PHYSICS 7B, Lecture 3 – Spring 2018
Midterm 1, C. Bordel
Wednesday, February 21, 2018
7pm-9pm

- Student name:
- Student ID #:
- Discussion section #:
- Name of your GSI:
- Day/time of your DS:

<u>Math Information Sheet</u>

$\cos^2 x + \sin^2 x = 1$

$\cos 2x = 2\cos^2 x - 1$

$\sin 2x = 2\sin x \cos x$

$\cos 2x = 1 - 2\sin^2 x$

Make sure you show all your work and justify your answers in order to get full credit!

Problem 1 – Thermal expansion - Ideal gas law (25 pts)

First part: Thermal expansion

A circular hole of radius R_0 is drilled in a sheet of metal whose linear coefficient of thermal expansion is α_s ($\alpha_s > 0$). Initially at ambient temperature T_a, the sheet is then cooled down uniformly to temperature $T < T_a$.

a- Express the radius R of the hole at temperature T and explain in 1 or 2 sentences why the hole expands or shrinks upon cooling.

The sheet of metal is now heated back up to ambient temperature. A rivet, made of a material with thermal expansion coefficient α_r ($\alpha_r > 0$), is to be placed in the hole. In order to make a secure fit, the radius r_0 of the rivet is initially 1% larger than the rivet hole.

b- Assuming that the sheet of metal remains at temperature T_a, determine the temperature T_r at which the rivet should be brought to in order to fit exactly into the hole (Fig. 1).

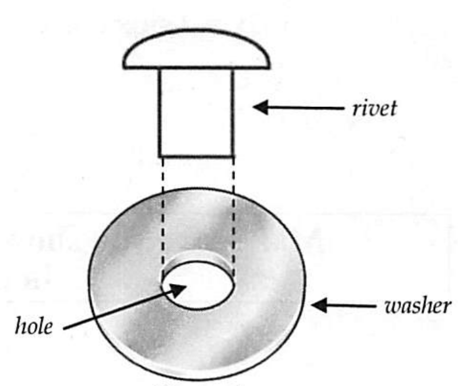

Figure 1

Second part: Ideal gas law

A pressure cooker is filled with air at ambient temperature T_a and atmospheric pressure P_a. The pressure cooker is then sealed with a lid of area A, and heated up to temperature T. Assume that the air, both inside and outside the pressure cooker, behaves like an ideal gas and that the temperature of the air outside the pressure cooker remains T_a.

c- Determine the magnitude of the net force F_1 acting on the lid due to the pressure difference when the air inside reaches temperature T.

The pressure relief valve is now opened, allowing hot air to escape ~~until the~~ pressure inside the cooker becomes equal to the outside pressure. The pot is then sealed again and removed from the stove, the air inside still being approximately at temperature T.

d- Determine the magnitude of the net force F_2 acting on the lid due to the pressure difference when the air inside has reached thermodynamic equilibrium with its surroundings.

Problem 2– Calorimetry - Heat transfer - Entropy (25 pts)

First part: Calorimetry

a- Based on the phase diagram shown in Fig.2, make a qualitative plot of the temperature variation of 1 kg of nitrogen as a function of the heat absorbed by the system under P = 1 atm. Take the initial and final temperatures to be $T_i < T_F$ and $T_f > T_V$, respectively. Make sure you mention symbolically all the relevant temperatures and heat transfers as necessary.

