Q_{net} < 0$	**16%**	***[correct]***

with correct explanation: ***13%***

with incorrect explanation: ***3%***

Uncertain: **6%**

More than two thirds of the interview sample believed that net heat absorbed was equal to zero.

Explanation offered for $Q_{net} = 0$

"*The heat transferred to the gas . . . is equal to zero . . . . The gas was heated up, but it still returned to its equilibrium temperature. So whatever energy was added to it was distributed back to the room.*"

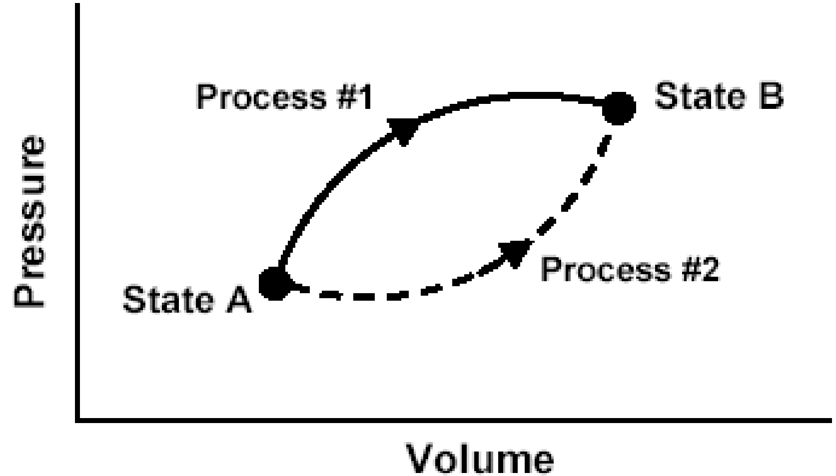
Most students thought that both Q_{net} and W_{net} are equal to zero

- 56% believed that both the net work done ***and*** the total heat transferred would be zero.
- Only three out of 32 students (9%) answered both parts of Interview Question #6 correctly.

Predominant Themes of Students' Reasoning

1. Understanding of concept of state function in the context of energy.
2. Belief that work is a state function.
3. Belief that heat is a state function.
4. Belief that net work done and net heat transferred during a cyclic process are zero.
5. Inability to apply the first law of thermodynamics.

This *P-V* diagram represents a system consisting of a fixed amount of ideal gas that undergoes two ***different*** processes in going from state A to state B:



[In these questions, ***W*** represents the work done ***by*** the system during a process; ***Q*** represents the heat ***absorbed*** by the system during a process.]

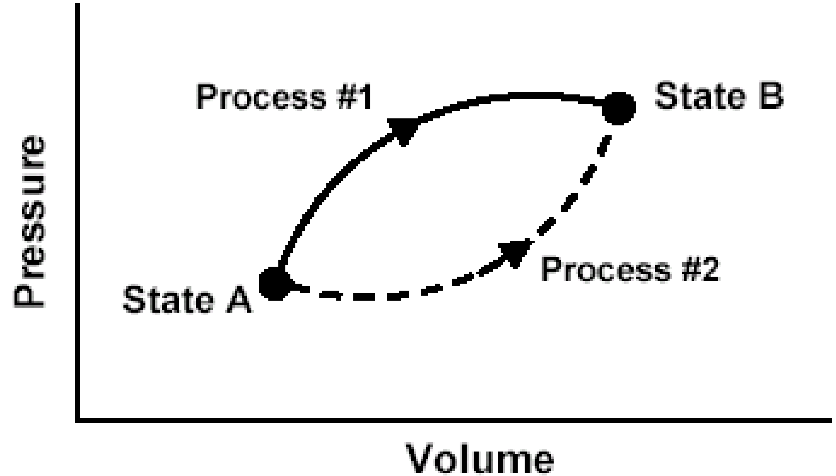
1. Is *W* for Process #1 ***greater than, less than***, or ***equal to*** that for Process #2? Explain.

2. Is Q for Process #1 ***greater than, less than***, or ***equal to*** that for Process #2?

3. Which would produce the largest change in the total energy of all the atoms in the system: ***Process #1, Process #2,*** or ***both processes produce the same change?***

This *P-V* diagram represents a system consisting of a fixed amount of ideal gas that undergoes two ***different*** processes in going from state A to state B:

Change in internal energy is the same for Process #1 and Process #2.



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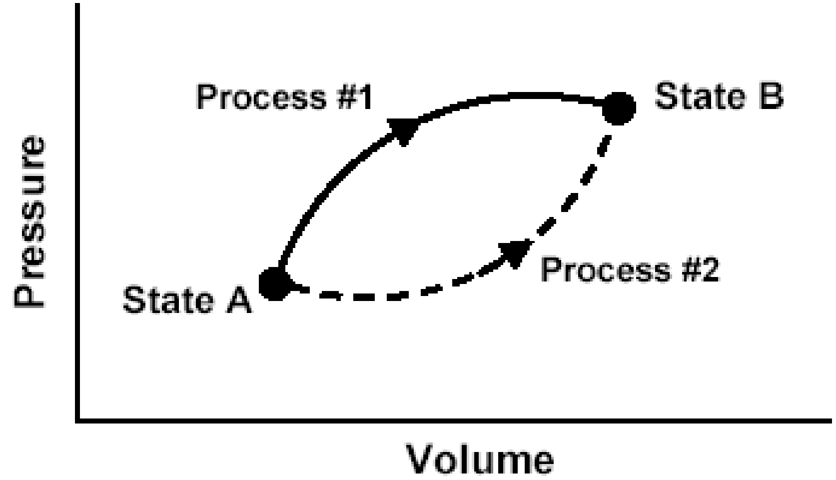
This *P-V* diagram represents a system consisting of a fixed amount of ideal gas that undergoes two ***different*** processes in going from state A to state B:

The system does more work in Process #1, so it must absorb more heat to reach same final value of internal energy:
$\boldsymbol{Q_1 > Q_2}$



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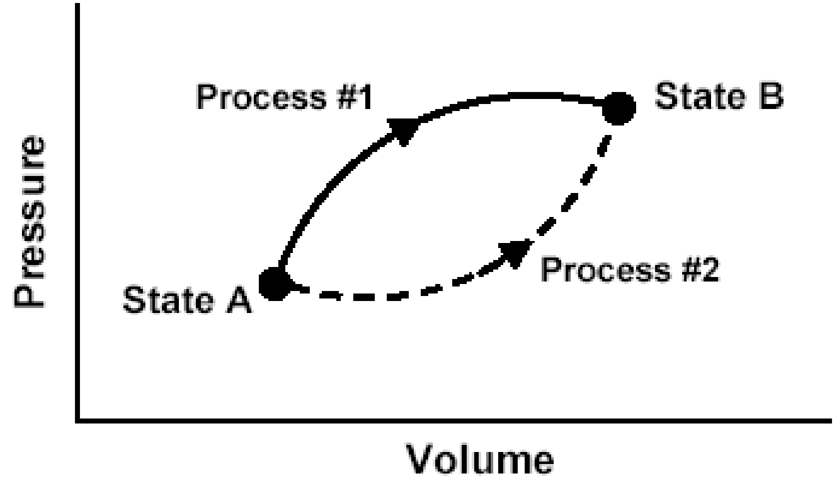

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Responses to Diagnostic Question #2
(Heat question)

	1999 (*N*=186)	**2000** (*N*=188)	**2001** (*N*=279)	**2002** Interview Sample (*N*=32)
$Q_1 > Q_2$ (disregarding explanations)	**56%**	**40%**	**40%**	**34%**

Examples of "Acceptable" Student Explanations for $Q_1 > Q_2$

"$\Delta U = Q - W$. *For the same* ΔU, *the system with more work done must have more* Q *input so process #1 is greater*."

"Q *is greater for process one because it does more work; the energy to do this work comes from the* Q_{in}."

Responses to Diagnostic Question #2
(Heat question)

	1999 (*N*=186)	**2000** (*N*=188)	**2001** (*N*=279)	**2002** Interview Sample (*N*=32)
$Q_1 > Q_2$	**56%**	**40%**	**40%**	**34%**
Correct or partially correct explanation	**14%**	**10%**	**10%**	**19%**
Incorrect, or missing explanation	**42%**	**30%**	**30%**	**15%**

Fewer than 20% of Students are Able to Apply First Law

- Fewer than 20% of students overall could explain why $Q_1 > Q_2$.
- 13% of students in interview sample were able to use first law to correctly answer Question #6(ii).

Large majority of students finish general physics course unable to apply first law of thermodynamics.

Consistent with results of Loverude, Kautz, and Heron, Am. J. Phys. (2002), for Univ. Washington, Univ. Maryland, and Univ. Illinois

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- Fewer than 20% of students overall could explain why $Q_1 > Q_2$.
- 13% of students in interview sample were able to use first law to correctly answer Question #6(ii).

Students very often attribute state-function properties to process-dependent quantities.

Primary Findings

*Even **after** instruction, many students (40-80%):*

- believe that heat and/or work are state functions independent of process

- believe that net work done and net heat absorbed by a system undergoing a cyclic process must be zero

- are unable to apply the First Law of Thermodynamics in problem solving

Primary Learning Difficulties

- Failure to recognize “work” as energy-transfer mechanism lies at root of many difficulties.
  - *Loverude et al. showed that this was remnant of difficulties developed during mechanics instruction*

- Association of “heat” and “work” with “internal energy” [*it’s all energy!*] leads to over-generalization of state-function concept.

Outline

Research-Based Curriculum Development

- Overview

Investigation of Students' Reasoning

- Students' reasoning in thermodynamics
- Students' reasoning in calorimetry
- Diverse representational modes in student learning

Curriculum Development

- Curricular materials for thermodynamics
- Curricular materials for calorimetry

Some Strategies for Instruction

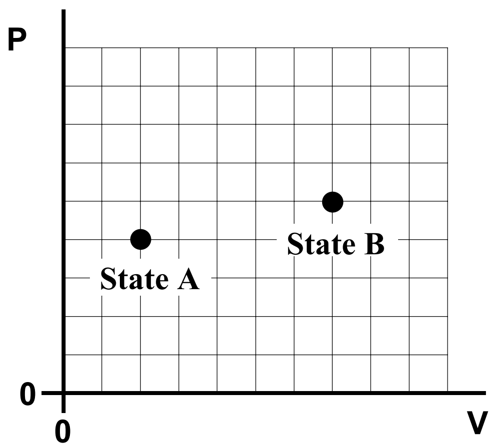
- Try to build on students' understanding of state-function concept.
- Focus on meaning of heat as ***transfer*** of energy, ***not*** quantity of energy residing in a system.
- Develop concept of work as energy transfer mechanism.
- Guide students to make increased use of *PV*-diagrams and similar representations.

Thermodynamics Worksheet

For an ideal gas, the internal energy U is directly proportional to the temperature T. (This is because the internal energy is just the total kinetic energy of all of the gas molecules, and the temperature is defined to be equal to the *average* molecular kinetic energy.) For a monatomic ideal gas, the relationship is given by $U = \frac{3}{2}nRT$, where n is the number of moles of gas, and R is the universal gas constant.

1. Find a relationship between the internal energy of n moles of ideal gas, and pressure and volume of the gas. Does the relationship change when the number of moles is varied?

2. Suppose that m moles of an ideal gas are contained inside a cylinder with a movable piston (so the volume can vary). At some initial time, the gas is in state A as shown on the PV-diagram in Figure 1. A thermodynamic process is carried out and the gas eventually ends up in State B. Is the internal energy of the gas in State B *greater than*, *less than*, or *equal to* its internal energy in State A? (That is, how does U_B compare to U_A?) Explain.

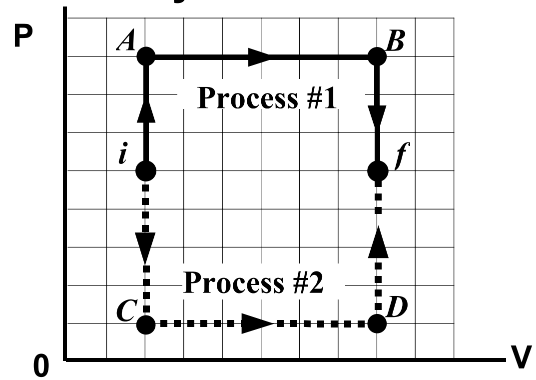


3. If a system starts with an initial internal energy of $U_{initial}$ and ends up with U_{final} some time later, we symbolize the *change* in the system's internal energy by ΔU and define it as follows: $\Delta U = U_{final} - U_{initial}$.

   a. For the process described in #2 (where the system goes from State A to State B), is ΔU for the gas system *greater than zero*, *equal to zero*, or *less than zero*?

   b. During this process, was there any energy transfer between the gas system and its surrounding environment? Explain.

Thermodynamics Worksheet



7. Rank the *temperature* of the gas at the six points *i*, *A*, *B*, *C*, *D*, and *f*. (Remember this is an *ideal* gas.)

8. Consider all sub-processes represented by straight-line segments. For each one, state whether the work is positive, negative, or zero. In the second column, rank all six processes according to their ΔU. (Pay attention to the sign of ΔU.) If two segments have the same ΔU, give them the same rank. In the last column, state whether heat is added *to* the gas, taken *away* from the gas, or is *zero* (i.e., *no* heat transfer). ***Hint:*** **First determine *U* for each point using the result of #1 on page 1.**

Process	**Is *W* +, –, or 0?**	**rank according to ΔU**	**heat added *to*, taken *away*, or *zero*?**
$i \rightarrow A$			
$A \rightarrow B$			
$B \rightarrow f$			
$i \rightarrow C$			
$C \rightarrow D$			
$D \rightarrow f$			

9. Consider **only** the sub-processes that have $W = 0$. Of these, which has the *greatest* absolute value of heat transfer Q? Which has the *smallest* absolute value of Q?

10. Rank the six segments in the table above according to the absolute value of their W. *Hint:* For processes at constant pressure, $W = P\,\Delta V$.

11. Using your answers to #8 and #10, explain whether W_1 is *greater than*, *less than*, or *equal to* W_2. [Refer to definitions, page 3.] Is there also a way to answer this question using an “area” argument?

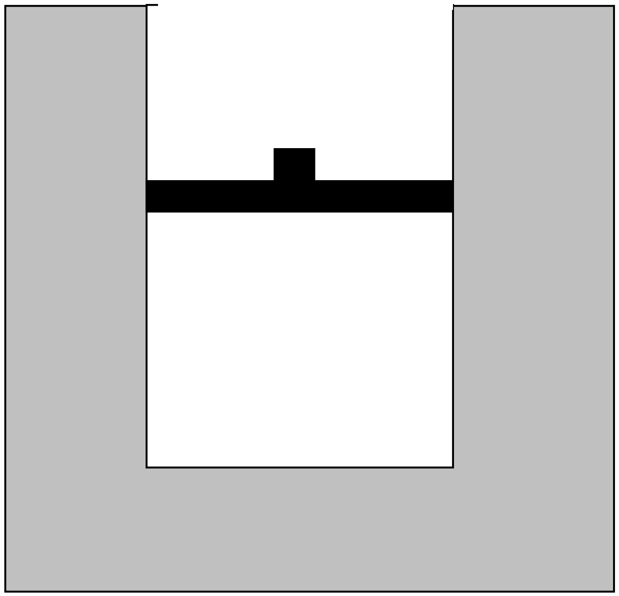
12. Is Q_1 *greater than*, *less than*, or *equal to* Q_2? Explain. *Hint:* Compare the magnitude of ΔU_1 and ΔU_2, and make use of the answer to #6.

Thermodynamics Curricular Materials

- Preliminary versions and initial testing of worksheets for:
  - calorimetry
  - thermochemistry
  - first-law of thermodynamics
  - cyclic processes
  - Carnot cycle
  - entropy
  - free energy

Preliminary testing in general physics and in junior-level thermal physics course

Step 1. We now begin Process #1: The water container is gradually heated, and the piston *very slowly* moves upward. At time *B* the heating of the water stops, and the piston stops moving when it is in the position shown in the diagram below:



Cyclic Process Worksheet

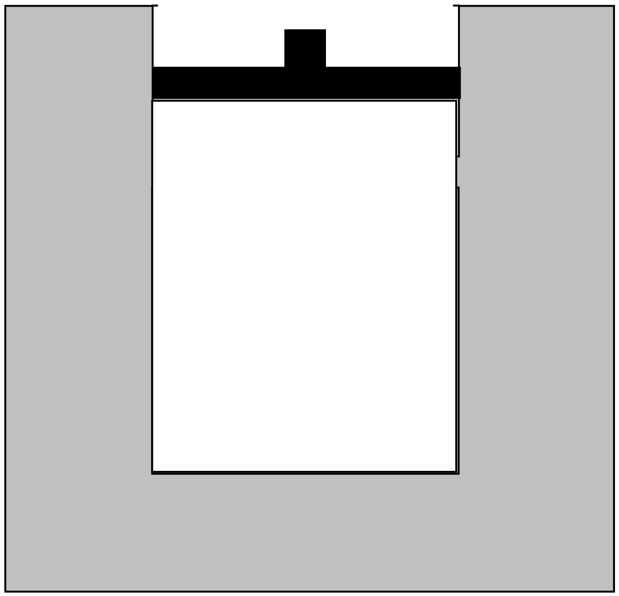
(adapted from interview questions)

Step 1. We now begin Process #1: The water container is gradually heated, and the piston *very slowly* moves upward. At time *B* the heating of the water stops, and the piston stops moving when it is in the position shown in the diagram below:

Time *B*

Piston in new position.

Temperature of system has changed.



1) For the process A → B, is the work done by the system (W_{AB}) *positive*, *negative*, or *zero*?

