MIDTERM 1 Fall-2017

Instructor: Prof. A. LANZARA

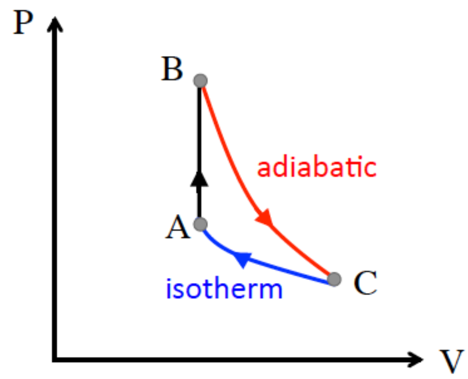
TOTAL POINTS: 100

Show all work, and take particular care to explain what you are doing. Partial credit is given. Please use the symbols described in the problems, define any new symbol that you introduce and label any drawings that you make. All answers should be in terms of variables.
If you get stuck, skip to the next problem and return to the difficult section later in the exam period.

PROBLEM 1 (Tot 20pts)

A sample of monoatomic ideal gas occupies a volume V_A at atmospheric pressure P_A and temperature T_A (point A in the figure below). It is heated at constant volume to a pressure $P_B = 3P_A$ (point B). Then it is allowed to expand adiabatically and last compressed isothermally to its original state. Write all your answers in terms of P_A, V_A and T_A.

a) (2pts) Find the number of moles in the sample.
b) (7pts) Find the temperature at points B and C and the volume and pressure at point C.
c) (7pts) Assuming that the molar specific heat does not depend on temperature, find Q, W and ΔE_{int} for each of the processes.
d) (4pts) Find Q, W and ΔE_{int} for the whole cycle.



PROBLEM 2 (Tot 20pts)

A thermodynamically isolated cylinder of volume V_A contains an ideal diatomic gas at temperature T_A and pressure P_A. The gas undergoes a free expansion. The final volume is twice the initial volume.

a) (5pts) Find the entropy change of the system. Discuss your result.

Following this new equilibrium state, the gas undergoes an adiabatic expansion, quadrupling its initial volume ($V_C = 4V_A$).

b) (5pts) Calculate the change of entropy of the system.

c) (5pts) Draw these processes in the PV diagram.

d) (5pts) How would you modify the result from part c for a monoatomic gas?

PROBLEM 3 (Tot 15pts)

A cylinder of volume V_0 contains a monoatomic gas at temperature T_0. The cylinder is closed by a movable piston and is submerged in an ice-water mixture.

The piston is quickly pushed all the way down to $V_1=V_0 / 3$.

The piston is then held in this new position until the gas is again at temperature T_0, and then is slowly raised back to same volume V_0 and temperature T_0.

1) (5pts) Draw the PV diagram for the process described above and give an expression in each point of the value of pressure, volume and temperature.

2) (10pts) If a mass M of ice is melted during the cycle, how much work has been done on the gas? Is this work positive or negative? Explain your answer. The latent heat of ice is L.

PROBLEM 4 (Tot 20pts)

The African bombardier beetle can emit a jet of defensive spray from the moveable tip of its abdomen. The beetle's body has reservoirs of two different chemicals, each at temperature T_0, same mass m and specific heat C_1 and C_2 respectively. The beetle total mass is M. When the beetle is disturbed, these chemicals are combined in a reaction chamber, producing a compound that is warmed from T_0 to $T_1 = 5T_0$ by the heat of the reaction. The high pressure produced allows the compound to be sprayed out at speeds v_0, scaring away predators of all kinds.

a) (10pts) Calculate the heat of reaction of the two chemicals.

Following the reaction, the beetle's body temperature has raised to $2T_0$ and its body has enlarged.

b) (10pts) If the coefficient of volumetric expansion of the beetle is β, find the work done on the beetle by the atmosphere (treat the beetle as a bar of initial volume V_0).

PROBLEM 5 (Tot 25pts)

Suppose you build a two-engine device such that the exhaust energy output from one heat engine is the input energy for a second heat engine. We say that the two engines are running in series. Let e_1 and e_2 represent the efficiencies of the two engines. The overall efficiency of the two-engines device is defined as the total work output divided by the energy put into the first engine by heat.

a) (10pts) Show that the overall efficiency is given by $e = e_1 + e_2 - e_1 e_2$

Let's now assume that the two engines are Carnot engines. Engine 1 operates between a hot temperature T_h and an intermediate temperature T_i. The gas in engine 2 varies in temperature between T_i and T_c.

b) (5pts) In terms of the temperatures, what is the efficiency of the combination engine?
c) (5pts) What value of the intermediate temperature T_i will result in equal work being done by each of the two engines in series?
d) (5pt) What value of T_i will result in each of the engines in series having the same efficiency?

Formula Sheet: Physics 7B, Midterm 1 (Fall 2016)

Thermodynamics

$$\Delta l = \alpha l_0 \Delta T$$

$$\Delta V = \beta V_0 \Delta T$$

$$Q = mc\Delta T = nC\Delta T$$

$$C_P - C_V = R = N_A k_B$$

$$\frac{dQ}{dt} = -kA\frac{dT}{dx}$$

$$v_{rms} = \sqrt{\frac{3k_B T}{m}} \text{ (for a monatomic gas)}$$

$$e = \frac{W_{net}}{Q_{in}}$$

$$\Delta S = \int \frac{dQ}{T} \text{ (For reversible processes)}$$

$$dQ = TdS$$

$$\Delta S_{syst} + \Delta S_{env} > 0$$

$$\oint dS = 0$$