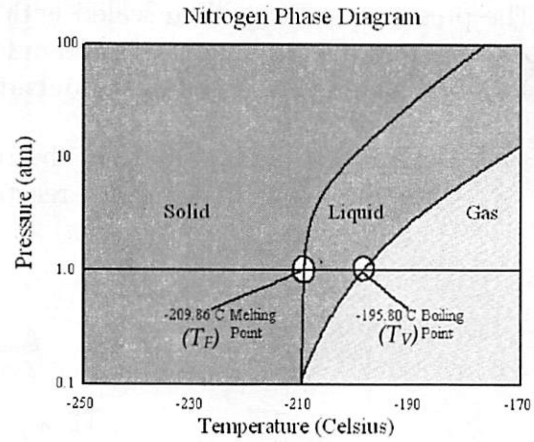

Figure 2

Second part: Heat conduction

Consider a cylindrical chimney of height h, with inner radius R_1 and outer radius R_2. The chimney is made of a homogeneous material whose thermal conductivity is k. The inner and outer surfaces are maintained at constant temperatures T_1 and T_2 ($T_1 > T_2$) respectively, and you may assume that a steady state of heat transfer has been reached within the wall of the chimney. You may ignore any heat loss through the top and bottom caps.

b- Determine the rate of conductive heat flow through the lateral wall and justify its sign.

c- Determine the temperature profile through the wall.

Third part: Entropy

n moles of an ideal gas undergo a complicated reversible process shown by a solid line on the PV diagram below (Fig.3).

d- Determine the change in entropy between the initial and final points assuming that T_b=T_a.

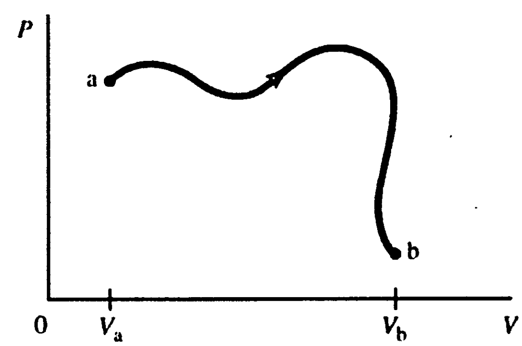

Figure 3

e- Recalculate the change in entropy if the 2 points fall on an adiabat and deduce the meaning of "isentropic" process.

<u>Problem 3</u> - **Heat engine (25 pts)**

The operation of a diesel engine can be idealized by the following cycle:
A→B: adiabatic compression
B→C: isobaric expansion
C→D: adiabatic expansion
D→A: isochoric cooling
The engine operates with n moles of an ideal diatomic gas, and the cycle is entirely defined by the volumes V_A , V_B and V_C and by the pressure P_A. Express all your answers in terms of thermodynamic constants and the previously listed given variables.

a- Draw the corresponding (ABCD) cycle on a PV diagram. Explain in which direction the cycle should be described by the gas and why.

b- Determine the net work done by the gas over a full cycle.

c- Determine the amount of heat absorbed/released by the gas during each branch of the cycle.

Problem 4 - Electrostatics (25 pts)

A thin glass rod is bent to form a semicircle of radius R, as shown in Fig. 4. Electric charge is non-uniformly distributed along the rod with a linear charge density given by $\lambda=\lambda_0 \sin\theta$, where λ_0 is a positive constant. Point P is at the center of the semicircle. All vectors should be expressed in the $(\hat{\imath}, \hat{\jmath})$ basis.

a- Determine the components of the unit vector $\hat{r}$, pointing from the infinitesimal source charge dQ to point P, for any infinitesimal electric field $\overrightarrow{dE}$ created at point P.

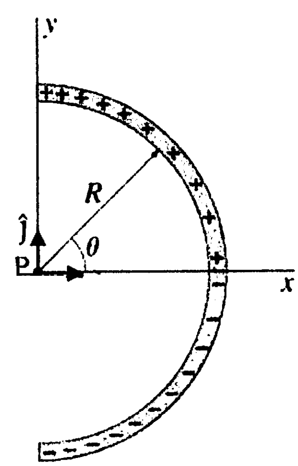

Figure 4

b- Determine the infinitesimal electric field $\overrightarrow{dE}$ created at point P by an infinitesimal charge dq on the rod.

c- Draw multiple infinitesimal fields at point P on Fig.4 and determine the direction of the net electric field $\vec{E}$.

d- Calculate the components of the net electric field $\vec{E}$.