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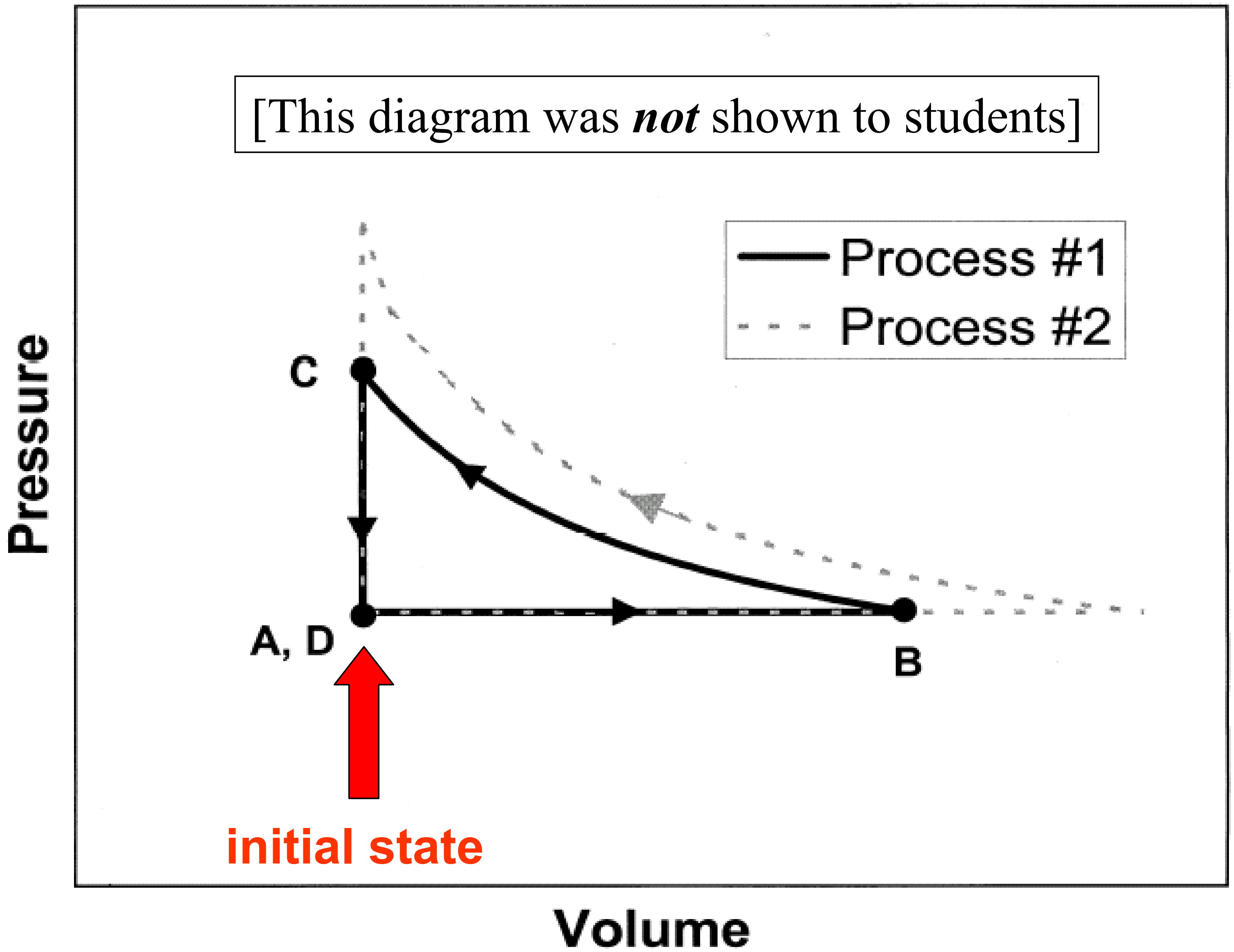
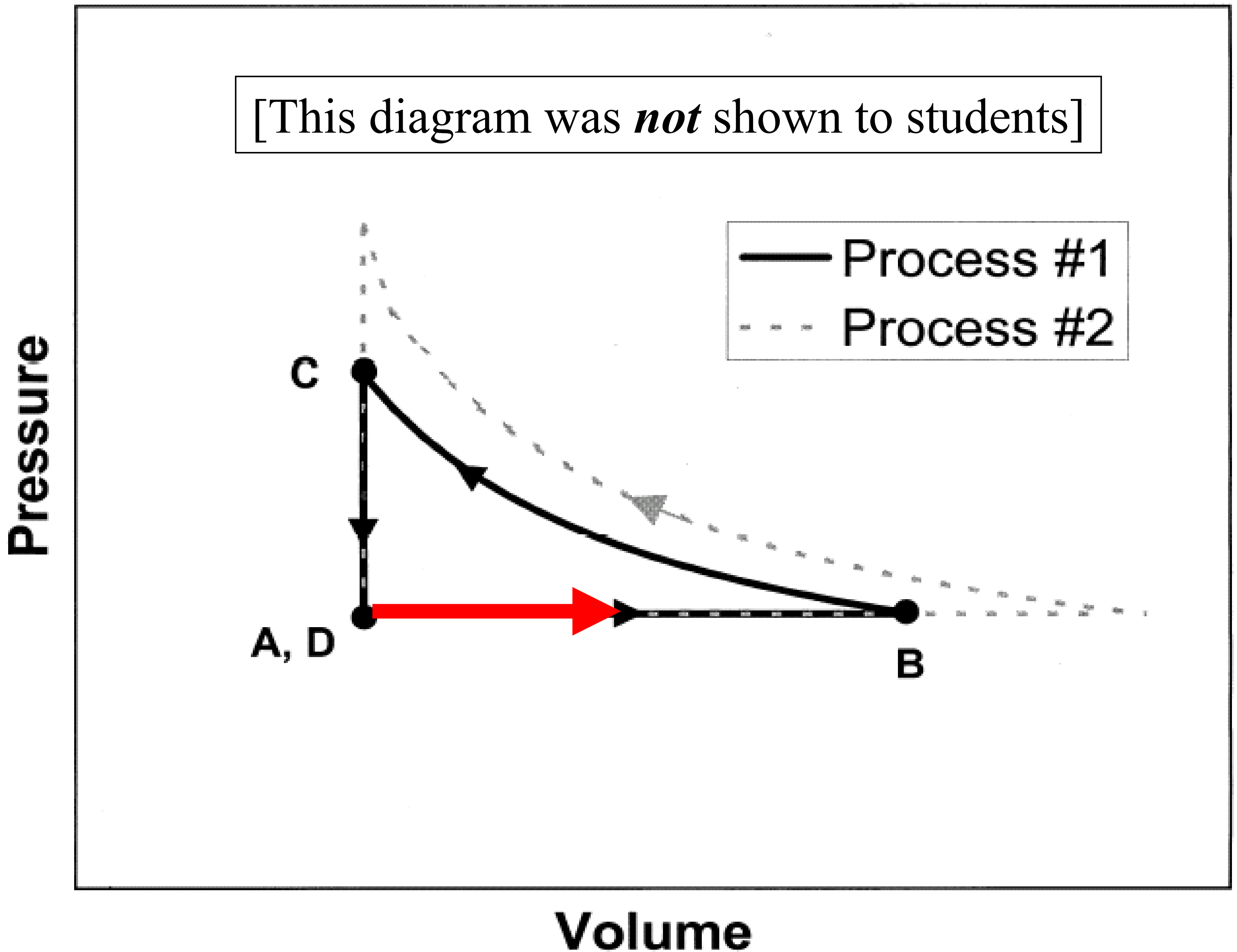
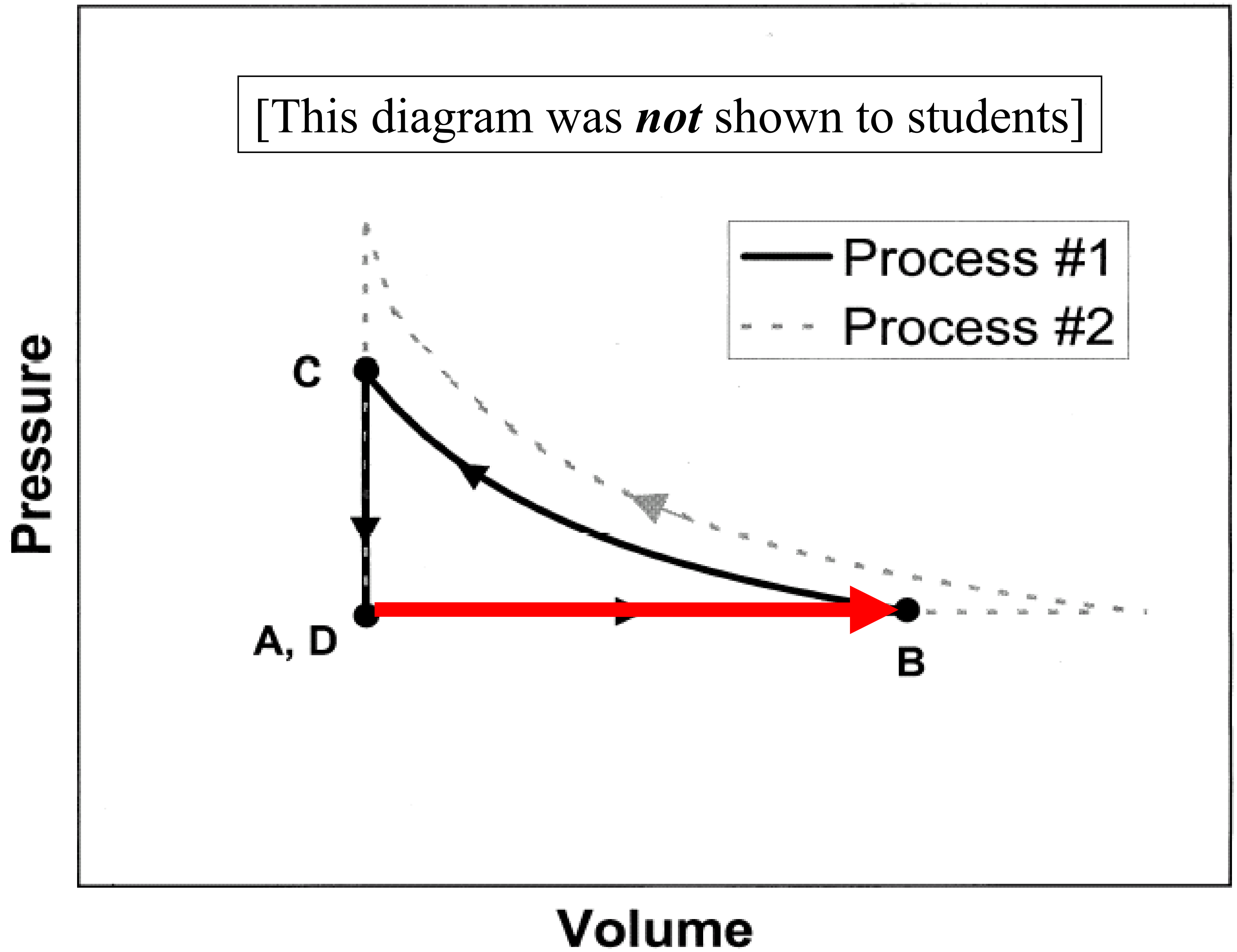
(The P-V diagram is not shown to the students. They answer the questions based only on the diagrams of the cylinder and piston.)


[This diagram was *not* shown to students]
Process #1
Process #2
C
A, D
B
initial state
Pressure
Volume



[This diagram was *not* shown to students]
Process #1
Process #2
C
A, D
B
Pressure
Volume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Process #2
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A, D
B
Pressure
Volume

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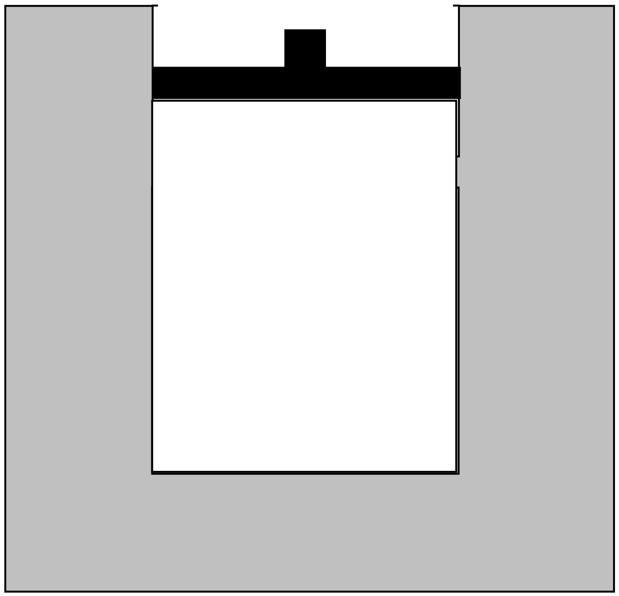
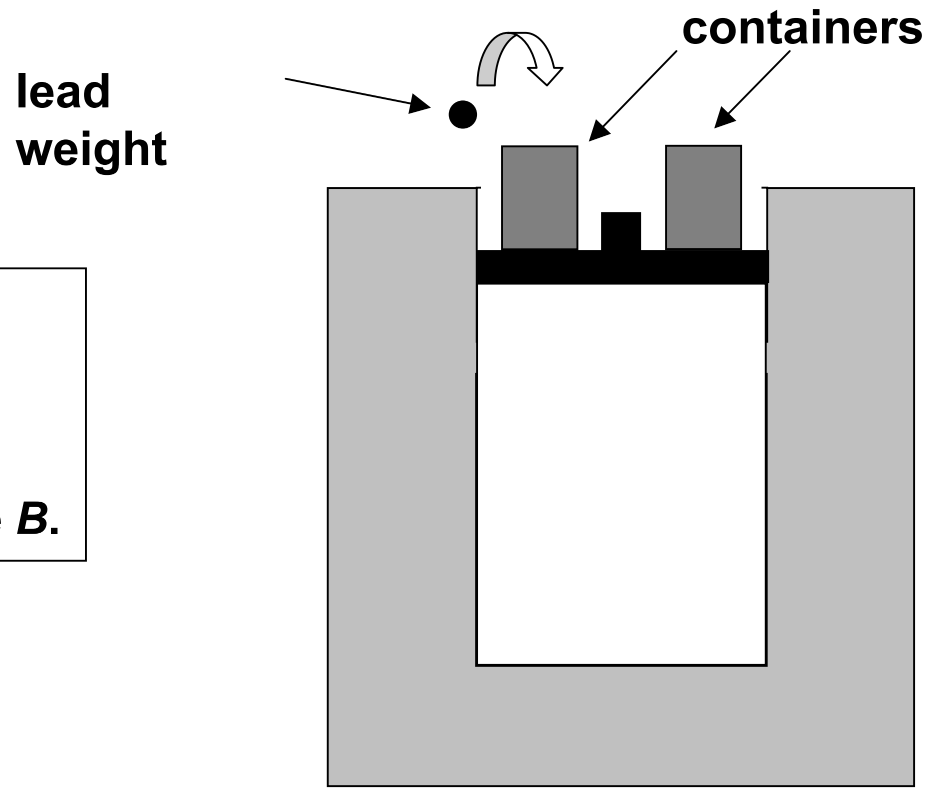
Time *B*

Piston in new position.

Temperature of system has changed.



Step 2. Now, empty containers are placed on top of the piston as shown. Small lead weights are gradually placed in the containers, one by one, and the piston is observed to move down slowly. While this happens, the temperature of the water is nearly unchanged, and the gas temperature remains practically *constant*. (That is, it remains at the temperature it reached at time *B,* after the water had been heated up.)



weights being added

Piston moves down slowly.

Temperature remains same as at time *B*.

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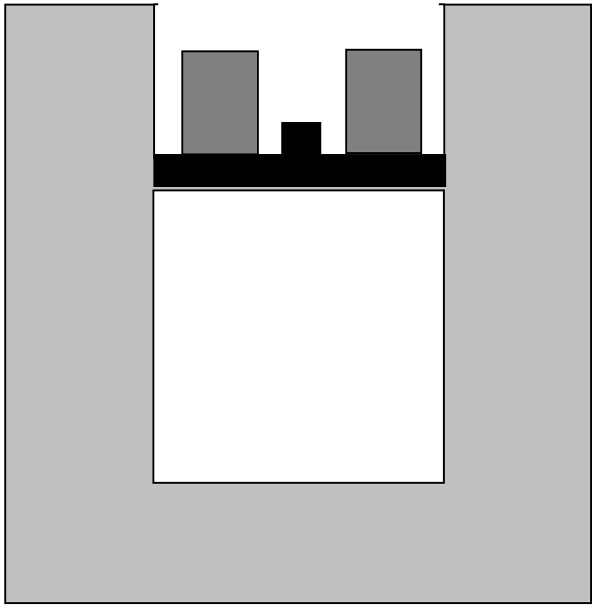
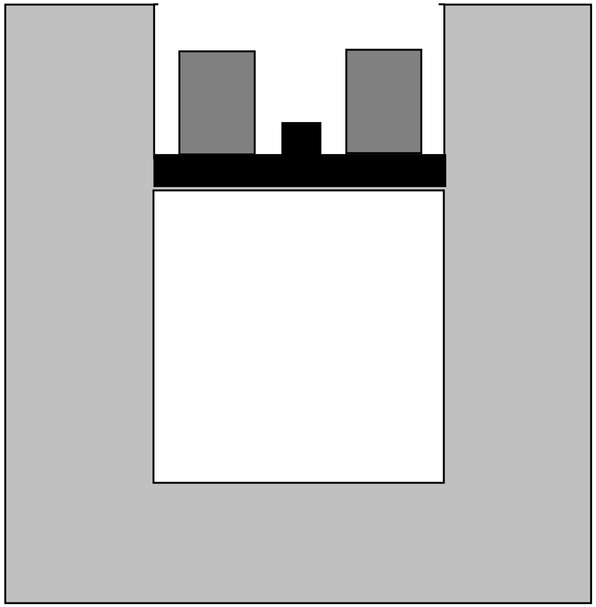


Step 3. At time *C* we stop adding lead weights to the container and the piston stops moving. (The weights that we have already added up until now are still in the containers.) The piston is now found to be at *exactly the same position it was at time* ***A*** .



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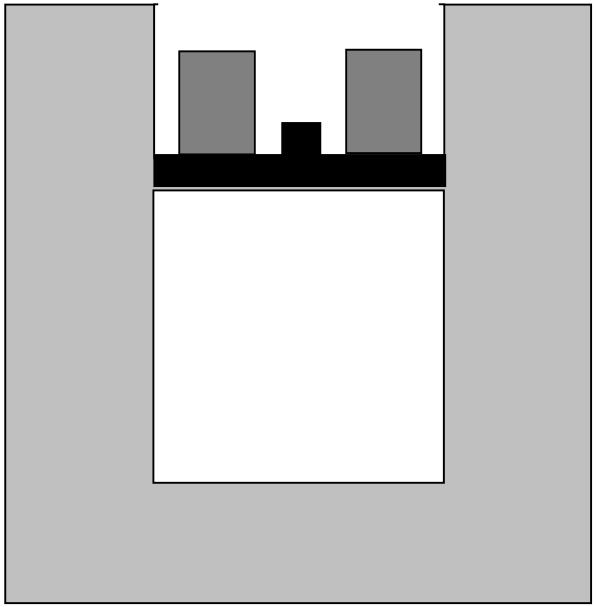
Time *C*

Weights in containers.

