Quantitative Methods in Chemistry
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Module No # 05
Lecture No # 24
Using Spreadsheet to Analyze Linear Dependence between Two Variables

Welcome to the next lecture in quantitative method in chemistry in the last class we try to understand how to use a simple software like the spreadsheet to make a first call to record our data and analyze it. We also solve simple fits as you might have seen in the previous week how to do fits and what is the fit mean. Basically in the last class we used that idea in order to understand how to calibrate burette and where all errors could come up. In today's class we will be extending the similar idea in order to use the spreadsheets software to see how data analysis could be done something for a more of a problem let us say.

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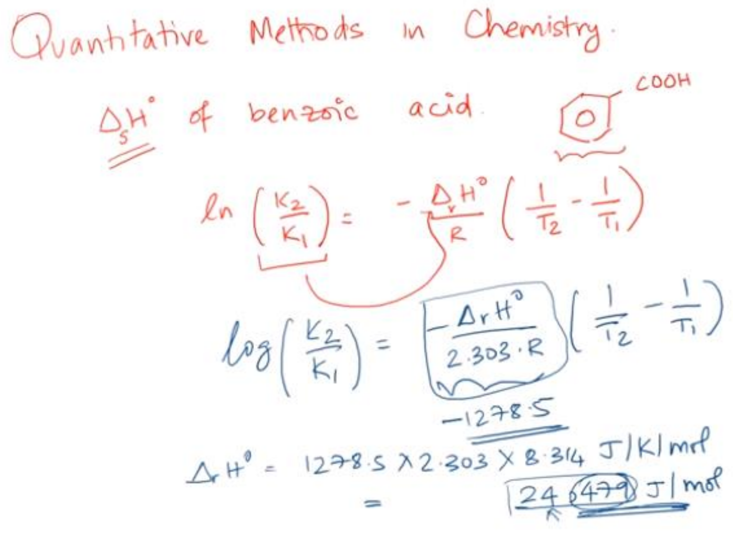

Quantitative Methods in Chemistry.

$\Delta_s H^\circ$ of benzoic acid. COOH

$$\ln\left(\frac{K_2}{K_1}\right) = -\frac{\Delta_r H^\circ}{R}\left(\frac{1}{T_2}-\frac{1}{T_1}\right)$$

$$\log\left(\frac{K_2}{K_1}\right) = \boxed{-\frac{\Delta_r H^\circ}{2.303\cdot R}}\left(\frac{1}{T_2}-\frac{1}{T_1}\right)$$

−1278.5

$\Delta_r H^\circ = 1278.5 \times 2.303 \times 8.314$ J/K/mol

= 24479 J/mol

So the problem that will be defining here would be to determine the heat of solution of benzoic acid. So basically this experiment will help you to define what is the standard enthalpy change that is associated with dissolving solid benzoic acid in water? And one would understand that benzoic acid although it has a carboxylic group although it has a COOH group does not dissolve that easily in water because of the presence of this aromatic moiety.

We will try to understand how this experiment will be setup and what can be done just to give a little bit of basic before we plunge into the background of what this experiment is. One has to understand how can we determine delta H naught it comes from the van't Hoff equation which relates equilibrium constant to the reaction enthalpy change as a function of temperature. So this is the relationship from which you are going to be determining what is the enthalpy change associated with such a process.

Why do not we take a look at what are steps are involved as we have done in the previous series of lectures what are the step you are going to be performing what are the apparatus that you would be needing after having known that what are all the possible sources of errors that could come up basically systematic error and how they could be minimized and what are the data that has been recorded and can be in fact determined the heat of dissolution of benzoic acid.

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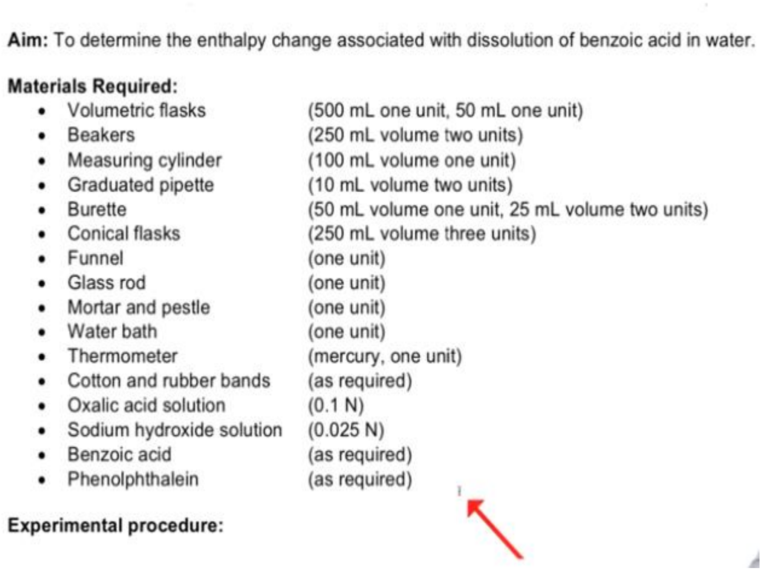

Aim: To determine the enthalpy change associated with dissolution of benzoic acid in water.

