Nonequilibrium Processes and Flows

- Homework solutions should be neat and logically presented, see format requirements (seitzman.gatech.edu/classes/ae6050/homeworkformat.html). Please note the requirement to draw some **implications** from the results of each problem. This could be implications for a practical device, a comparison of the results of different parts of a problem, a physical interpretation for an equation, etc.
- To receive credit, show ALL work in the format described above. If you use equations from the notes, the class textbook or another book, please cite the reference.

1. **Nonequilibrium Ionization Rates**

Consider the two following reactions that can ionize xenon (Xe):

$Xe + Xe \rightarrow Xe^+ + e^- + Xe$ (1)

$Xe + e^- \rightarrow Xe^+ + e^- + e^-$ (2)

Experimental data acquired in the range 5000-7500 K has suggested the following Arrhenius-fit rate constant parameters for these reactions:

Reaction	A (cm^3/mol/s)	B	E_a (kJ/mol)
1	2.071×10^4	1.771	810.49
2	1.485×10^{14}	0.510	1170.1

In addition, the following atomic properties are known for Xe and Xe^+:

	ε_i (eV)*	g_o	g_1	ε_1 (eV)	g_2	ε_2(eV)
Xe	12.130	1	5	8.315	3	8.437
Xe^+	20.975	4	2	1.306	2	11.27

For the following questions, consider a gas composed solely of Xe, Xe^+ and e^- at a fixed temperature and pressure of 7000 K and 2.5 kPa.

a) Which of these reactions has a higher rate constant at these conditions?

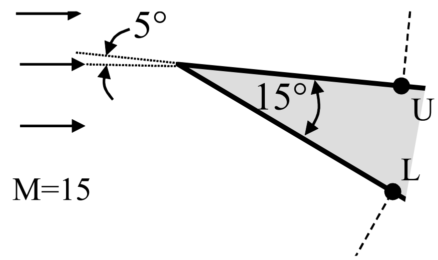
b) Which of the backward versions of these reactions would have a higher rate constant at these conditions?

c) What is d[Xe]/dt at a time when the gas has a degree of ionization of zero?

d) What is d[Xe]/dt at a time when the gas has a degree of ionization of 2.5% of its equilibrium value?

2. **Hypersonic Sharp-Edged Airfoil**

A hypersonic (terrestrial) aircraft is being designed to travel at Mach 15 at an altitude of 35 km (T_∞=237 K, p_∞=0.559 kPa). The aircraft is to have a two-dimensional wing with a sharp leading edge (15°), as shown in the figure, which shows a close-up view of the leading edge. The figure also shows the geometry at the nominal cruise angle of attack. For this problem, assume the wing is an adiabatic, slip wall (i.e., ignore viscous and thermal boundary layer effects).



a) For a streamline that passes very close to the lower surface, assume the O_2 vibrational energy mode has just reached equilibrium with the translational energy mode of the air at point L. Would the N_2 vibrational energy mode come into equilibrium with the translational energy at L, upstream of L (left in the figure), or downstream of L (right in the figure)? **You must include a justification/explanation**.

b) Make a <u>qualitatively</u> accurate plot (drawing) of how the entropy of the air varies along a line that is normal to the lower surface of the wing at location L (i.e., along the dashed line show in the figure). The y-axis of your plot should be entropy, and the x-axis should be distance from the wing surface). Your drawing should encompass a region extending from the surface and going until you have reached the freestream (unperturbed) air. **Include a justification/explanation of your drawing**.

c) On the same axes, make a <u>qualitative</u> plot of the entropy of the air along a line that is normal to the upper surface of the wing at location U (i.e., along the dashed line show in the figure). Again, extending from the surface to the freestream. While the plot need only be qualitative, the entropy behavior for this region should be relatively correct in relation to the result you drew for the lower surface. Again, **include a justification/explanation**.

3. **Extra Credit –Shock-Heated Nonequilibrium Xenon**

A gas composed of pure Xe at 521 K and 50.0 Pa passes through a M=6.34 steady shock.

a) What are the conditions (temperature, pressure, density and velocity) right behind the leading edge of the shock?

b) Write a complete set of equations (can be a combination of ordinary differential equations and algebraic equations), including all necessary constants and parameter values, that could be used to determine the following properties as a function of distance behind the leading edge of the shock:
   - temperature
   - pressure
   - density
   - mole fractions of Xe, Xe^+ and e^-
   - velocity

   You may assume that the reactions defined in problem 1 are the only relevant ionization reactions, and that the amount of energy in the electronic energy modes of Xe and Xe+ are negligible.