4) An ingenious chemical engineer named poison Ivy has been preparing a potion using plants to fight off ghostly spirits on the night of Halloween. In the potion she discovered that a series of reactions are occurring

$$(1) \quad A + 2B \underset{k_{-1}}{\overset{k_1}{\rightleftarrows}} C + D$$

$$(2) \quad C + 3D \xrightarrow{k_2} E$$

$$(3) \quad 2E + A \underset{k_{-3}}{\overset{k_3}{\rightleftarrows}} F$$

$$(4) \quad F \xrightarrow{k_4} G$$

The rate constant of each reaction is $k_{1,A} = 0.1, k_{-1,C} = 0.05, k_{2,C} = 0.2, k_{3,A} = 0.02, k_{-3,F} = 10.0, k_{4,F} = 1.2$. Ivy forgot to write the units of each rate constant, but she know that the concentrations were in mol/L and that time was in seconds. She plans on running her reaction in an ideal Batch reactor cast iron pot on the night before Halloween. She will keep the temperature constant at 400K, and the pressure constant so that it keeps glowing of a gleaming green. The initial concentration of A and B will be 1.2 [mol/L] and all other species will be absent.

- **a.** Write the net rate of formation of each of the chemical species and specify the missing units of the reaction rate constants (you may assume each reaction is elementary).
- **b.** Use Python to solve your set of coupled ordinary differential equations as a function of time and generate a plot of the concentration. How many hours will Ivy have to wait to generate 0.08 mol/L of the zombie repellant species G?
- **c.** Now imagine that $k_{-3} = 0$, how does that change the amount of time she needs to wait to generate the same number of moles of the zombie repellant compound G (provide a numerical answer)? What do you expect would happen if on the other hand it was $k_3 = 0$?
- **d.** An evil Joker has come to mix things up and has thrown a catalyst in the pot. The catalyst now acts only on the reverse reaction with rate k_{-1}. With the catalyst the new activation energy is $E_a^{(-1)} = 18 \frac{kcal}{mol}$. The Joker was kind enough to tell you that the previous activation energy value was $20 \frac{kcal}{mol}$. Use Python to find the new value of the reaction rate constant.
- **e.** Solve your system of ODE's as a function of time using Python with this new value of the reaction rate constant and show a plot of your result. How much damage has the Joker made? Explain how and why things changed.

Note: Include all code used in this homework, clearly labeled for the problem it belongs to.