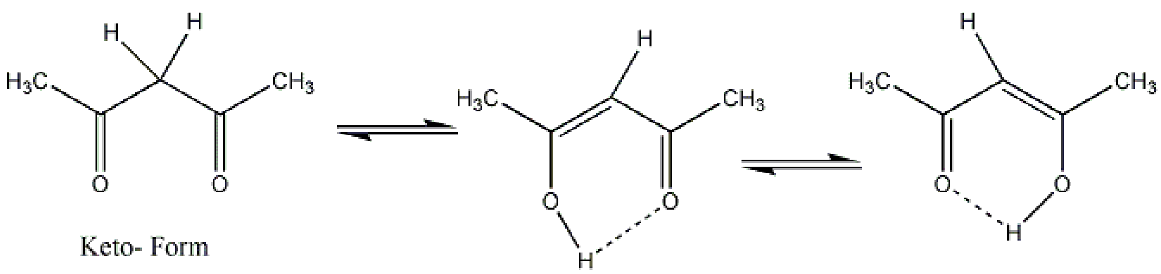
Examination of Keto-Enol Tautomerization by Variable Temperature NMR

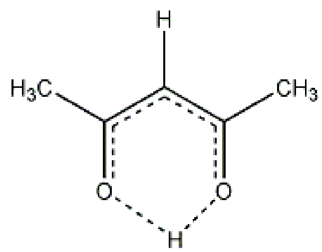
We will use NMR spectroscopy to examine the equilibrium process that converts 2,4-Pentanedione (acetylacetone) from its keto- form to its enol form as shown in the figure below.



Keto- Form

Enol-1 (dotted line is hydrogen bond)

Enol-2 (dotted line is hydrogen bond)



Average Enol

The 2 enol forms are related by symmetry so we will not be able to tell them apart – we will only be able to observe the ketone and the “average” enol. As you learned in organic chemistry, the ketone is usually the predominant form of such a molecule. However, for this particular molecule, when it is in its enol form, you can see that there is the tendancy for **intra**molecular hydrogen bonding. The resonance structure that I drew for the “average” enol shows this and you should note that the position of the two other double bonds in the molecule can move about. This effectively makes a six membered ring with 3 double bonds free to move around (i.e. an aromatic ring). Because of the stability of the aromatic system, it turns out that the enol form of 2,4-pentanedione is more stable than the ketone form and is the one typically present.

In this experiment, we will use a quantum mechanical tool (the NMR) to investigate the equilibrium (a thermodynamics issue) between the keto and the enol forms of 2,4-pentanedione. The two forms will give dramatically different signals in the NMR, and integration of the appropriate peaks will allow us to calculate the relative amounts of each species present. The way the experiment will work is that we will measure NMR spectra at various temperatures. At each temperature, we will calculate the equilibrium constant:

$$K_{eq} = \text{Mole fraction enol}/\text{Mole fraction ketone}$$

Changing the temperature will cause the equilibrium to shift, and we will then calculate the free energy for the reaction at each temperature:

$$\Delta_rG° = -RT\ln K_{eq}$$

Subsequently, we can use the relationship that $\Delta_rG = \Delta_rH - T\Delta_rS$ to determine what the value of the enthalpy of the reaction is. We will assume that the enthalpy is independent of temperature so you will have to use all of your data and make a plot to determine the value of the reaction enthalpy. Finally, we can use that same relationship to calculate the entropy of the reaction (we'll also assume that the entropy of the reaction isn't temperature dependent over the range of temps we've used).

PRELAB:

1) Determine (qualitatively) what the NMR spectrum of the keto- tautomer will look like (i.e. how many peaks and their locations).
2) Determine (qualitatively) what the NMR spectrum of the enol- tautomer will look like (i.e. how many peaks and their locations).
3) For each of the spectra that you come up with in the above 2 questions, assign each proton to the appropriate peak. Be sure to note how many protons are in each peak
4) Decide what signals would be the most useful to measure in order to do this experiment.

EXPERIMENTAL PROCEDURE:

SAFETY CONCERNS: Both the solvent and the sample are flammable and toxic. Avoid exposure. The NMR generates high radiofrequency and magnetic fields. You should not approach the machine carrying or wearing anything metallic or magnetic. This includes keys, pocketknives etc. You also should not bring anything with a magnetic stripe (like a credit card) near the machine because it may get demagnetized. Anyone with a pacemaker or any implanted medical device (like metal pins holding a bone together) **MUST NOT APPROACH THE NMR – OR EVEN BE IN THE ROOM.**

1. The sample that you will use will be mostly $CDCl_3$ with a bit of the 2,4-pentanedione in it. The sample will be provided by the instructor. **Be very careful** with this NMR tube, it is very expensive. It is sealed and can withstand moderately high pressure – important since we will be heating a volatile solvent in a closed system.

2. Acquire proton spectra at 25°C, 30°C, 35°C, 40°C, 45°C and 50°C. Do not go above 50°C!!!

3. Process your spectrum, assigning and integrating the relevant peaks and recording the integrations. You should also print a hard copy of the spectrum.

LAB REPORT

1. Make a table of all of the integrations along with the ratio of the keto form to the enol form (i.e. the equilibrium constant). **Pay close attention to how many protons each peak corresponds to when you do this.** Include in this table the value of the Gibbs energy that you find for each of the temperatures. **Show sample calculations**

2. Make the appropriate plot to determine the enthalpy of the reaction and report the value that you find

3. Find the entropy of the reaction and report the value you find.

4. Consider the values that you determined for enthalpy and entropy and decide what the driving force of the tautomerization reaction is.

REFERENCES:

"Experiments in Physical Chemistry, 7th ed." C.W. Garland, J.W. Nibler, D.P Shoemaker. McGraw-Hill, 2003.

http://www.colby.edu/chemistry/PChem/lab/enthalpyenolnmr.pdf