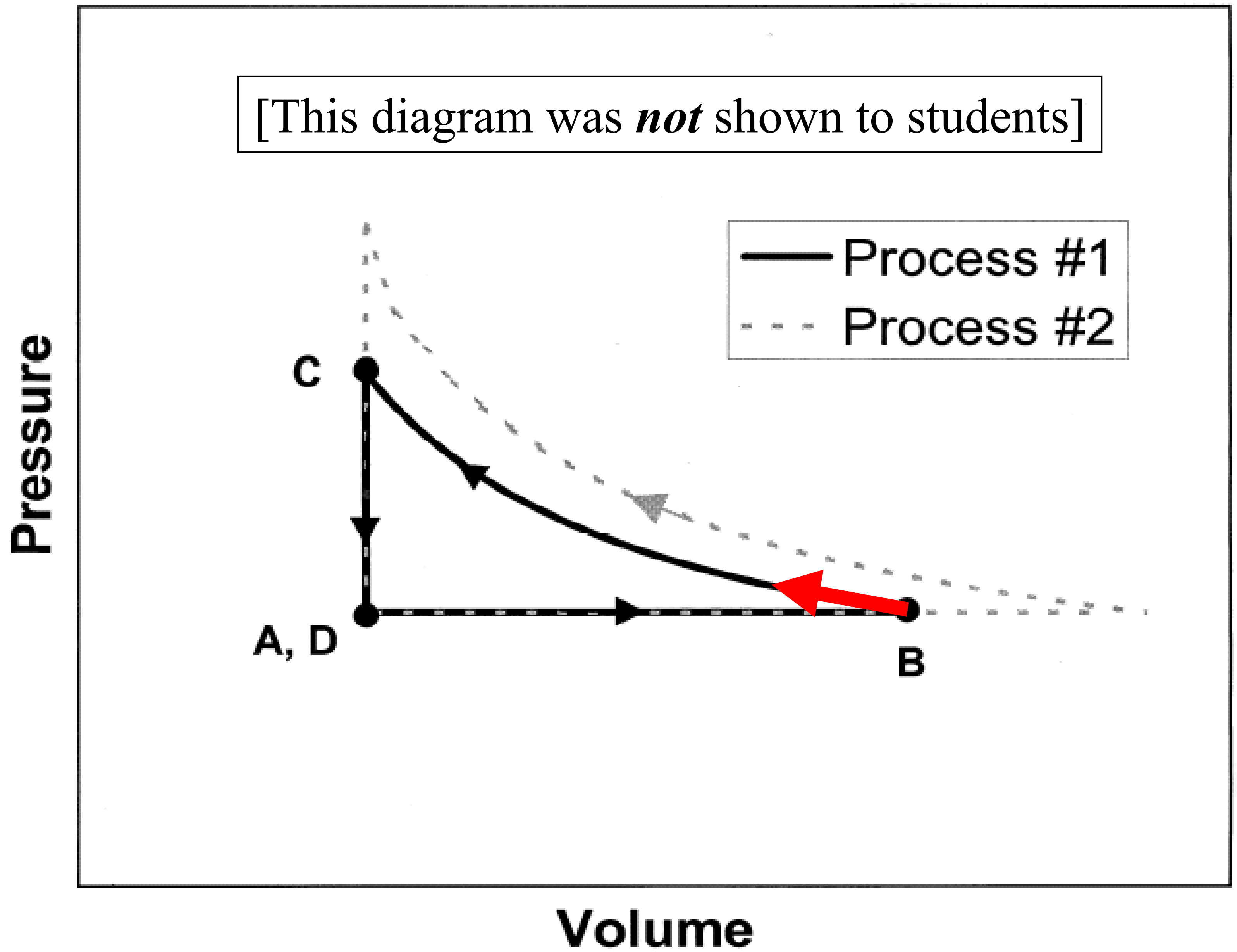
Piston in same position as at time *A*.

Temperature same as at time *B*.



1) For the process A → B, is the work done by the system (W_{AB}) *positive*, *negative*, or *zero*?

2) For the process B → C, is the work done by the system (W_{BC}) *positive*, *negative*, or *zero*?



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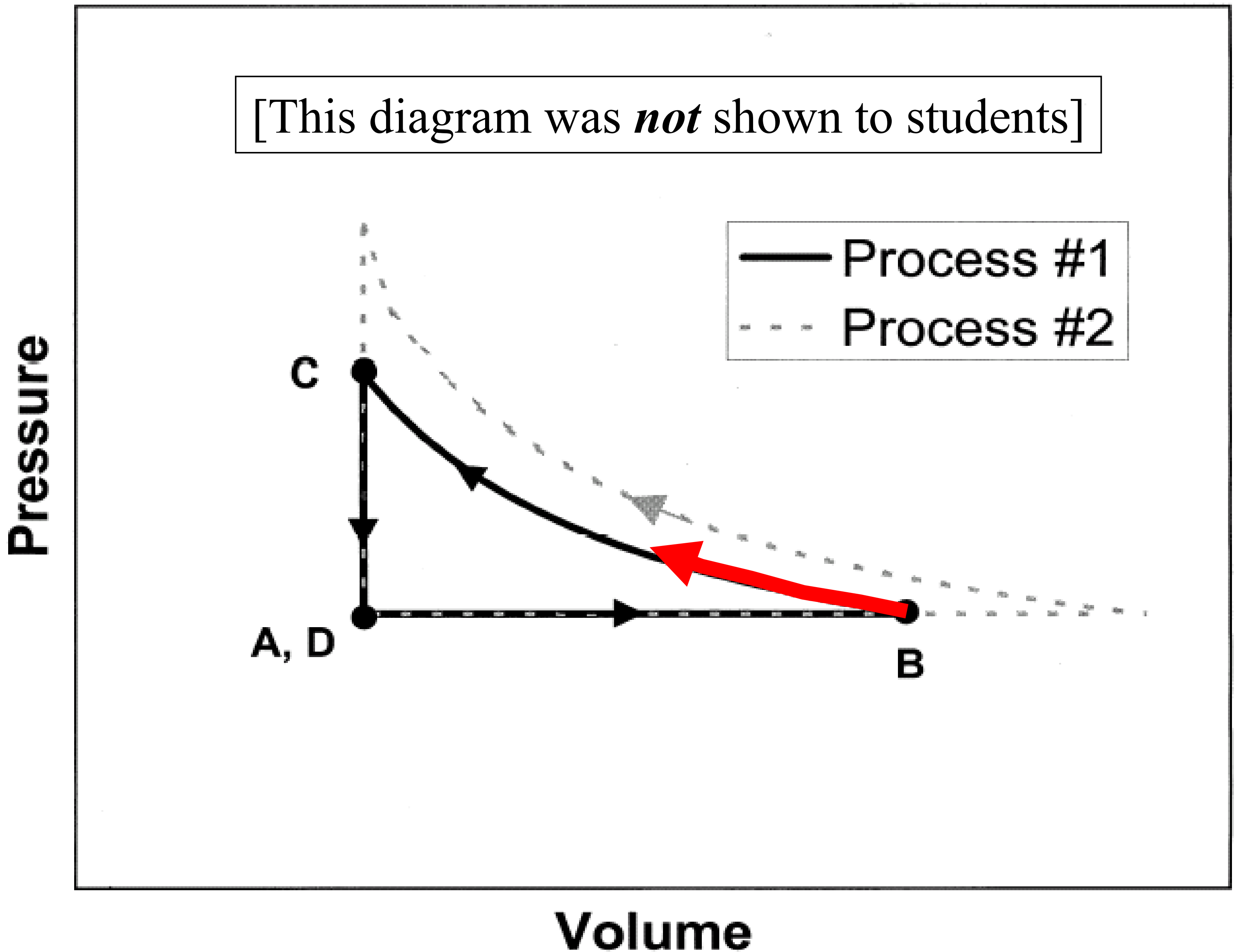
Process #1
Process #2
C
A, D
B
Pressure
Volume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Process #2
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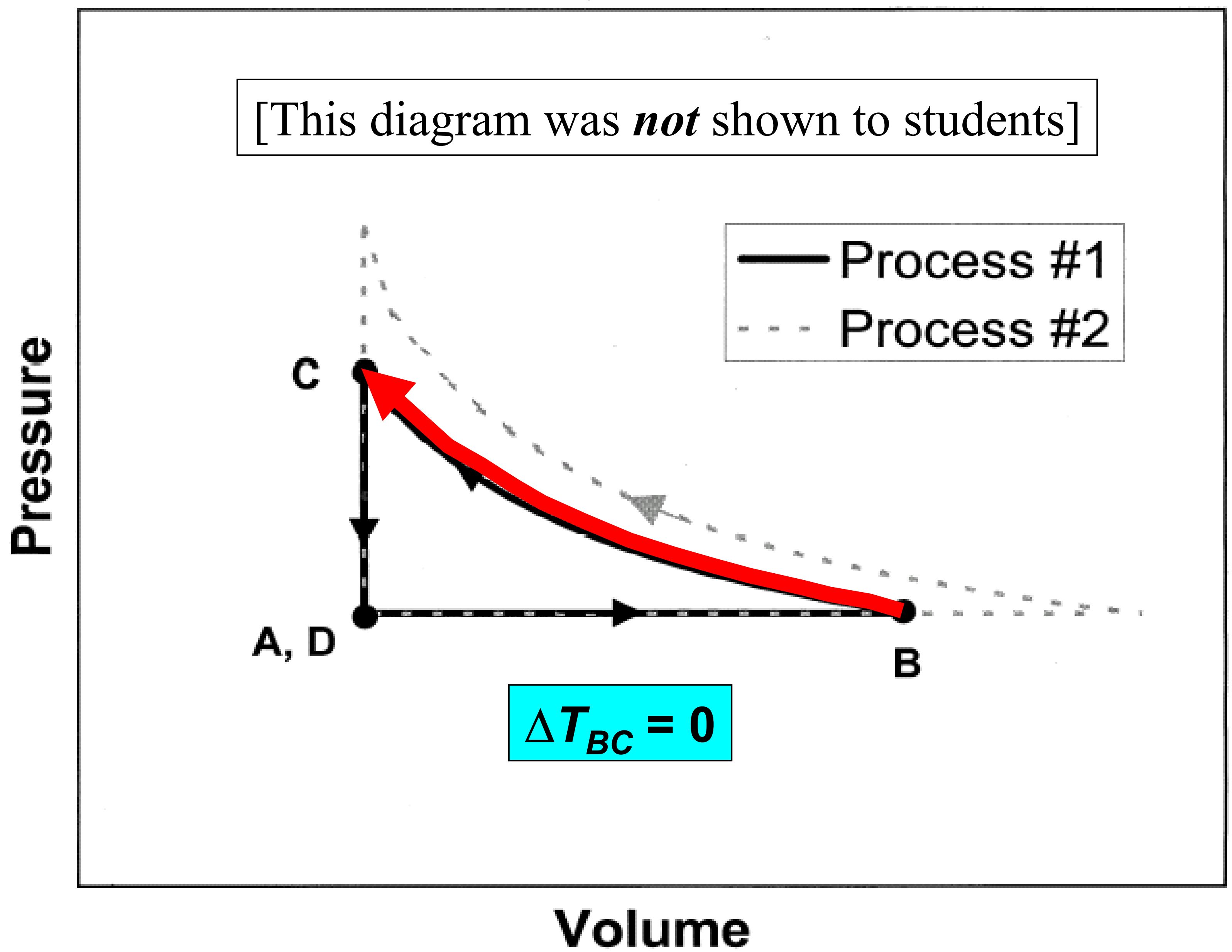
A, D
B
Pressure
Volume


[This diagram was *not* shown to students]
Process #1
Process #2
C
A, D
B
$\Delta T_{BC} = 0$
Pressure
Volume

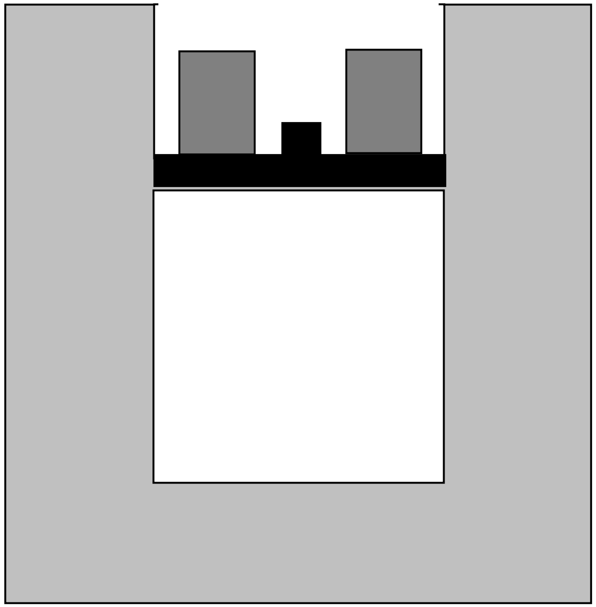
Step 3. At time *C* we stop adding lead weights to the container and the piston stops moving. (The weights that we have already added up until now are still in the containers.) The piston is now found to be at *exactly the same position it was at time **A*** .

Time *C*

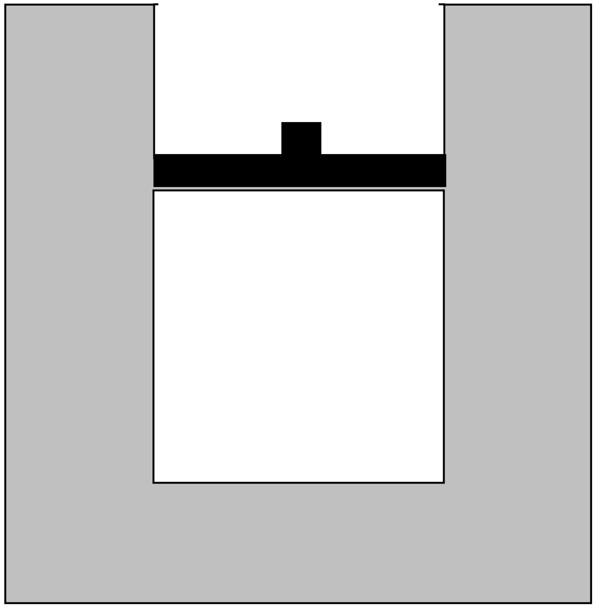
Weights in containers.

Piston in same position as at time *A*.

Temperature same as at time *B*.



Step 4. Now, the piston is locked into place so it *cannot move*; the weights are removed from the piston. The system is left to sit in the room for many hours, and eventually the entire system cools back down to the same room temperature it had at time *A.* When this finally happens, it is time *D*.



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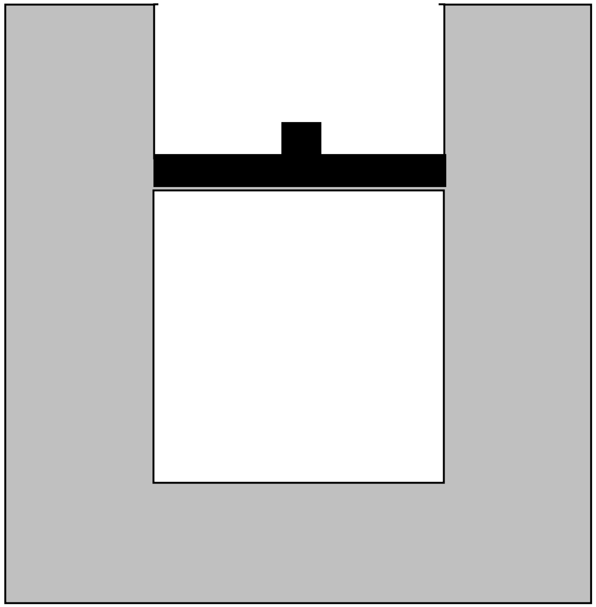
Time *D*

Piston in same position as at time *A*.

Temperature same as at time *A*.



