MASSACHUSETTS INSTITUTE OF TECHNOLOGY

Thermodynamics of Materials

3.00 Fall 2001

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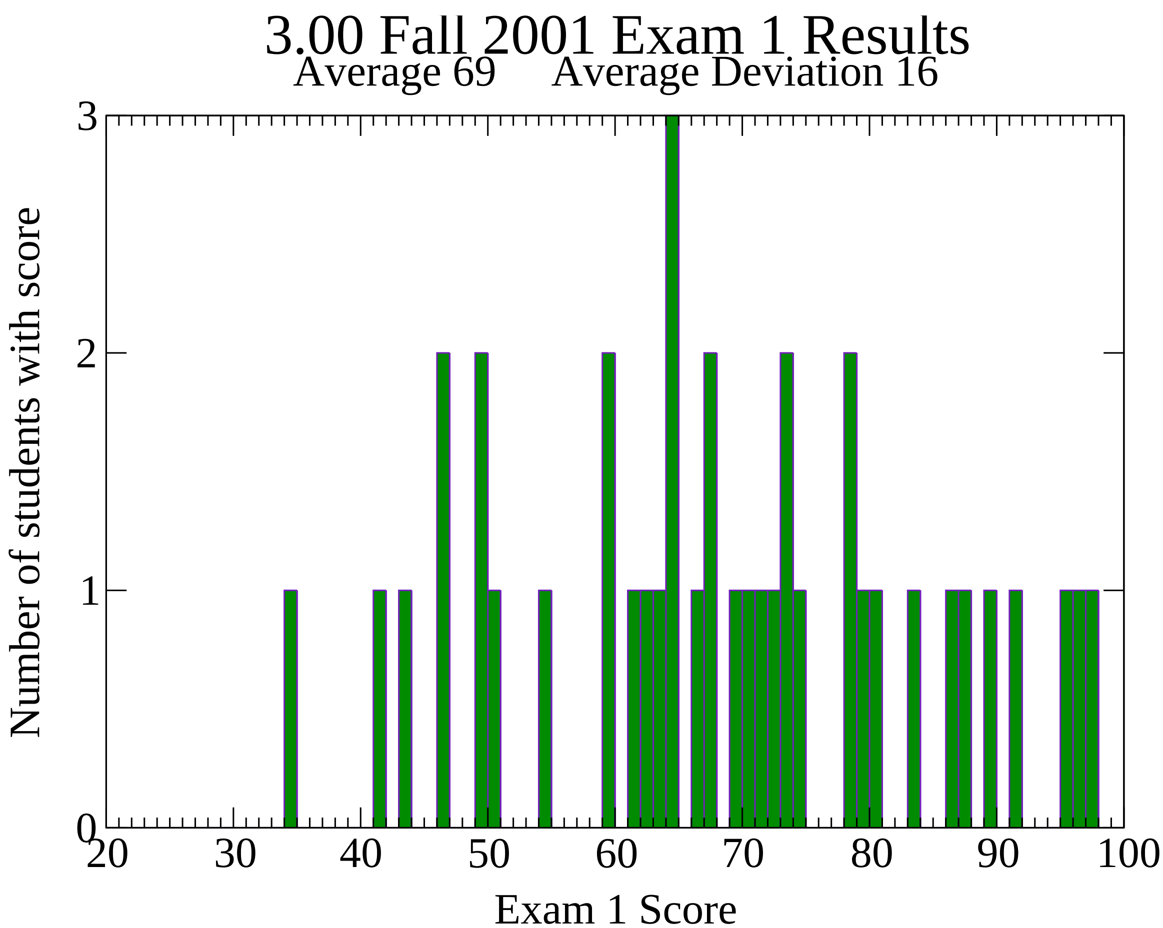
Exam 1: Friday October 5, 2001 (11:05-11:55AM)

Solutions and Results



Question 1.1: 36 points possible

Question 1.2: 30 points possible

Question 1.3: 34 points possible

Total: 100 points possible

Exam Question 1.1

Read *carefully* and determine whether the following statements are true or false and indicate your thermodynamic reasoning. If you claim that a statement is false, you may state which law or laws of thermodynamics that it violates or you may employ a physical counter-example or any other plausible physical reason. You may wish to amend any false statement with a clarifying phrase that makes the statement true.

