Solve each problem on separate sheets of paper, and clearly indicate the problem number and your name on each. Carefully and neatly document your answers. You may use a mathematical solver like Jupyter/iPython. Use plotting software for all plots.

1 All in balance

1.1 One way under consideration for removing harmful "NO_x" ($NO + NO_2$) from flue gas is the thermal deNOx process, in which NH_3 is used to reduce the NO to NO_2:

$$\_NO(g) + \_O_2(g) + \_NH_3(g) \longrightarrow \_N_2(g) + \_H_2O(g)$$

The research lab has several gas tanks available to study this reaction, including one containg 2.0% NO in an N_2 diluent, one containing 10% O_2 in an N_2 diluent, and a bottle of 4% anhydrous ammonia in N_2. You can assume all gases behave ideally.

1. Balance the thermal deNOx reaction, assuming each NH_3 titrates one NO.
2. What mass flow rates are necessary to create a stoichiometric mixture at 1 bar total pressure, 400 °C, and 10 l/s total volumetric flow rate?
3. Plot the molar flow rates of all five gases as a function of reaction advancement.
4. Plot the total volumetric flow rate as a function of reaction advancement.

1.2 NH_3 oxidation is an undesirable side-reaction of thermal deNOx:

$$\_NH_3(g) + \_O_2(g) \longrightarrow \_NO(g) + \_H_2O(g)$$

1. Balance the NH_3 oxidation reaction.
2. Under the stoichiometric conditions described above, the reactor generates 0.036 g/s NO and 0.017 g/s NH_3. How effectively is the NH_3 being used for thermal deNOx? (*Hint:* What are the advancements of the two reactions?)

2 NOx, NOx, who's there?

2.1 A simpler and confounding reaction of NO is it's oxidation to NO_2:

$$\_NO(g) + \_O_2(g) \longrightarrow \_NO_2(g)$$

You can assume all gases behave ideally under the conditions considered in this problem.

1. Determine $\Delta H^\circ(298\,\mathrm{K})$, $\Delta S^\circ(298\,\mathrm{K})$, $\Delta G^\circ(298\,\mathrm{K})$, and $K_p(298\,\mathrm{K})$ for the NO oxidation reaction. Be sure to specify your source and the standard state.
2. Calculate the equilibrium partial pressure ratio of NO_2 to NO in the atmosphere near the surface of the earth. Assume the mixing ratio of O_2 to be 0.2 and a temperature of 25 °C.
3. From standard compilations and at 1 atm standard state, $\Delta H^\circ(250) = -116.532\,\mathrm{kJ\,mol^{-1}}$ and $\Delta S^\circ(250) = -152.179\,\mathrm{J/mol/K}$. Use the van't Hoff relationship to plot $\Delta G^\circ(T)$ vs T from room temperature to 600 C. Add a point on your plot for the $\Delta G^\circ(298\,\mathrm{K})$ you found from a tabulation.

4. NO oxidation is catalyzed over diesel oxidation catalysts (DOCs) on diesel vehicles. Plot the equilibrium conversion of NO to NO_2 vs T from room temperature to 600 C for an isobaric 1 atm reactor presented with 0.1% NO and 5% O_2, and balance N_2.