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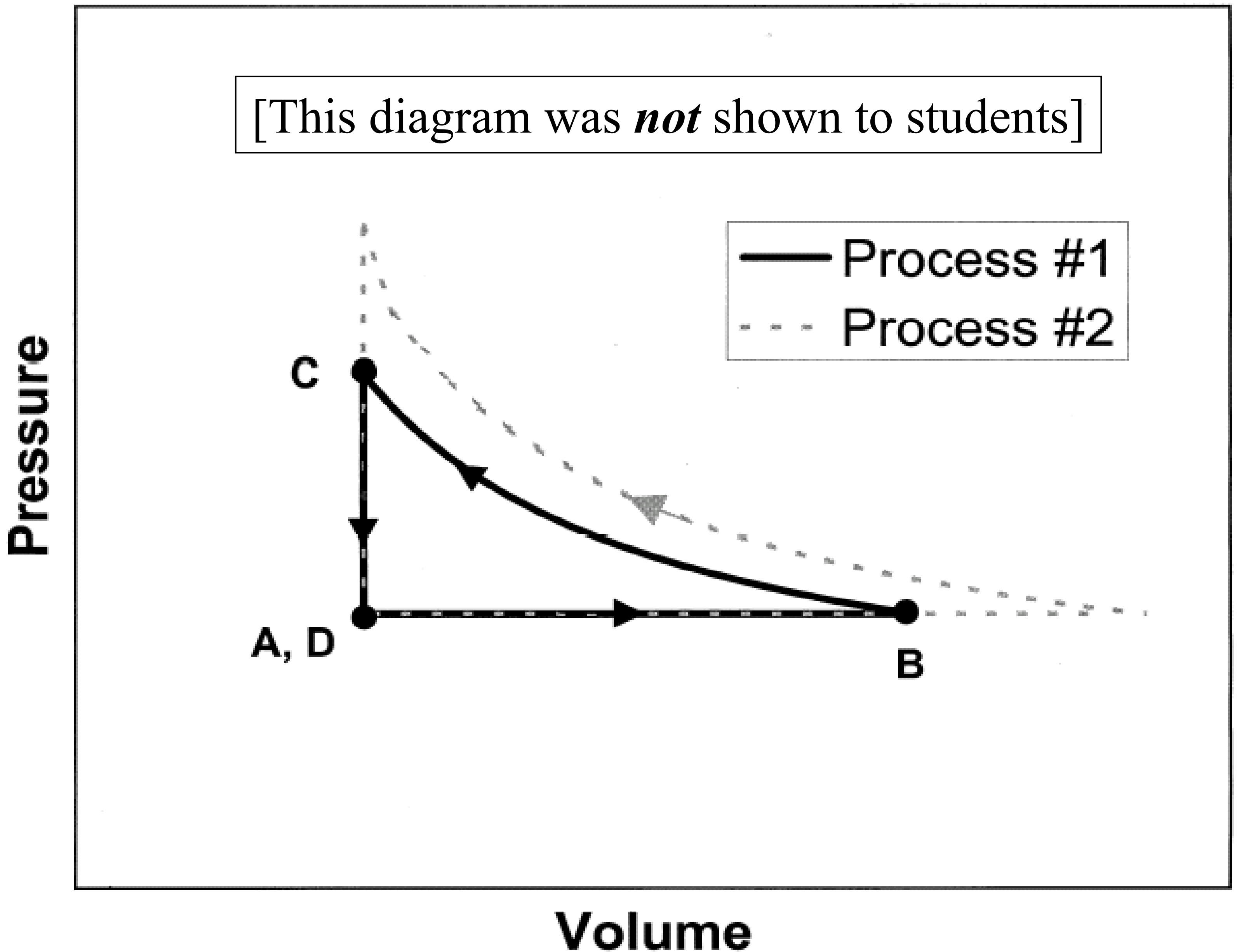
3) For the process C → D, is the work done by the system (W_{CD}) *positive*, *negative*, or *zero*?



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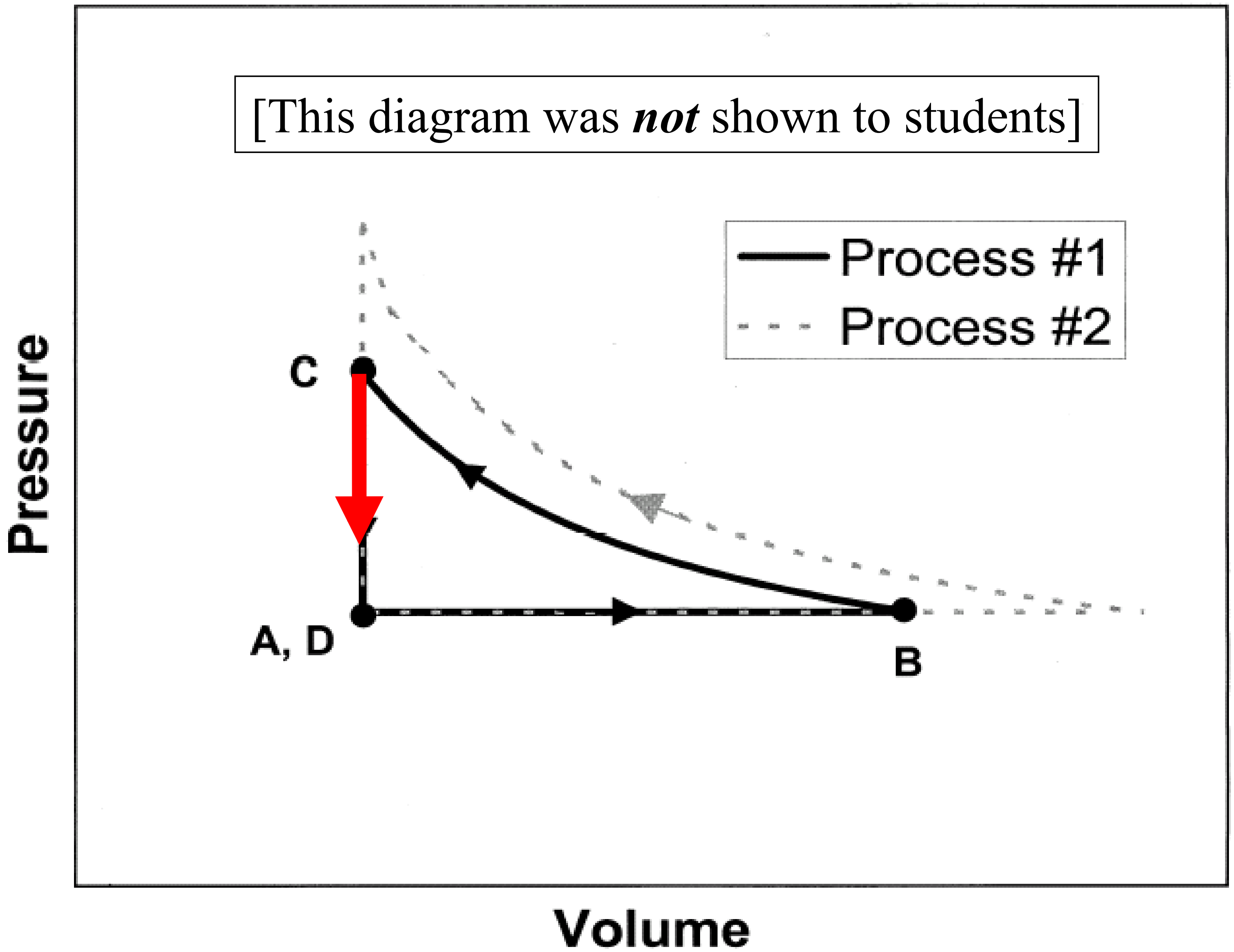
Process #1
Process #2
C
A, D
B
Pressure
Volume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C
A, D
B
Pressure
Volume

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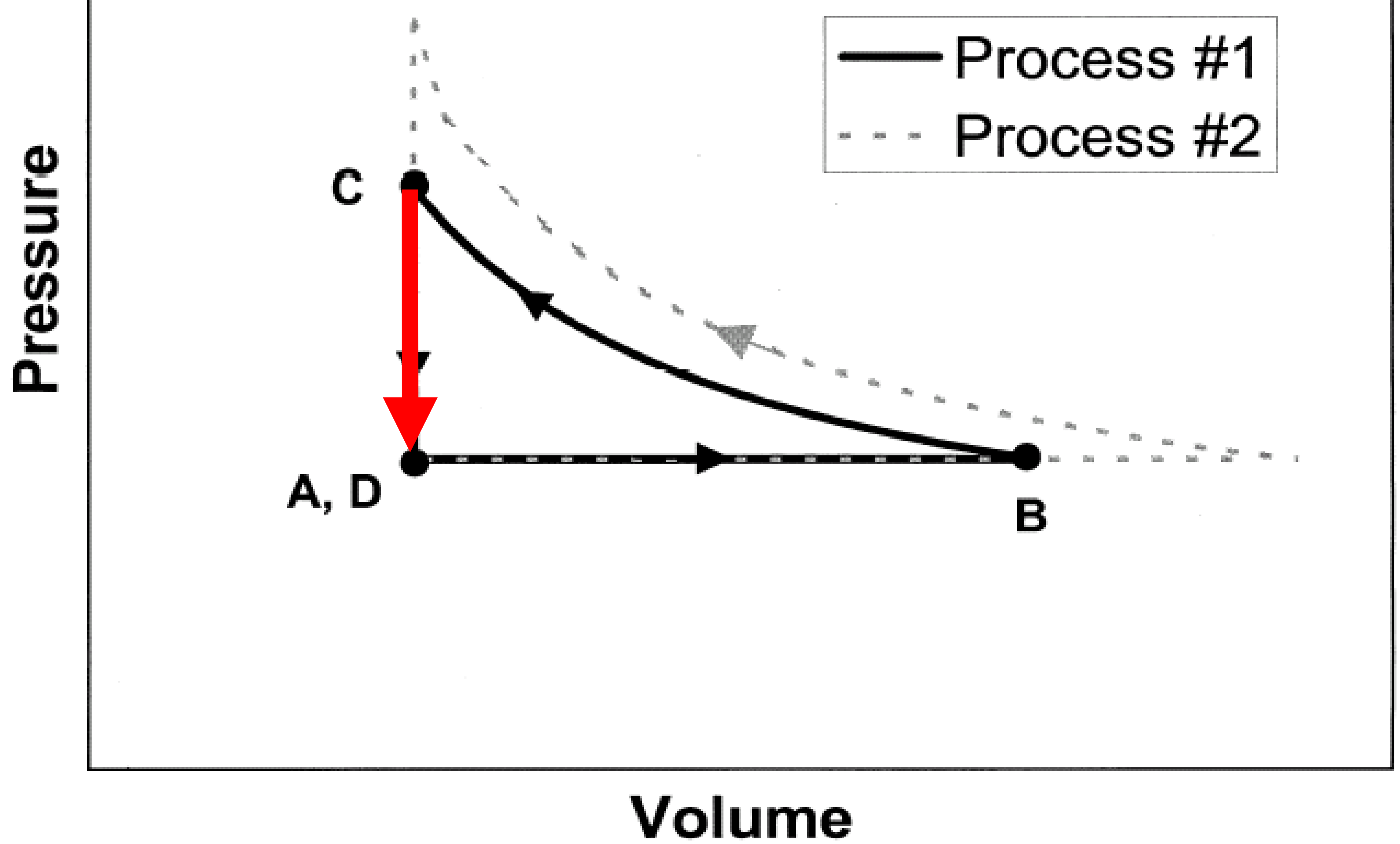

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3) For the process C → D, is the work done by the system (W_{CD}) *positive*, *negative*, or *zero*?

4) Rank the *absolute values* $|W_{AB}|$, $|W_{BC}|$, and $|W_{CD}|$ from largest to smallest; if two or more are equal, use the "=" sign:

largest ______________________________ *smallest*

Explain your reasoning.

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largest $|\mathbf{W_{BC}}| > |\mathbf{W_{AB}}| > |\mathbf{W_{CD}}| = \mathbf{0}$ *smallest*

Explain your reasoning.

Consider the net work done by the system during the complete process A → D, where

$$W_{\mathrm{net}} = W_{\mathrm{AB}} + W_{\mathrm{BC}} + W_{\mathrm{CD}}$$

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$$W_{\mathrm{net}} = W_{\mathrm{AB}} + W_{\mathrm{BC}} + W_{\mathrm{CD}}$$

i) Is this quantity *greater than zero*, *equal to zero*, or *less than zero*?

Consider the net work done by the system during the complete process A → D, where

$$W_{\text{net}} = W_{AB} + W_{BC} + W_{CD}$$

i) Is this quantity *greater than zero*, *equal to zero*, or *less than zero*?

ii) Is your answer consistent with the answer you gave for #6 (i)? Explain.

Consider the net work done by the system during the complete process A → D, where

$$W_{net} = W_{AB} + W_{BC} + W_{CD}$$

i) Is this quantity *greater than zero*, *equal to zero*, or *less than zero*?

ii) Is your answer consistent with the answer you gave for #6 (i)? Explain.

Thermodynamics Curricular Materials

- Preliminary versions and initial testing of worksheets for:
  - calorimetry
  - thermochemistry
  - first-law of thermodynamics
  - cyclic processes
  - Carnot cycle
  - entropy
  - free energy

Preliminary testing in PHYS 222 and PHYS 304

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Related Work on Calorimetry

- Investigate students' understanding of chemical calorimetry
  - *with T. J. Greenbowe, ISU Chemistry Dep't., and post-doc Irene Grimberg*
  - *paper in* International Journal of Science Education *(2003)*

- Probe understanding of students in physics courses
  - *with N.-L. Nguyen and Warren Christensen*

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Student Learning of Thermochemical Concepts

T. J. Greenbowe and DEM, Int. J. Sci. Educ. *25, 779 (2003)*

- Investigated students' misunderstanding of role of bond breaking and forming in determining heats of reaction
  - *student belief that heat flows <u>from</u> one reactant <u>to</u> the other*
- Uncovered students' misinterpretation of role of mass in relationship $Q = mc\Delta T$
  - *strong tendency to associate "m" with reactants only, instead of with total mass undergoing temperature change*

Thermochemistry Tutorial

The textbook (p. 161) describes an experiment in which Silver Nitrate ($AgNO_3$) solution is mixed with hydrochloric acid (HCl) solution in a constant-pressure calorimeter. (We assume that the calorimeter loses only a negligible quantity of heat.) The temperature of the resulting solution is observed to increase, due to the following reaction:

$$AgNO_3(aq) + HCl(aq) \rightarrow AgCl(s) + HNO_3(aq)$$

2. Three students are discussing this experiment. Here is part of their discussion:

Mary: The silver nitrate was originally a solid. When it's put into solution along with the HCl, I think that heat flows out from the $AgNO_3$ and into the HCl solution, and that's why the temperature increases.

Bob: Well, the hydrochloric acid is the more powerful reactant; it's a strong acid, so it must be the one that reacts most strongly. I think that the heat must come out of the HCl.

Lisa: I don't really think that the heat flows into either of those two. I think heat flows out of both the silver nitrate *and* the hydrochloric acid solution, and that's why the temperature rises.

Mary: But how could heat flow out of *both* of the reactants? Where is it coming from then? Doesn't that violate conservation of energy?

Comment on the students' statements. Do you agree with one of them more than the others? If so, explain why. If you don't think that any of them are completely correct, give your own opinion.

Related Work on Calorimetry

- Investigate students' understanding of chemical calorimetry
  - *with T. J. Greenbowe, ISU Chemistry Dep't., and post-doc Irene Grimberg*
  - *paper in* International Journal of Science Education *(2003)*

- Probe understanding of students in physics courses
  - *with N.-L. Nguyen and Warren Christensen*

- Develop and test worksheets for both physics and chemistry

Physics Students' Reasoning in Calorimetry

N.-L. Nguyen, W. Christensen, and DEM

- Investigation of reasoning regarding calorimetric concepts among students in calculus-based general physics course
- Development and testing of curricular materials based on research

Investigation of student learning in calculus-based physics course (PHYS 222)

Pretest Question #1

Written pretest given after lecture instruction 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 *lower* 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

$$Q = mc\Delta T$$

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

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

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

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

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

Pretest Question #1 Results

Second-semester calculus-based course (PHYS 222)

		N=311
Correct		
	$\Delta T_{LSH} > \Delta T_{GSH}$	62%
	With correct explanation	***54%***
Incorrect		
	$\Delta T_{LSH} = \Delta T_{GSH}$	22%
	$\Delta T_{LSH} < \Delta T_{GSH}$	16%

LSH = lower specific heat
GSH = greater specific heat

(five different versions of question were administered)

Pretest: Question #1

	All students N=311
Correct ($\Delta T_{\text{lower specific heat}} > \Delta T_{\text{greater specific heat}}$) *With correct explanation*	***55%***
Incorrect	
($\Delta T_{\text{lower specific heat}} = \Delta T_{\text{greater specific heat}}$)	
temperature changes are equal since energy transfers are equal	9%
temperature changes are equal since system goes to equilibrium	6%
Other	6%
($\Delta T_{\text{lower specific heat}} < \Delta T_{\text{greater specific heat}}$)	
specific heat directly proportional to rate of temperature change	7%
Other	8%

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*."

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

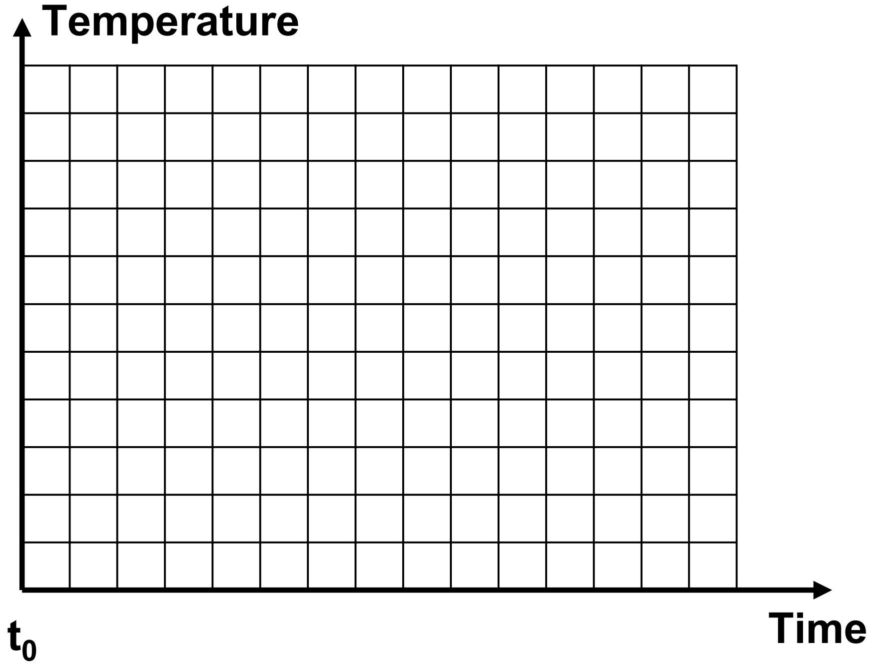
Pretest Question #2

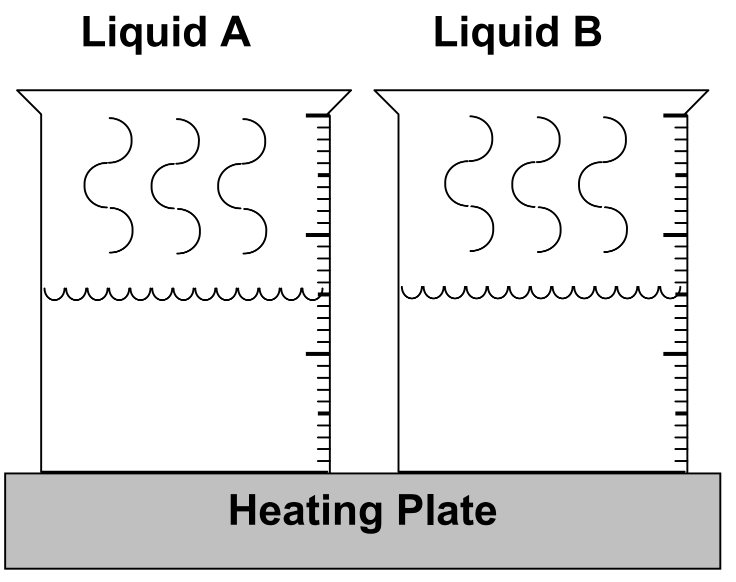
Suppose we have two ***separate*** containers: One container holds Liquid A, and another contains Liquid B. The mass and initial temperature of the two liquids are the same, but the ***specific heat*** of Liquid A is ***two times*** that of Liquid B.