1-1-i The internal energy of an isolated system is constant.

True. This is a statement of the first law of thermodynamics which has never been shown to be false.

1-1-ii If an ideal gas increases its volume by 1 cubic meter at a constant pressure of 1 newton/(square meter), then its internal energy will decrease by 1 joule.

Not necessarily true, because the heat that is transfered into the system is unspecified and cannot be determined from the problem statement.

Common Errors	
Symbol	Error Descritpion
α	Assumption that no heat was transfered between the system and its surroundings.
β	Confused the sign of the change of internal energy with the work done by a system.

1-1-iii The molar heat capacity of any metal, measured at constant fixed strain ($\overline{C_\epsilon}$) is less than the molar heat capacity of the same metal measured at constant stress ($\overline{C_\sigma}$).

True. The heat capacity with an intensive variable fixed is always greater than that with a conjugate extensive variable fixed. It is also permissible to reason by analogy to $C_P > C_V$.

Common Errors	
Symbol	Error Descritpion
α	Assumption that constant stress implies constant strain as temperature changes.

1-1-iv The internal energy of a system and its surroundings is not conserved during an irreversible process.

True. The first law is assumed to be true regardless of the process that allows a system to change.

Common Errors	
Symbol	Error Descritpion
α	Violation of first law of thermodynamics.

1-1-v The increase of internal energy of an adiabatic system consisting of an incompressible diamagnetic material is the work performed on the system.

True, the first law holds for all materials and all systems.

Common Errors	
Symbol	Error Descritpion
α	Supposition that work cannot be done to a diamagnetic material.

1-1-vi If one mole of monotomic ideal gas increases its temperature by 1°C by a reversible (quasi-static) process, the the work *performed* on the gas by its surroundings must be numerically equal to the molar heat capacity at constant volume, $\overline{C_V}$.

This would be true if no heat is transfered to the gas; it is false in general.

Common Errors	
Symbol	Error Descritpion
α	Equating work done on the gas with the change in its total energy.
β	Suppositon that this was a constant volume process.

Exam Question 1.2

Suppose that, in a desperate attempt to lower the temperature in your *adiabatically enclosed* dorm room, you prop open the door of your refrigerator. Your refrigerator operates at 110 volts and draws a constant 30 amperes.

Using the axes below, draw two *schematic* curves of the temperature in your adiabatically enclosed room as a function of time. For one curve, plot the temperature versus time for the case that the refrigerator door is kept closed; for the other curve, plot the temperature versus time for the case that the refrigerator door is kept open. *A schematic plot is one that illustrates relevant physical aspects of the system, but need not be numerically quantitative.*

Illustrate or annotate any relevant characteristics of your curves—and be sure to indicate which curve corresponds to each case.

Because the room is adiabatic and work is being transfered to it at constant rate, then (in the absence of phase transitions in the room) the room temperature must increase as work is transfered to it, regardless of whether the door is open or closed.

Depending on the precise location of the thermometer, the temperature may initially decrease. However, at long times the two curves (open and closed) should look roughly the same.

One could argue that the temperature for the open fridge may be slightly higher at long times because the heat pump would become increasingly less efficient—and also because the heat capacity of the room is slightly smaller without the contribution of the material that is within the fridge. I think the two curves probably converge to the same monotonically increasing value demonstrates sufficient understanding.

