University of California, Berkeley, Department of Physics

Physics 7B,

Midterm 1, Spring 2017

- Calculators or other electronic devices are not permitted.
- Put a box around your final answer and cross out any work you wish the grader to disregard.
- Try to be neat and organized.

Problems are weighted as indicated. Remember to look over your work. Good Luck!

Problem 1	____/18
Problem 2	____/18
Problem 3	____/18
Problem 4	____/26
Problem 5	____/20
Total	____/100

Problem 1. [18 points] Short questions

a) **[6 points]-** For a diatomic ideal gas near room temperature, what fraction of the heat supplied is available for external work if (i) the gas is expanded at constant pressure? And (ii) if the gas is expanded at constant temperature?

b) **[6 points]** A liquid in cup has a coefficient of volume expansion β and is heated by an amount ΔT. The cup has constant area A, independent of temperature,and the liquid is initally at a height H. By how much does the liquid rise when heated? Express your answer in terms of the given quantities in the problem. Ignore evaporation.

c) **[6 points]** A gas in thermal equilibrium at temperature T=300K is composed of Nitrogen molecules, N_2. Hydrogen gas (H_2) is added at the same temperature T. What is the fraction of the Hydrogen molecules that have speed faster than the rms speed of the Nitrogen. You may leave your answer in the form of an integral and use, if needed, m_{H2} for the mass of hydrogen molecules and m_{N2} for the mass of Nitrogen molecules.

Problem 2. [18 points] Ice and water

An ice cube of mass m=1kg, at temperature T=-5°C, is placed into a container which is filled with 1kg of water at a temperature of 90°C. Assume that there is no heat conduction with the container and ignore any thermal expansion. Calculations should be carried out to only one significant figure. Demonstrating that you understand how to solve the problem is more important than getting a precise answer.

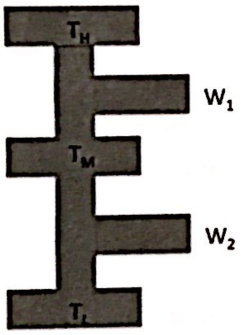
(a) **[9 points]** What is final temperature does this system reach?

(b) **[9 points]** What is the entropy change?

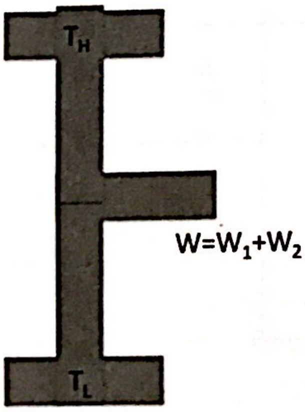
Problem 3. [18 points] Ideal heat engines in series

Suppose that an ideal heat engine operates as below between T_H and T_L producing work W. It is replaced with two ideal heat engines connected in series and produce the same work $W=W_1+W_2$. The heat output from Engine 1 is used to power engine 2. The temperatures T_H, T_M and T_L are as indicated. The high and low temperatures for the series configuration are the same as that for the original engine. Engine 2 operates between temperatures T_M and T_L and Engine 1 operates between temperatures T_H and T_M where $T_H > T_M > T_L$. The ideal efficiencies for each engine are e_1 and e_2.

Show the overall efficiency of the heat engines in series is $e = e_1 + (1 - e_1)\, e_2 = 1 - T_L/T_H$.



One ideal heat engine with equivalent work output



Problem 4. [26 points]

A heat engine uses n moles of an ideal diatomic gas as its working substance. The rotational states are available and the vibrational states are frozen out. The gas undergoes a reversible Sterling Engine heat cycle. The steps are:

1. From State 1 to State 2: An isothermal expansion from a system at (P_1,V_1) to P_2
2. From State 2 to State 3: A decrease in pressure at constant volume V_2 from P_2 to P_3
3. From State 3 to State 4: An isothermal compression from P_3 to P_4
4. From State 4 to State 1: A increase in pressure at constant volume from P_4 back to (P_1,V_1)

Express all answers in terms of the given variables $(P_1,V_1, n, P_2\ P_3)$

(a) **[3 points]** What is the ratio of specific heats $\frac{c_p}{c_v} = \gamma$? The quantity should be left as a symbol anywhere it appears in the answers to the questions below.

(b) **[6 points]** Sketch this cycle in a P-V diagram. The sketch does not need to be to scale. The direction of each step should be indicated with an arrow and the States should be labeled 1, 2, 3 and 4. Indicate V_1, V_2 on the plot.

(c) **[14 points]** Find Q, W and ΔS for each of Steps 1,2 3 and 4 above. Make and fill a table in your blue book similar to the one below.

(d) **[3 Points]** What physical effects could make this process irreversible?

	W	Q	ΔS
1			
2			
3			
4			

Problem 5. [20 points]

A spherical black body of radius R_B, at absolute temperature T_B, is surrounded by black body radiation at temperature T_0.

(a) **[5 points]** Find the rate of radiant heat loss of the spherical body. Express your answer in terms of the given parameters and any physics constants that are relevant.

(b) **[15 points]** The spherical body is now surrounded by a thin spherical and concentric shell of radius R_S, black on both sides. This shell is called a radiation shield. The spherical body is assumed to maintain its temperature T_B and the shell reaches a steady temperature T_S. The shell is surrounded by the black body radiation at temperature T_0. Express your answers to the questions below in terms of the given parameters and any physics constants that are relevant.

i. **[3 points]** Find the new rate of radiant heat loss of the spherical body.

ii. **[3points]** Find the rate radiant heat loss of the spherical shell.

iii. **[4 points]** Find the temperature of the shell, T_S., in terms of R_B, R_S, T_B, and T_0

iv. **[5 points]** Using your answers to the above, find the factor by which this radiation shield reduces the rate of cooling of the body (consider space between spheres evacuated, with no thermal conduction losses). Your answer should be independent of the temperatures T_B, and T_0.