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

$[c_A = 2c_B]$





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

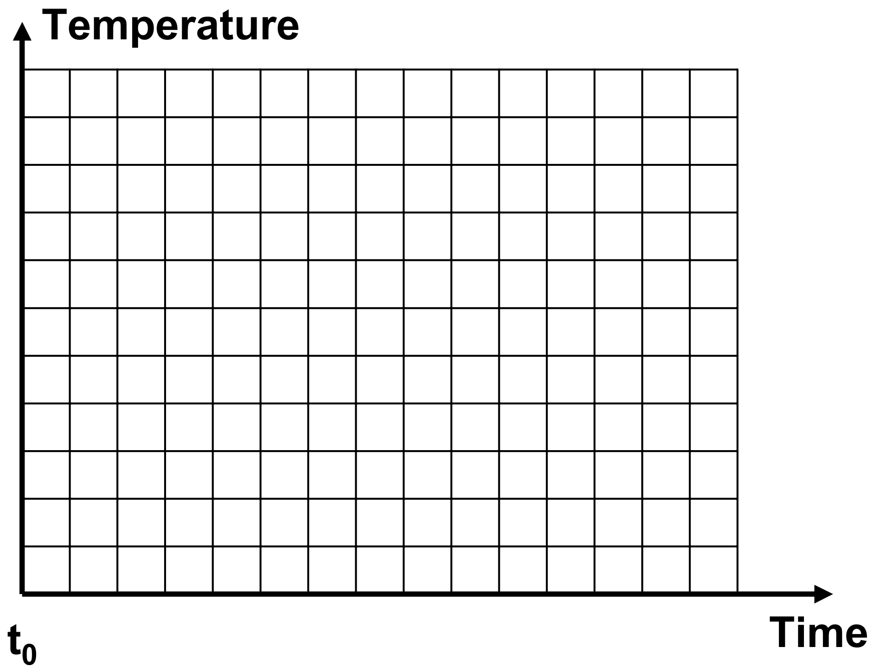
Pretest Question #2 (cont'd)

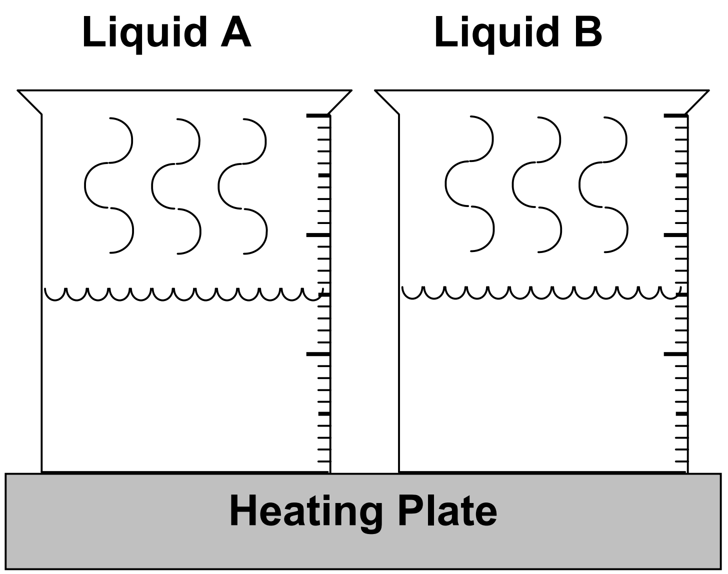
On the grid below, graph the temperature as a function of time for *each* liquid, A and B. Use a separate line for each liquid, even if they overlap. Make sure to clearly <u>label</u> your lines, and use proper graphing techniques.

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

Pretest Question #2 Graph

$[c_A = 2c_B]$



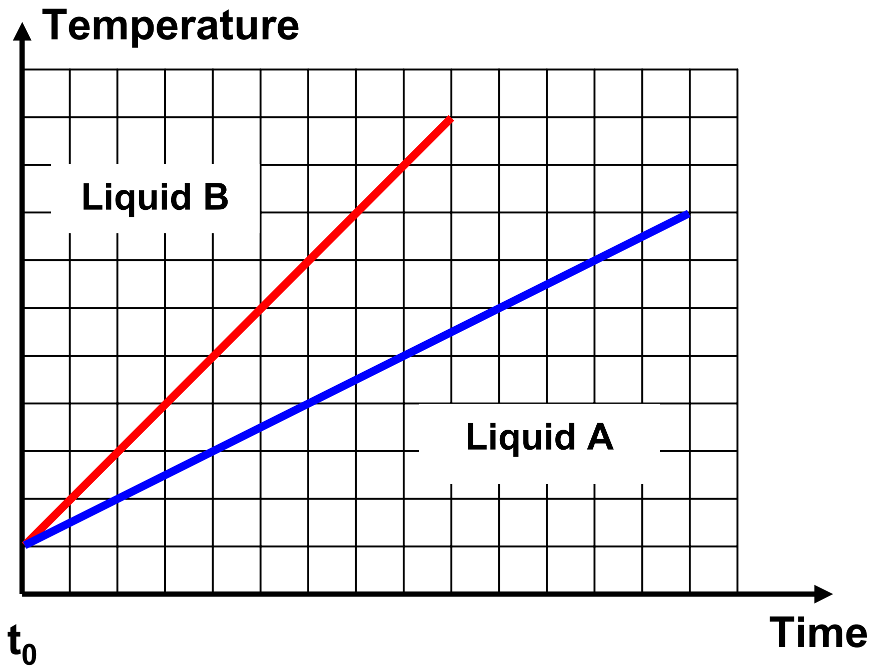


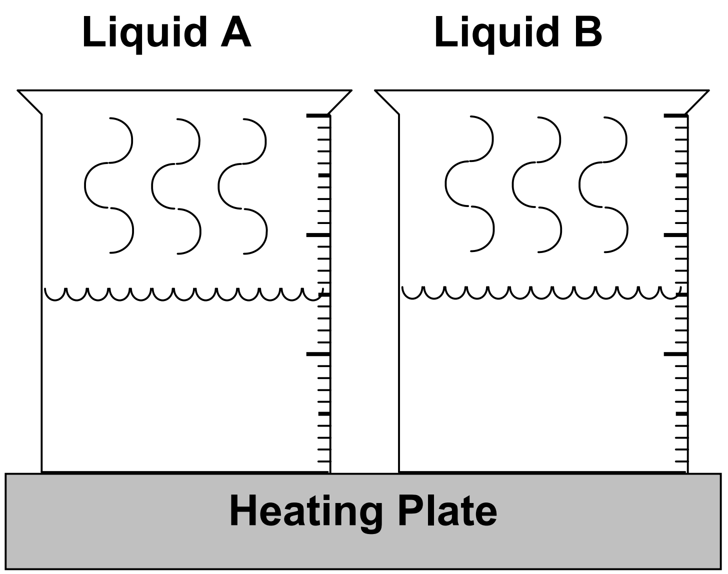
The specific heat of A is greater than the specific heat of B.

Pretest Question #2 Graph

$[c_A = 2c_B]$

[Equal amounts of energy added will result in smaller temperature change for liquid with greater specific heat]





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

Pretest Question #2 Results (N = 311)

Second-semester calculus-based course (PHYS 222)

Correct *(Slope of B > A)*	70%
with correct explanation	50%
Incorrect	
Slope of B < A	28%
Other	2%

Example of Incorrect Student Explanation

"Since the specific heat of A is two times that of liquid B, and everything else is held constant … the liquid of solution A will heat up two times as fast as liquid B."

Belief that specific heat is proportional to rate of temperature change

Outline

Research-Based Curriculum Development

- Overview

Investigation of Students’ Reasoning

- Students’ reasoning in thermodynamics
- Students’ reasoning in calorimetry
- Diverse representational modes in student learning

Curriculum Development

- Curricular materials for thermodynamics
- Curricular materials for calorimetry

Worksheet Strategy

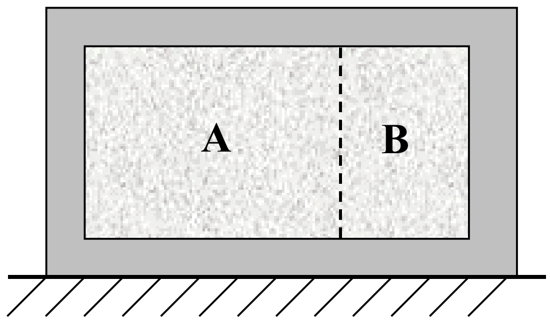
- Guide students to confront distinction between temperature of a system, and its internal energy
- Explore meaning of specific heat by finding temperature changes of different objects in thermal contact with each other

Worksheet Strategy

- Guide students to confront distinction between temperature of a system, and its internal energy
- Explore meaning of specific heat by finding temperature changes of different objects in thermal contact with each other
- Practice proportional reasoning and algebraic skills by varying system parameters, gradually increasing problem complexity.

Calorimetry Worksheet

. Suppose we again have two samples, *A* and *B*, of an **ideal gas** placed in a partitioned insulated container. The gas in Sample *A* is the **same gas** that is in Sample *B*; however, Sample *A* now has **twice the mass** of sample *B* **(**and the volume of sample *A* is twice the volume of sample *B*). Energy but no material can pass through the conducting partition; the partition is rigid and cannot move.



On the bar chart on the next page, the values of the samples' internal energy are shown at some initial time ("Time Zero"); "Long After" refers to a time long after that initial time. ***.*** *The mass of sample A is still twice the mass of sample B,* ***However****, note carefully:* ***<u>In this case,</u>*** **<u>A</u>** ***<u>and</u>*** **<u>B</u>** ***<u>do NOT have the same</u>*** **<u>initial</u>** ***<u>internal energy</u>*** **<u>.</u>** *Refer to the set of three bar charts to answer the following questions.*

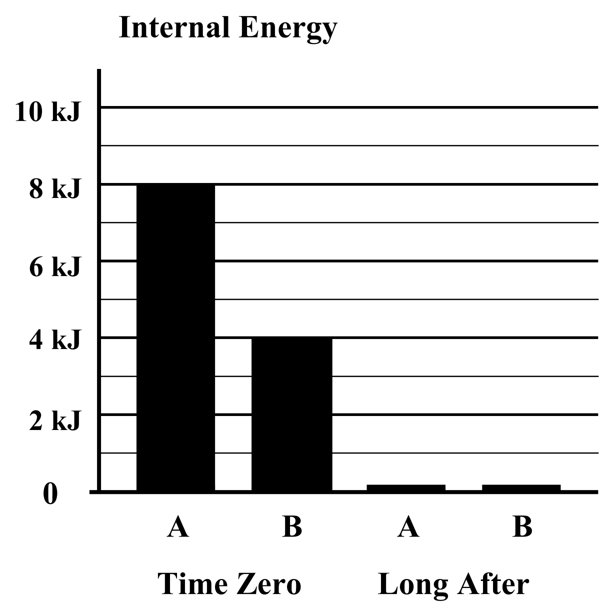
a. Find the absolute temperature of sample *A* at time zero (the initial time), and plot it on the chart.

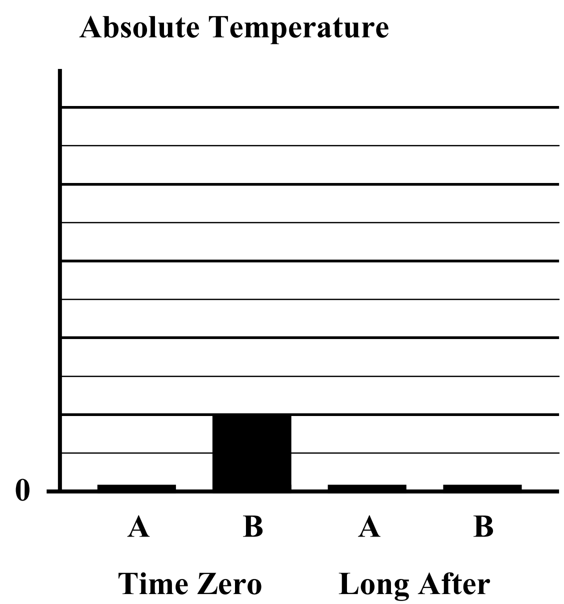
b. A long time after time zero, what ratio do you expect for the temperatures of the two samples?

c. A long time after time zero, what ratio do you expect for the internal energies of the two samples? Explain.

Calorimetry Worksheet

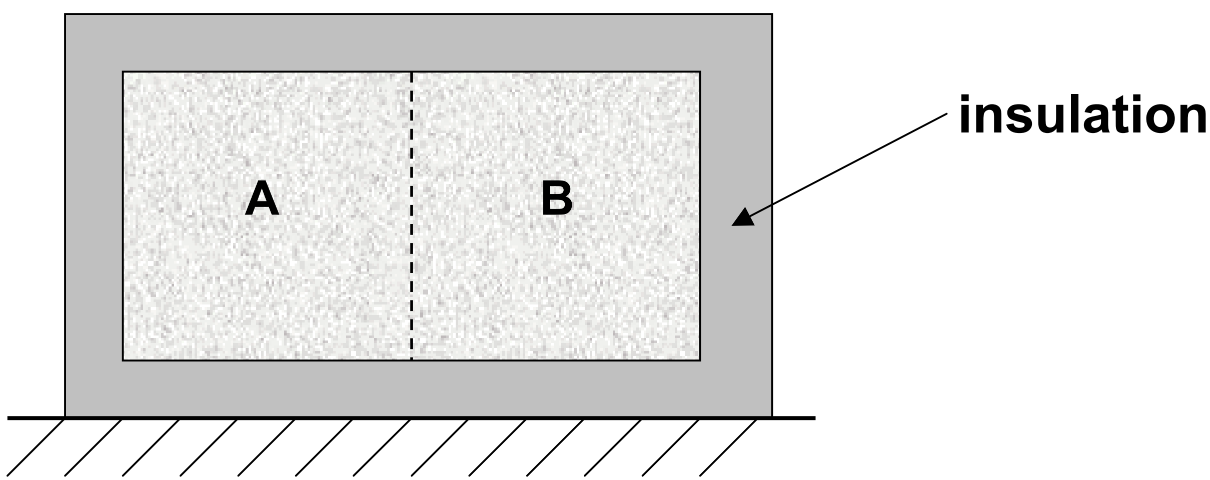
Complete the bar charts by finding the "Long After" values for temperature and internal energy, and also the amounts of energy transferred to each sample. (This is the net transfer that occurs between time zero and the time "long after.") If any quantity is zero, label that quantity as zero on the bar chart. Explain your reasoning below. *NOTE: The missing values – indicated by a thick line on the horizontal axis – are* <u>*not*</u> *necessarily zero – you need to determine whether or not they are actually zero!*



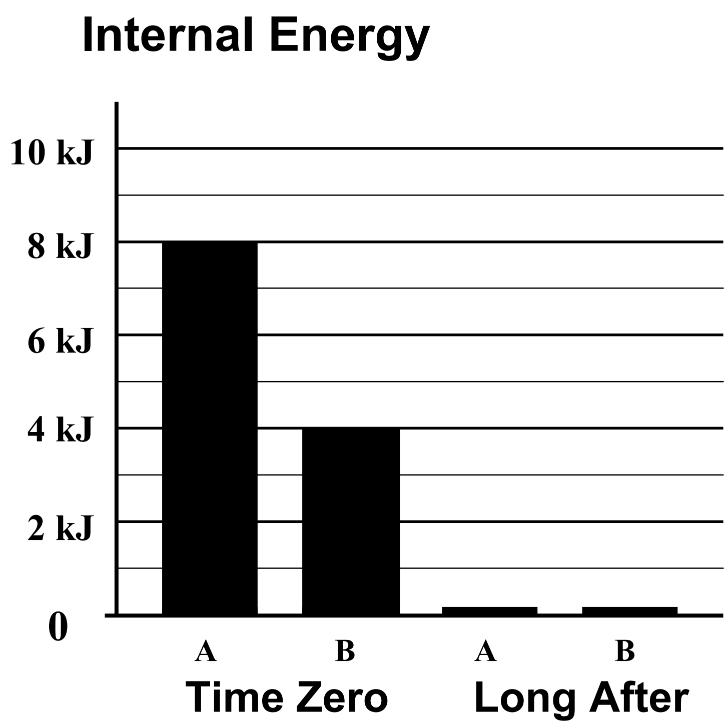


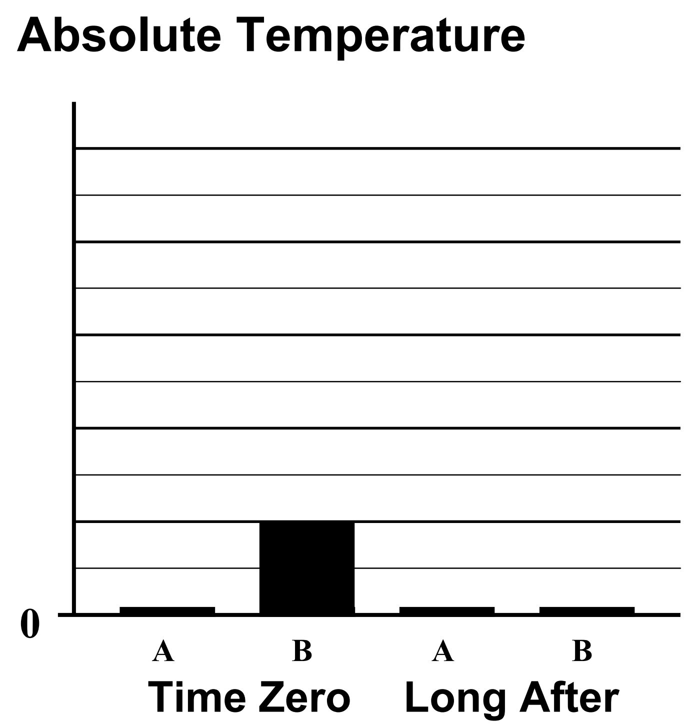
Ideal Gas Problem

Suppose we have two samples, *A* and *B*, of an **ideal gas** placed in a partitioned insulated container which neither absorbs energy nor allows it to pass in or out. The gas in sample *A* is the **same gas** that is in Sample *B*. 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. Complete the bar charts by finding the "Long After" values for temperature and internal energy. Explain your reasoning.