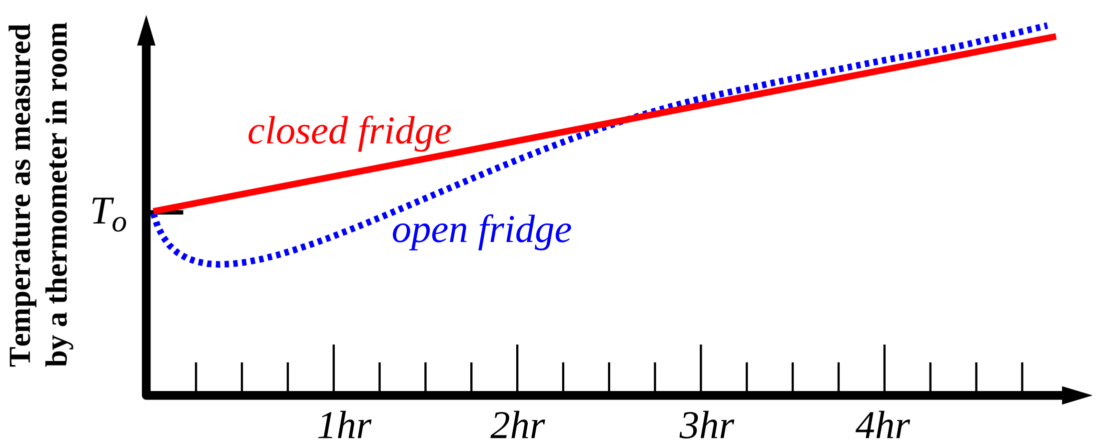


Figure 1: Schematic Solution for Question 2

Common Errors	
Symbol	Error Descritpion
α	Temperature can decrease continuously in an adiabatic system recieving positive work.
β	Suppositon that and equilbrium temperature exists.

Exam Question 1.3

Consider an isolated system consisting of a kilogram of lead and a kilogram of water illustrated below.

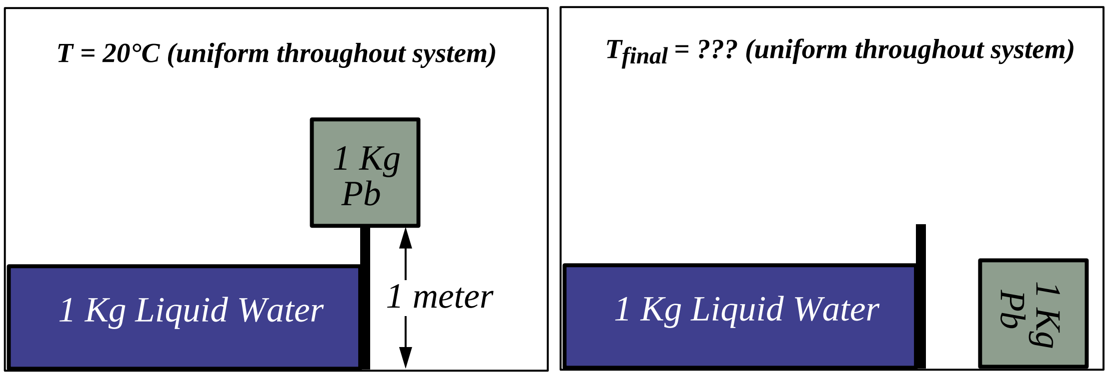


Figure 2: Isolated system illustrated before and after.

The heat capacity of 1 kilogram of Pb is given by C_{Pb}; the heat capacity of 1 kilogram of water is given by $C_{\mathrm{H_2O}}$; all other heat capacities in the isolated system can be neglected. C_{Pb} and $C_{\mathrm{H_2O}}$ may be considered independent of any constraints (e.g., constant pressure or constant volume) and to be independent of temperature.

1-3-i Derive an expression for the final temperature after a process leading to the figure on the right of the illustration.

$$\text{Change in internal energy of system} = \text{Heat flow into Pb and water}$$
$$|mgh| = C_{\mathrm{Pb}}(T_{final} - 20) + C_{\mathrm{H_2O}}(T_{final} - 20)$$
$$T_{final} = 20 + \frac{|mgh|}{C_{\mathrm{Pb}} + C_{\mathrm{H_2O}}}$$

Common Errors	
Symbol	Error Descritpion
α	No consideration of effect of temperature change in water.

1-3-ii Would the temperature be larger or smaller if the block of lead had fallen to the left (i.e., into the water)?

Tricky. The answer is that the temperature will be lower.

The center of mass of the water will raise and so part of the potential energy of the lead weight will be converted to potential energy of the water. $|mgh|$ would be decreased by an amount corresponding to the raise of center of mass of the water.