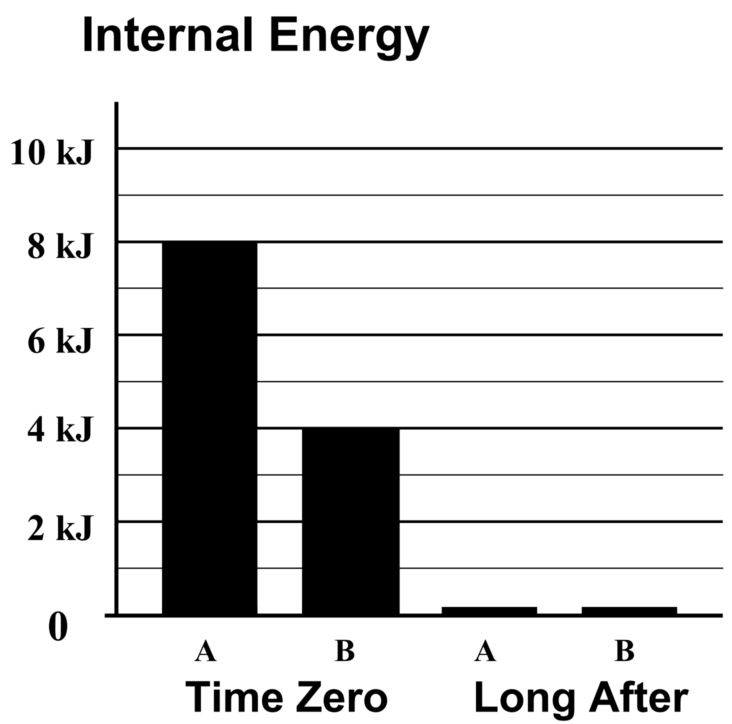


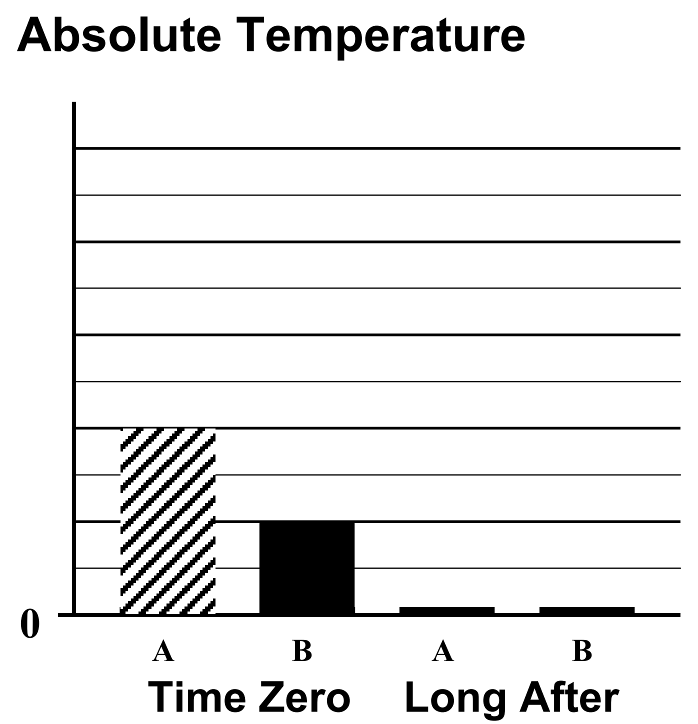


Ideal Gas Bar Graph Solution

with same mass

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

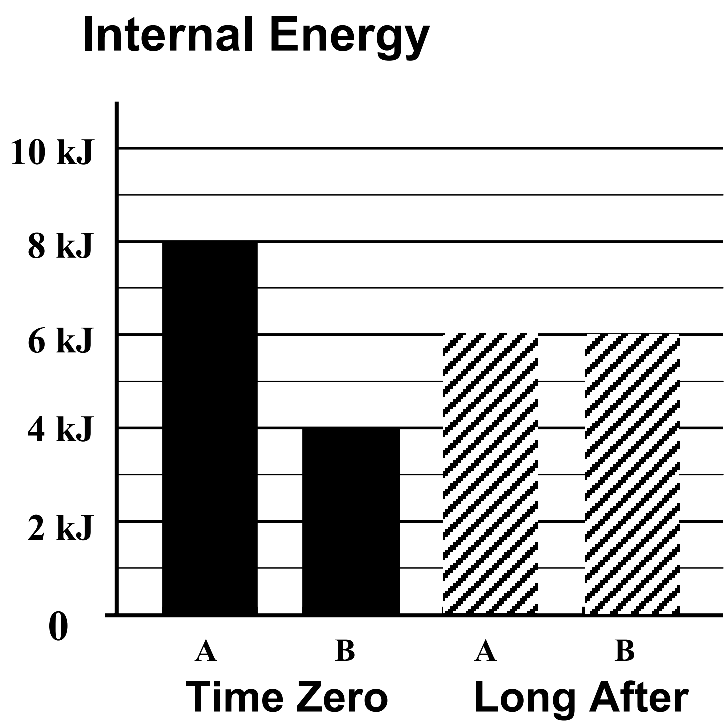


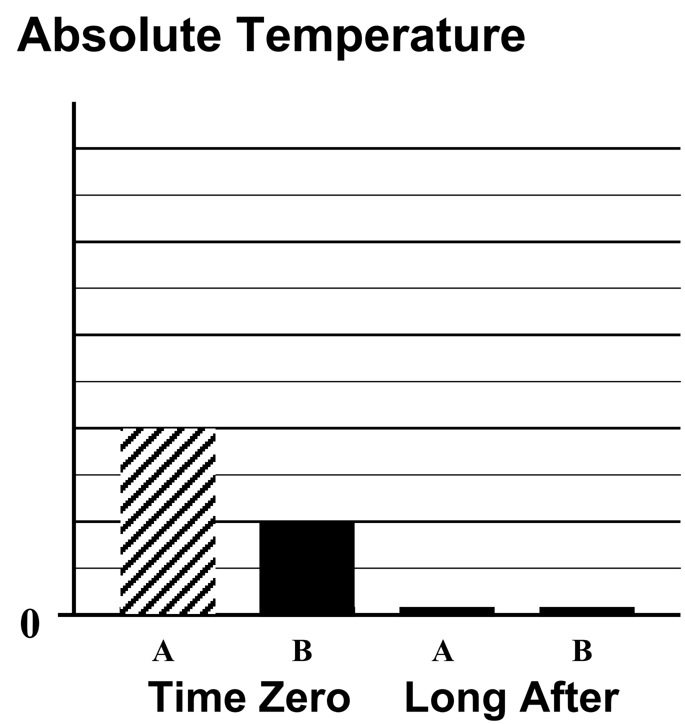


Ideal Gas Bar Graph Solution

with same mass

energy lost by A = energy gained by B

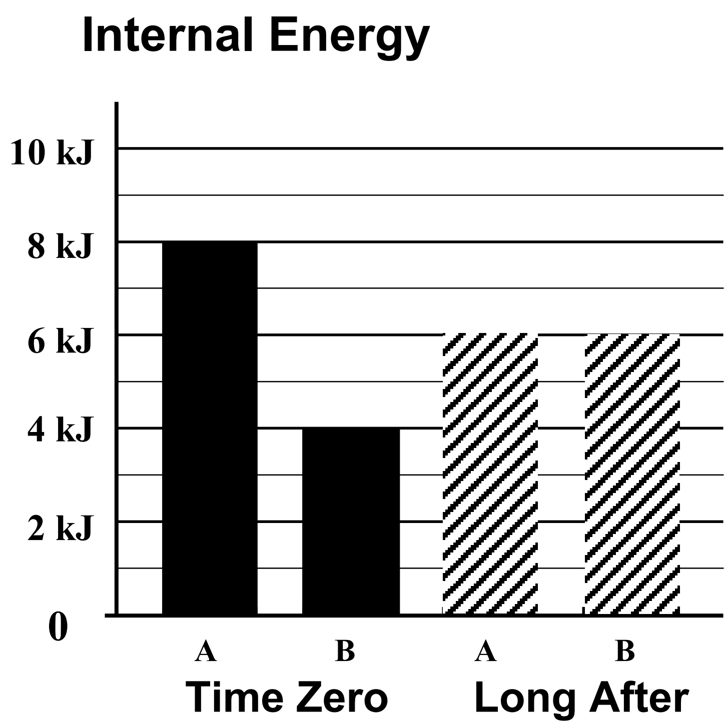


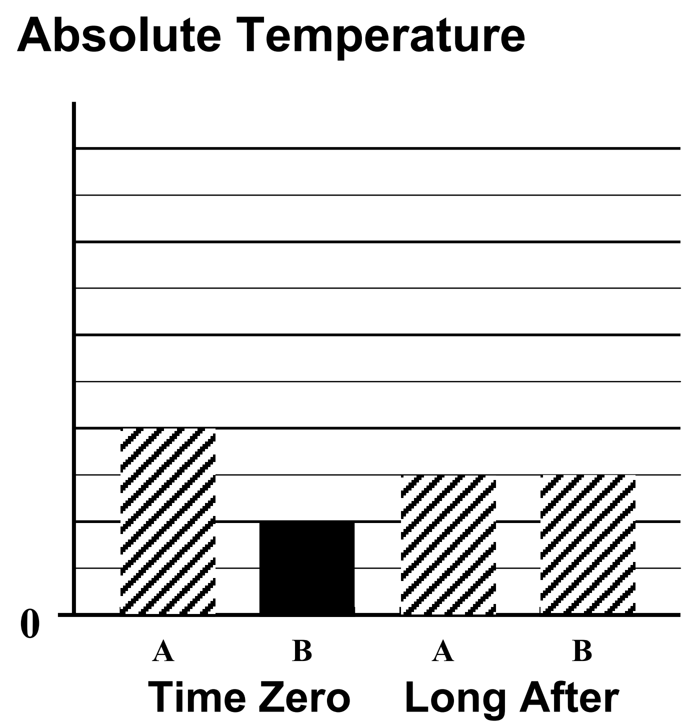


Ideal Gas Bar Graph Solution

with same mass

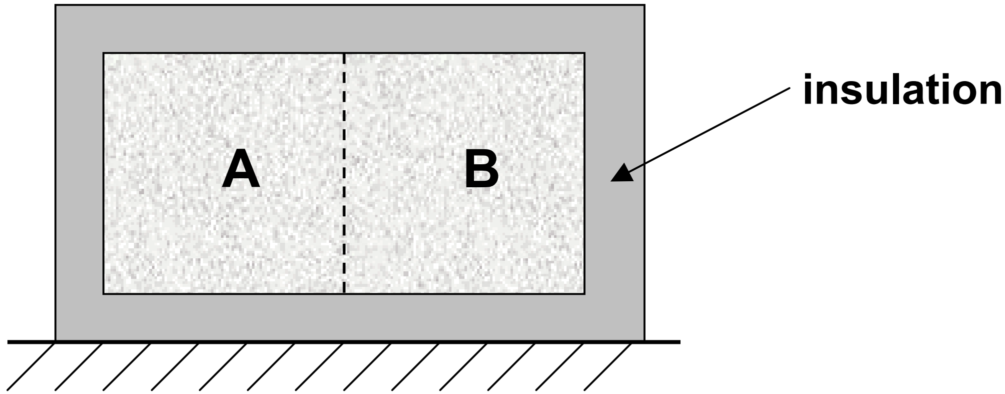
temperature decrease of *A* = temperature increase of *B*



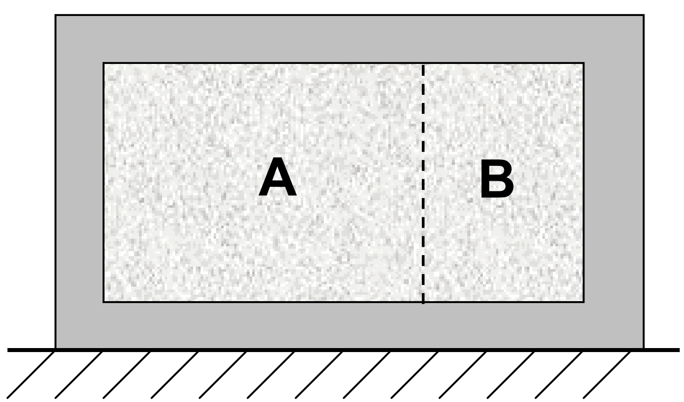


Problem Sequence

Ideal Gas with equal masses



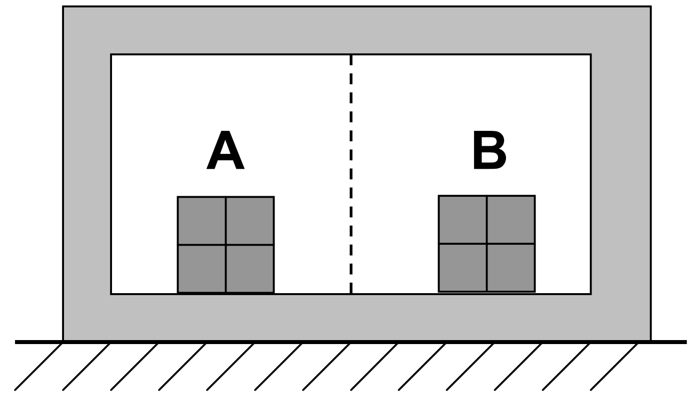
Ideal Gas, $m_A = 2m_B$



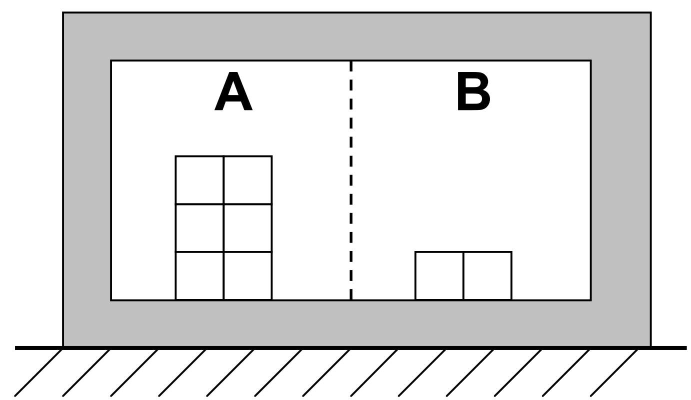
Change of Context

Problem: *A and B in thermal contact; given ΔT_A find ΔT_B.*

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

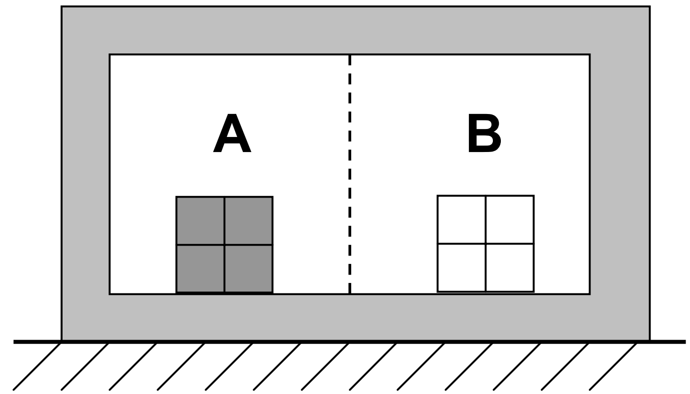


A and B are same material, have different initial temperatures, and $m_A = 3m_B$

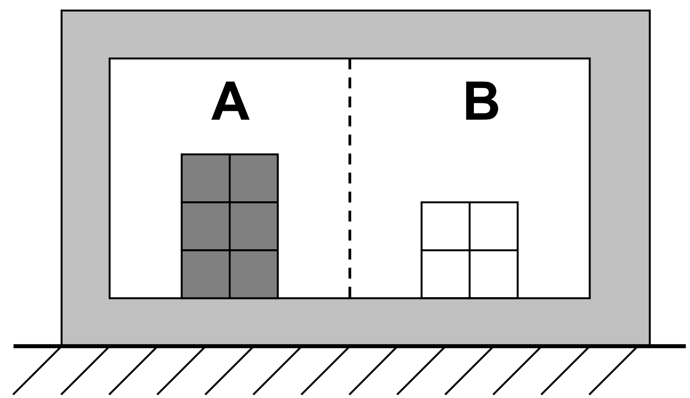


More examples

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 $m_A = 1.5m_B$



Classroom Testing

- Use worksheets in randomly chosen recitation sections (assisted by PERG graduate students).
- Compare exam performance of students in experimental sections to those in control sections.
- Modify worksheets based on input from recitation instructors and PERG graduate students.

Preliminary Results

Second-semester calculus-based course (PHYS 222)

- Experimental group had lower pretest scores than control group (45% vs. 57%), but higher posttest scores (49% vs. 41%).
  - *posttest problem more challenging than pretest problem*
  - *random selection failed to produce equivalent experimental and control groups*
- Posttest-score difference not statistically significant
- No difference between groups on qualitative or quantitative multiple-choice questions

Preliminary conclusion: Worksheet too lengthy in present form for single recitation session in PHYS 222

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Investigation of Students' Reasoning

- Students' reasoning in thermodynamics
- Students' reasoning in calorimetry
- Diverse representational modes in student learning

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- Curricular materials for thermodynamics
- Curricular materials for calorimetry

Investigation of Diverse Representational Modes in the Learning of Physics and Chemistry

Supported by *NSF "Research on Learning and Education" program, Co-PI: T. J. Greenbowe*

- Probe students' reasoning with widely used representations
  - e.g., force-vector, free-body, *P-V*, and field-vector diagrams
- Compare student reasoning with different forms of representation of same concept
  - e.g., verbal, diagrammatic, mathematical/symbolic, graphical

Physics Students' Understanding of Vector Concepts

N.-L. Nguyen and DEM, Am. J. Phys. ***70****, 630 (2003)*

- Seven-item quiz administered in all ISU general physics courses during 2000-2001
- Quiz items focus on basic vector concepts posed in graphical form
- Given during first week of class; 2031 responses received

Two Key Items

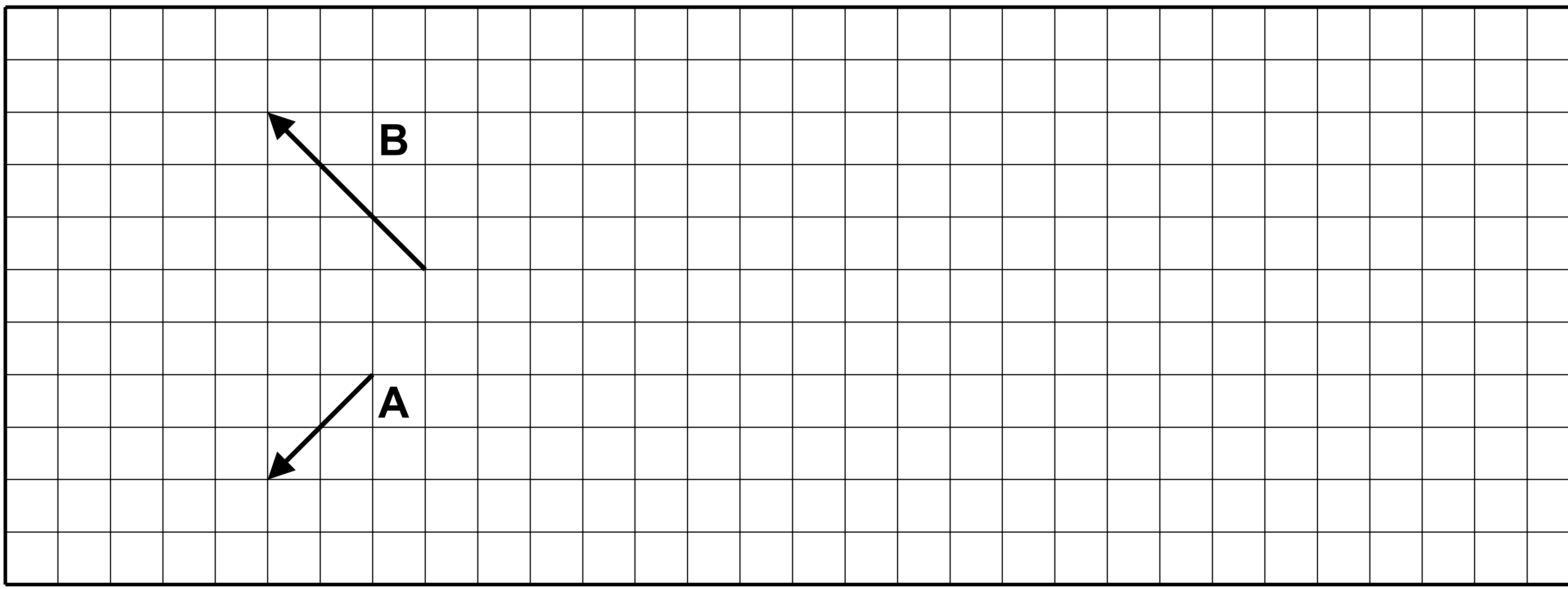
- **Question #5:** Two-dimensional vector addition (vectors shown on grid)
- **Question #7:** Two-dimensional vector addition (no grid present)

Two Key Items

- **Question #5:** Two-dimensional vector addition (vectors shown on grid)

- **Question #7:** Two-dimensional vector addition (no grid present)

5. In the figure below there are two vectors $\vec{\mathbf{A}}$ and $\vec{\mathbf{B}}$. Draw a vector $\vec{\mathbf{R}}$ that is the sum of the two, (i.e. $\vec{\mathbf{R}} = \vec{\mathbf{A}} + \vec{\mathbf{B}}$). Clearly label the resultant vector as $\vec{\mathbf{R}}$.



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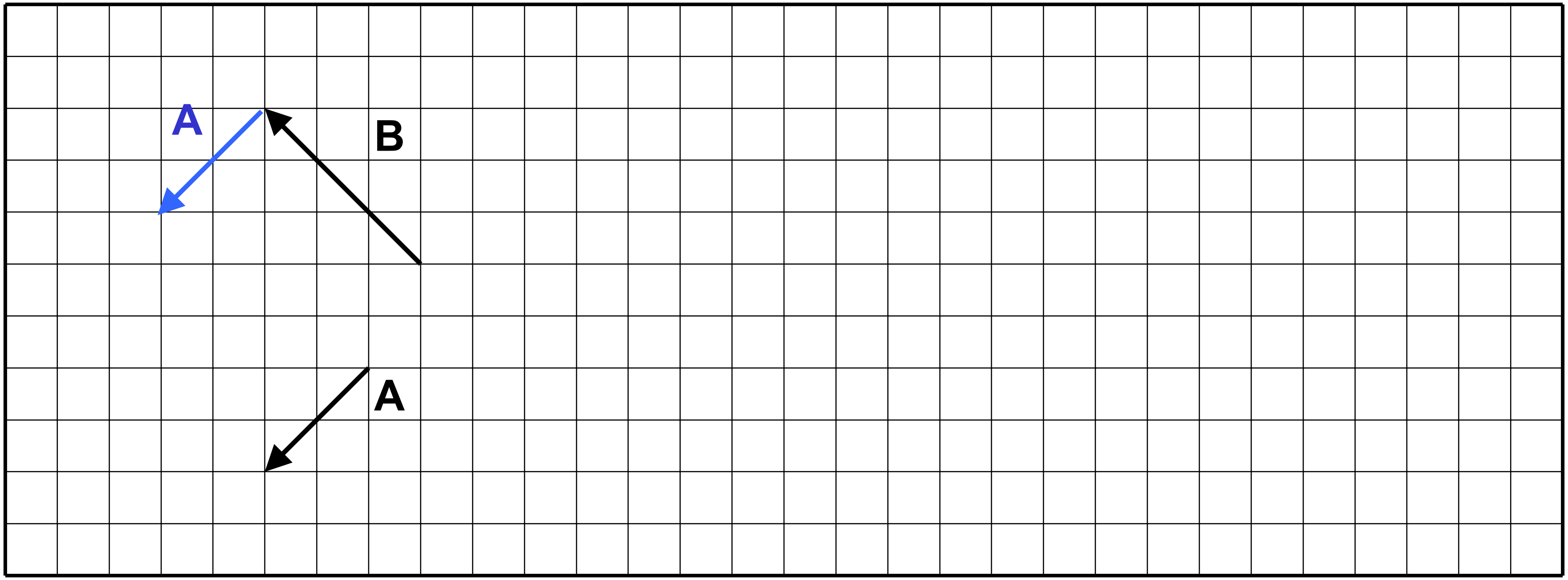

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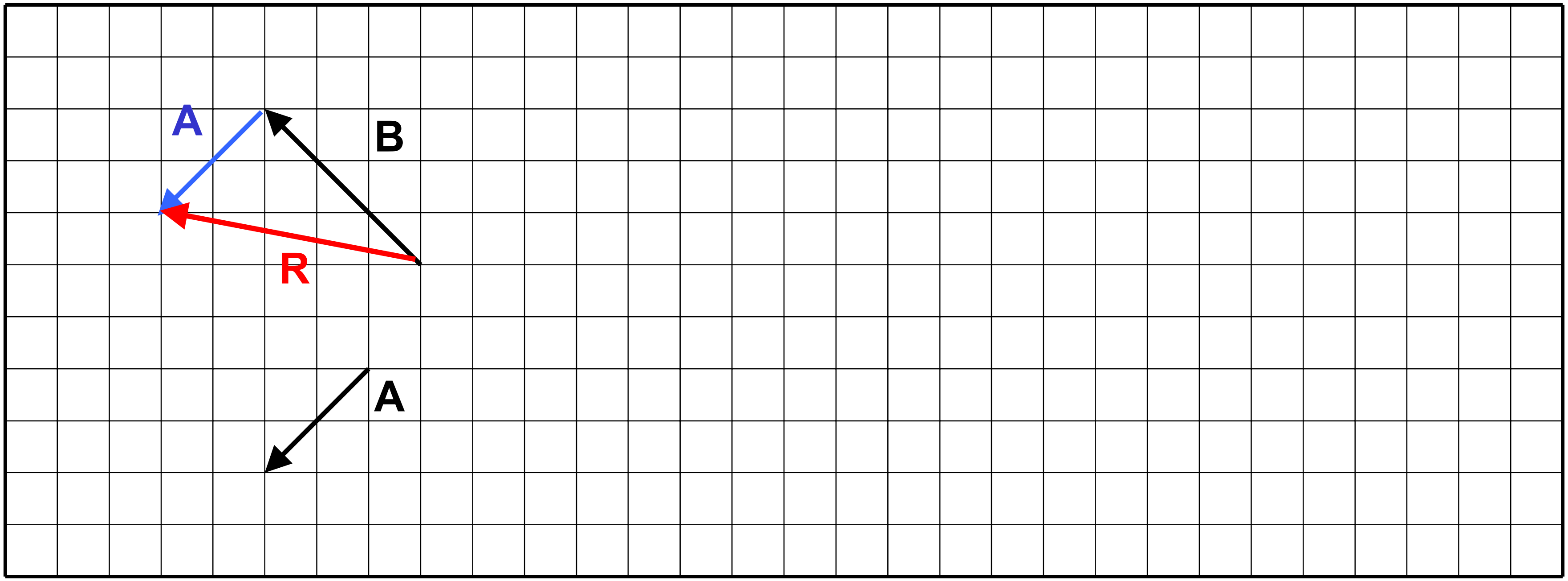


Many Students Have Difficulties with Vectors

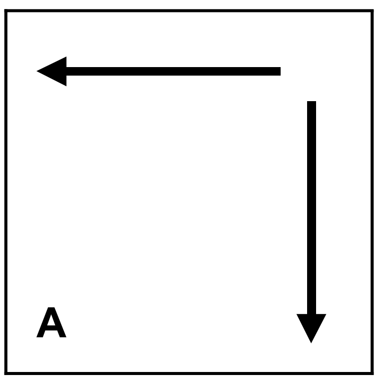
Among students in second-semester courses:

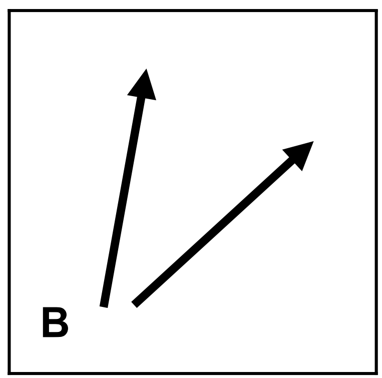
- 56% of algebra-based physics students were unsuccessful in solving #5

Two Key Items

- **Question #5:** Two-dimensional vector addition (vectors shown on grid)
- **Question #7:** Two-dimensional vector addition (no grid present)

7. In the boxes below are two pairs of vectors, pair **A** and pair **B**. (All arrows have the same length.) Consider the magnitude of the ***resultant*** (the vector sum) of each pair of vectors. Is the magnitude of the resultant of pair **A** *larger than*, *smaller than*, or *equal to* the ***magnitude*** of the resultant of pair **B**? Write an explanation justifying this conclusion.





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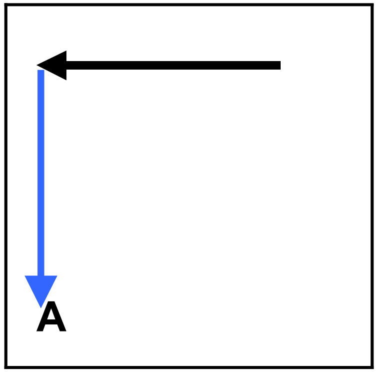

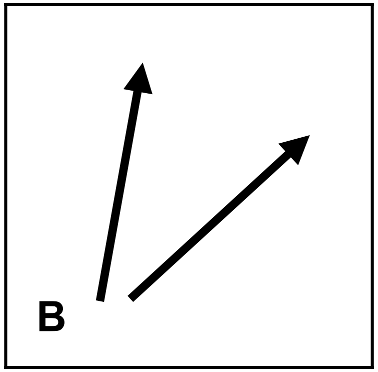

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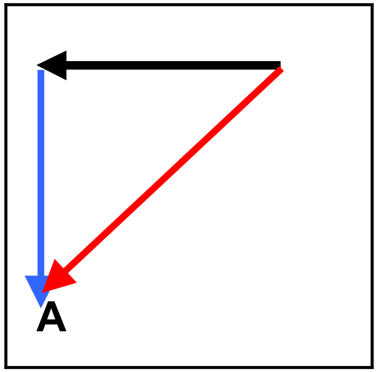

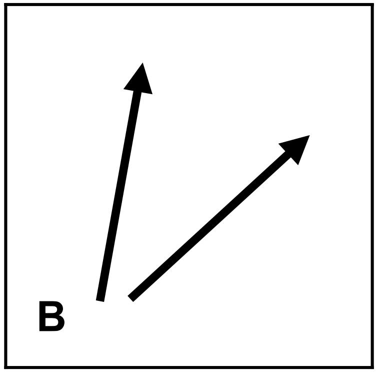

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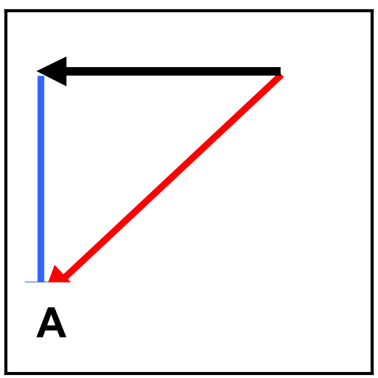

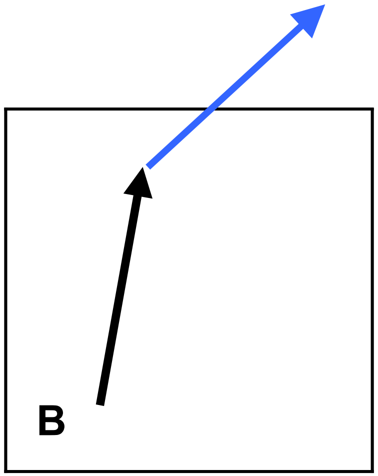

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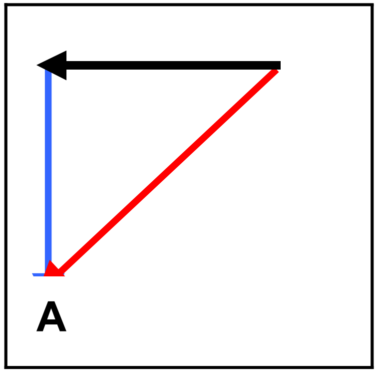

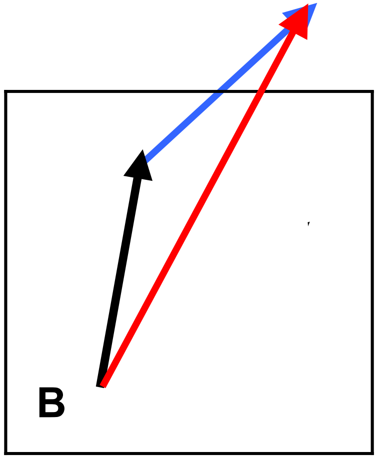

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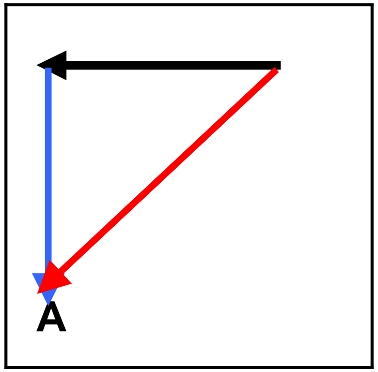

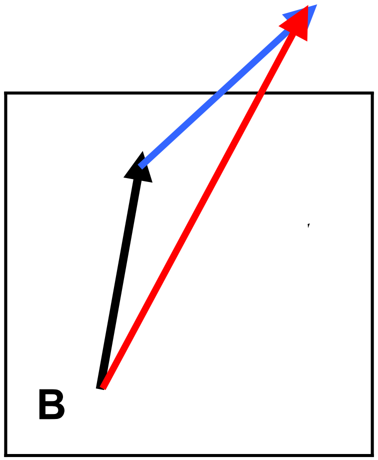

$$|R_A| < |R_B|$$

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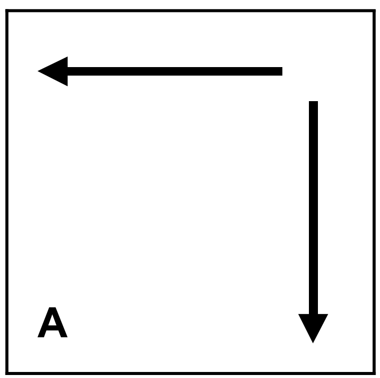

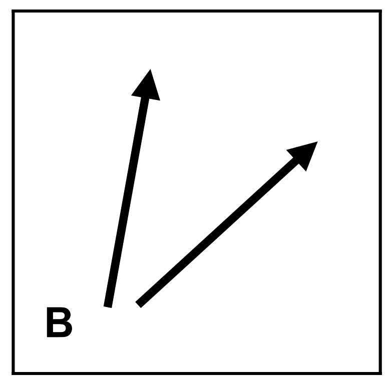

Many Students Have Difficulties with Vectors

Among students in second-semester courses:

- 56% of algebra-based physics students were unsuccessful in solving #5

Many Students Have Difficulties with Vectors

Among students in second-semester courses:

- 56% of algebra-based physics students were unsuccessful in solving #5

- 44% of calculus-based physics students were unsuccessful in solving #5, or #7, or both.

Difficulties with Vector Concepts

- Imprecise understanding of vector direction
- Vague notion of vector addition

  "***R*** should be a combination of ***A*** and ***B*** so I tried to put it between ***A*** and ***B***"

- Confusion regarding parallel transport
  (must maintain magnitude ***and*** direction as vector "slides")

Difficulties with Graphical Representation of Vectors

- **Dependence on grid:** many students were unable to add vectors without a grid
- **Little gain:** Relatively small gains resulting from first-semester instruction

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➢ **Quiz de vectores disponible en Español; Pedir copia electronica:**

dem@iastate.edu

Investigation of Diverse Representational Modes in the Learning of Physics and Chemistry

Supported by *NSF "Research on Learning and Education" program, Co-PI: T. J. Greenbowe*

- Probe students' reasoning with widely used representations
  - e.g., force-vector, free-body, *P-V*, and field-vector diagrams
    [*N.-L. Nguyen and DEM,* Am. J. Phys. ***70****, 630 (2003)]*

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Students' Problem-Solving Performance and Representational Mode

DEM, submitted to Am. J. Phys. *(2003)*

“Multiple-Representation” Quiz

- Same or similar question asked in more than one form of representation
  - e.g., verbal [words only], diagrammatic, mathematical, etc.
- Comparison of responses yields information on students’ reasoning patterns with diverse representations

Must ensure that students have first had extensive practice with each form of representation

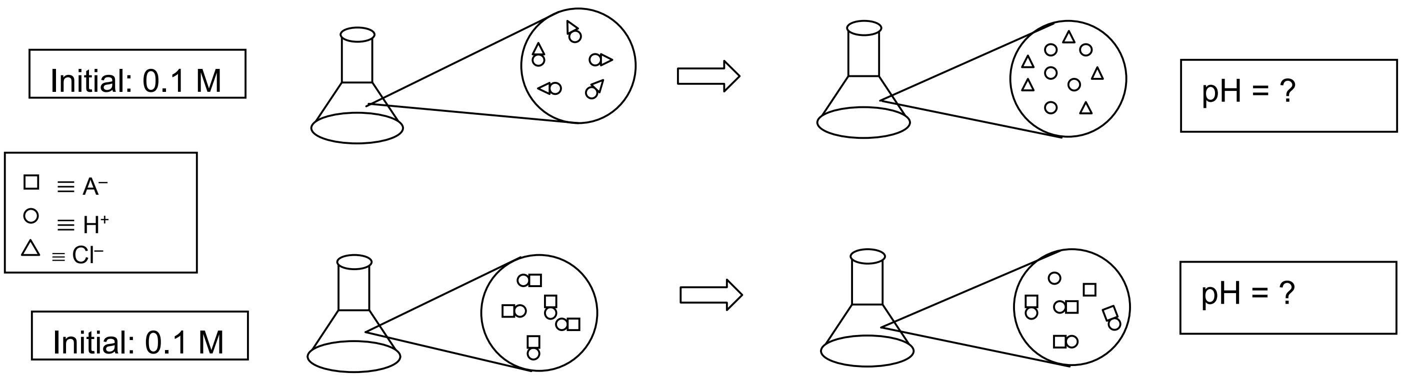
[Chemistry Multi-representation Quiz]

1. Hydrogen chloride gas is bubbled into water, resulting in a one-tenth molar hydrochloric acid solution. In that solution, after dissociation, all of the chlorine atoms become chloride ions, and all of the hydrogen atoms become hydronium ions. In a separate container, HA acid is added to water creating an initial concentration of one-tenth molar HA-acid solution. In that solution (at equilibrium), twenty percent of the H atoms becomes hydronium ions, and twenty percent of the A atoms become A^- ions.

(a) Find the pH of the hydrochloric acid solution and explain your reasoning

(b) Find the pH of the HA-acid solution and explain your reasoning

2. (a) Given these two samples below, find the pH of each solution



(b) Explain the reasoning you used to come to this conclusion.

Investigation of Physics Students' Understanding of Representations

- Second-semester, algebra-based general physics course at Iowa State University.
- Data collected during five separate years (1998-2002).

Example: Quiz on Gravitation

- 11-item quiz given on second day of class (all students have completed study of mechanics)

- Two questions on quiz relate to Newton's third law in astronomical context
  - verbal version and diagrammatic version

#1. The mass of the sun is about 3×10^5 times the mass of the earth. How does the magnitude of the gravitational force exerted by the sun on the earth compare with the magnitude of the gravitational force exerted by the earth on the sun?

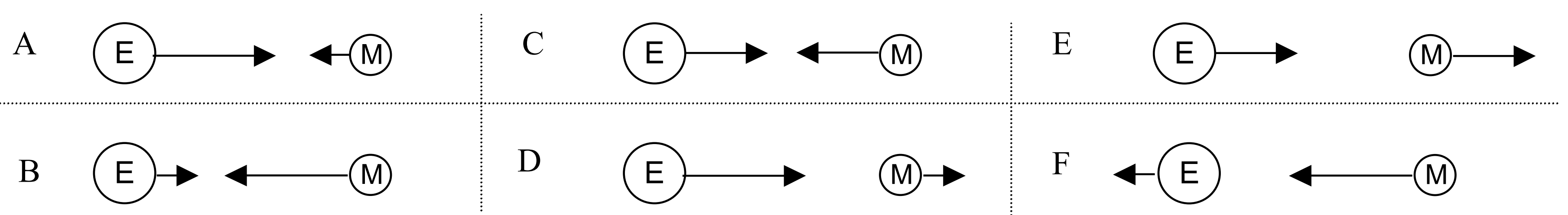
The force exerted by the sun on the earth is:

A. about 9×10^{10} times larger
B. about 3×10^5 times larger
C. exactly the same
D. about 3×10^5 times smaller
E. about 9×10^{10} times smaller

"verbal"

#8. Which of these diagrams most closely represents the gravitational forces that the earth and moon exert ***on each other***? (Note: The mass of the earth is about 80 times larger than that of the moon.)

"diagrammatic"



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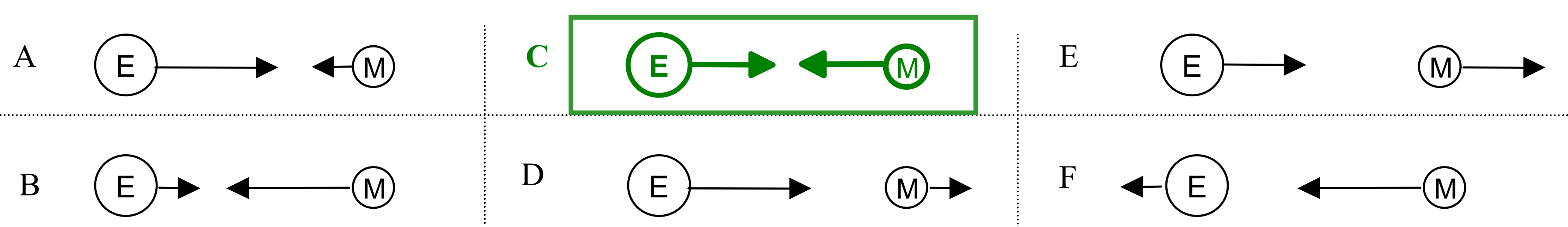

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Results of Quiz on Gravitation

	1998-2002	
#1. force by sun is:	*N = 408*	
larger	**79%**	
*** the same**	**16%**	***(s.d. = 5%)***
smaller	**5%**	

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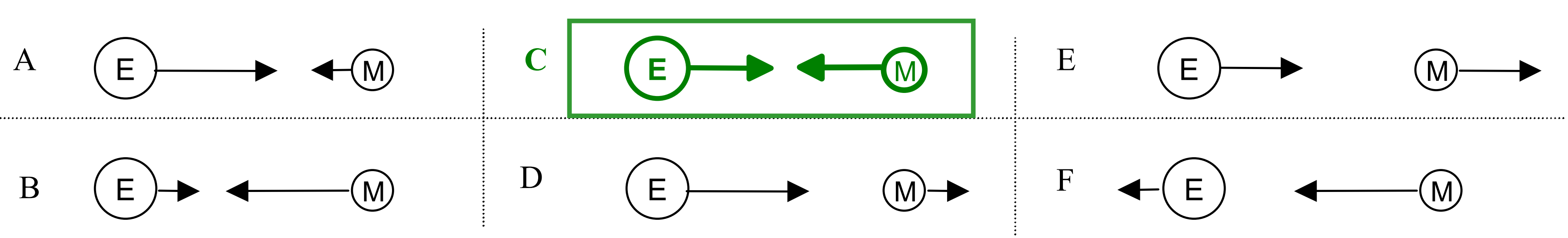

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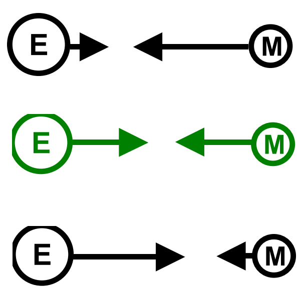


*

[wrong direction]

9% ***(s.d. = 3%)***

Results of Quiz on Gravitation

1998-2002

#1. force by sun is: *N = 408*

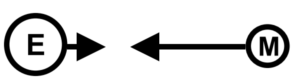
larger **79%**

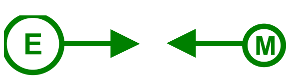
*** the same** **16%** ***(s.d. = 5%)***

smaller **5%**

#8. earth/moon force

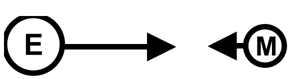
48%



* 

9% ***(s.d. = 3%)***

41%



[wrong direction] 2%

Comparison of Responses

- Proportion of correct responses on diagrammatic version of question is consistently lower than on verbal version.

- Pattern of incorrect responses is dramatically different on two versions of question:
  - most common response on verbal version: *force exerted by more massive object has larger magnitude*
  - on diagrammatic version: *force exerted by more massive* ***or*** *less massive object has larger magnitude*

Students' written explanations confirm that most believed that more massive object exerts larger force.

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  - on diagrammatic version: *force exerted by more massive **or** less massive object has larger magnitude*

Apparently, many students have difficulty translating phrase "*force exerted on*" into vector diagram form.

Students' Problem-Solving Performance and Representational Mode

DEM, submitted to *Am. J. Phys.* (2003)

- Significant discrepancy between student responses on Newton's third-law questions in "verbal" and "diagrammatic" representations

Coulomb's Law Quiz in Multiple Representations

IF YOU WANT A QUESTION GRADED OUT OF THREE POINTS (–1 [MINUS ONE] FOR WRONG ANSWER!!) WRITE "3" IN SPACE PROVIDED ON EACH QUESTION.

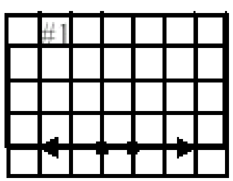
1. When two identical, isolated charges are separated by two centimeters, the magnitude of the force exerted by each charge on the other is eight newtons. If the charges are moved to a separation of eight centimeters, what will be the magnitude of that force now?

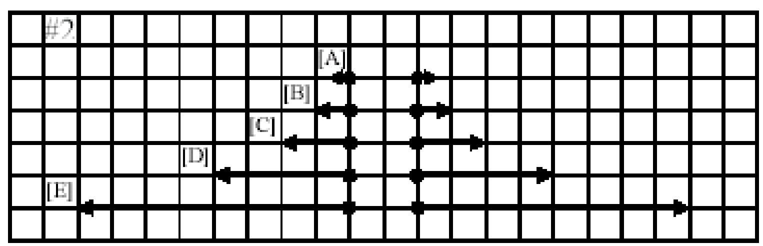
A. one-half of a newton
B. two newtons
C. eight newtons
D. thirty-two newtons
E. one hundred twenty-eight newtons

Grade out of three? Write "3" here: ______

V [verbal]

2. Figure #1 shows two identical, isolated charges separated by a certain distance. The arrows indicate the forces exerted by each charge on the other. The same charges are shown in Figure #2. Which diagram in Figure #2 would be correct?





A.
B.
C.
D.
E.

Grade out of three? Write "3" here: ______

D [diagrammatic]

3. Isolated charges q_1 and q_2 are separated by distance r, and each exerts force F on the other. $q_1^{initial} = q_1^{final}$ and $q_2^{initial} = q_2^{final}$; $r^{initial} = 10m$; $r^{final} = 2m$. $F^{initial} = 25N$; $F^{final} = ?$

A. 1 N
B. 5 N
C. 25 N
D. 125 N
E. 625 N

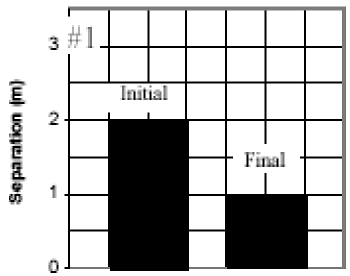
Grade out of three? Write "3" here: ____

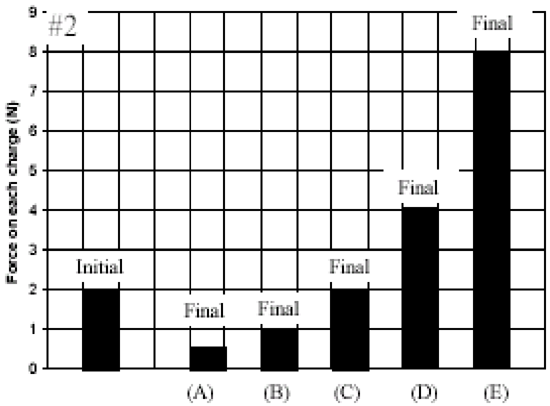
M [mathematical/symbolic]

4. Graph #1 refers to the initial and final separation between two identical, isolated charges. Graph #2 refers to the initial and final forces exerted by each charge on the other. Which bar is correct?

Grade out of three? Write "3" here: ____

A.
B.
C.
D.
E.





G [graphical]

DC Circuits Quiz

1. In a parallel circuit, a three-ohm resistor and a six-ohm resistor are connected to a battery. In a series circuit, a four-ohm and an eight-ohm resistor are connected to a battery that has the ***same*** voltage as the battery in the parallel circuit. What will be the ratio of the current through the six-ohm resistor to the current through the four-ohm resistor? Current through six-ohm resistor divided by current through four-ohm resistor is:
   A. greater than one
   B. equal to one
   C. less than one
   D. equal to negative one
   E. cannot determine without knowing the battery voltage

   Grade out of 3? Write "3" here: _____

$\boxed{V}$

2. Parallel circuit: $R_A = 6\ \Omega;\ R_B = 9\ \Omega$.
   Series circuit: $R_C = 7\ \Omega;\ R_D = 3\ \Omega$.
   $\Delta V_{bat}(series) = \Delta V_{bat}(parallel)$

$\boxed{M}$

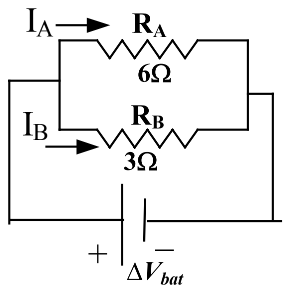
A. $\frac{I_B}{I_C} > 1$ B. $\frac{I_B}{I_C} = 1$ C. $\frac{I_B}{I_C} < 1$ D. $\frac{I_B}{I_C} = -1$ E. need ΔV_{bat}

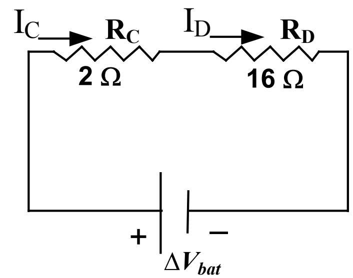
Grade out of 3? Write "3" here: _____

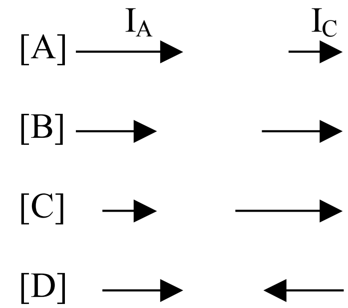
D

3. The arrows represent the magnitude and direction of the current through resistors A and C. Choose the correct diagram.

A.
B.
C.
D.
E. need to know ΔV_{bat}







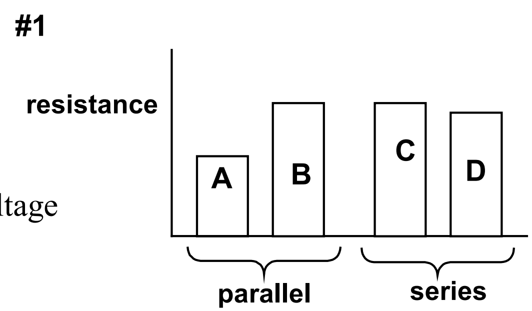
[E] (need to know ΔV_{bat})

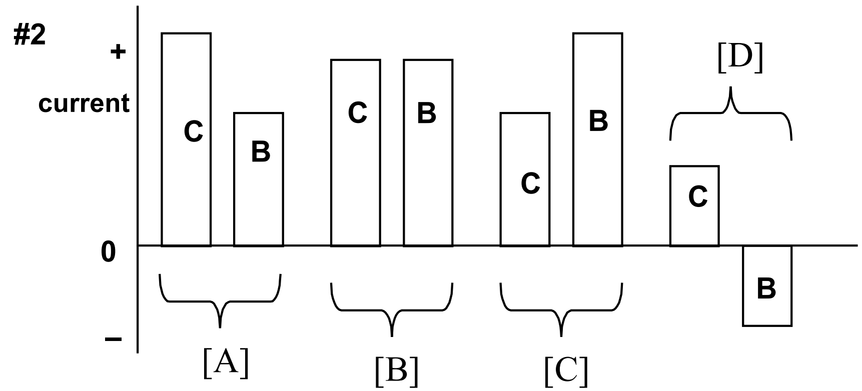
Grade out of 3? Write "3" here: _____

G

4. Graph #1 represents the relative resistances of resistors A, B, C, and D. Resistors A and B are connected in a parallel circuit. Resistors C and D are connected in a series circuit. The battery voltage in both circuits is the same. Graph #2 represents the currents in resistors C and B respectively. Which pair is correct?

A.
B.
C.
D.
E. need to know voltage





Students' Problem-Solving Performance and Representational Mode

DEM, submitted to *Am. J. Phys.* (2003)

- Significant discrepancy between student responses on Newton's third-law questions in "verbal" and "diagrammatic" representations

- Even after identical instruction, consistent discrepancy between female and male performance on circuit-diagram questions
  - *50% higher error rates for female students in algebra-based physics*

Summary

- Research into student learning lays the basis for development of improved instructional materials.
- New materials based on research must be carefully tested and revised repeatedly.
- Use and testing of instructional materials lays the basis for new directions in research.