Materials Required:

Volumetric flasks	(500 mL one unit, 50 mL one unit)
Beakers	(250 mL volume two units)
Measuring cylinder	(100 mL volume one unit)
Graduated pipette	(10 mL volume two units)
Burette	(50 mL volume one unit, 25 mL volume two units)
Conical flasks	(250 mL volume three units)
Funnel	(one unit)
Glass rod	(one unit)
Mortar and pestle	(one unit)
Water bath	(one unit)
Thermometer	(mercury, one unit)
Cotton and rubber bands	(as required)
Oxalic acid solution	(0.1 N)
Sodium hydroxide solution	(0.025 N)
Benzoic acid	(as required)
Phenolphthalein	(as required)

Experimental procedure:

As we would start with the materials required for the all the experiments the first thing that you would end up needing is a bunch of flasks. Basically you would need one of about half a liter and another half about 50mL one would be used for equilibration so as to get the temperature at which you are doing the measurement well the other one would be useful towards dissolving a benzoic acid. You would also require a beakers we will see why you requiring them so always such a idea to list exactly what you need and how much of what you need so that you can prepare appropriately.

You would also need measuring cylinders graduated pipettes so as to measure out the given amount of volume that you want and the burette remember you just calibrate at a burette last week so you would release that similar you would the way of calibration of burette one could also calibrate the graduate pipette let so as to make sure that errors that come out of that is also minimized.

You need conical flask a funnel a glass rod for storing and mortar and pestle you are going to see that you have to crush the solid that you are going to end up using we will try to understand why that is the case and a water bath. If you remember the last experiment I have told you to make a note of the temperature so as to determine the density of water at that given temperature. This is one experiment where we will be doing the same equilibrium measurement but as a function of temperature meaning that you will keep changing the temperature to measure something.

And for such a reason you have maintain the temperature at which you want to measure it and for that matter the water bath is going to be extremely useful. And of course the thermometer to measure the temperature you will understand why we have to use cotton in order to make sure no solids come up when you are making measurement. You would be using Oxalic acid if you would realize we are going to be measuring benzoic acid concentration and one way of doing it is by taking sodium hydroxide solution and titrating it again benzoic acid.

But one might remember that if you are taking pellets of sodium hydroxide and keeping it outside it is extremely hydroscopic it is going to absorb water from the atmosphere making it a secondary standard. Since sodium hydroxide as a secondary standard you cannot do titration unless the sodium hydroxide is standardized and for that reason you will be using oxalic acid. You are able to realize how one measurement feeds on to another measurement so therefore one as to be careful in preparing the 0.1 normal oxalic acid solution else that is going to be introducing some systematic errors that might come up.

And of course the sodium hydroxide solution at an certain normality that to know but of course this as to be standardized with oxalic acid then the benzoic acid so as to perform the experiment and phenolphthalein dye which will helps you to do the acid by its titillation to visualize the end point.

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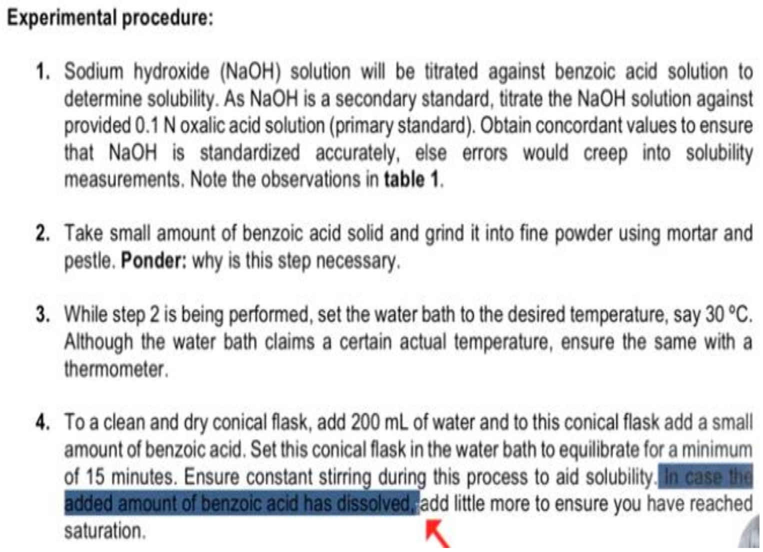

Experimental procedure:

1. Sodium hydroxide (NaOH) solution will be titrated against benzoic acid solution to determine solubility. As NaOH is a secondary standard, titrate the NaOH solution against provided 0.1 N oxalic acid solution (primary standard). Obtain concordant values to ensure that NaOH is standardized accurately, else errors would creep into solubility measurements. Note the observations in **table 1**.
2. Take small amount of benzoic acid solid and grind it into fine powder using mortar and pestle. **Ponder:** why is this step necessary.
3. While step 2 is being performed, set the water bath to the desired temperature, say 30 °C. Although the water bath claims a certain actual temperature, ensure the same with a thermometer.
4. To a clean and dry conical flask, add 200 mL of water and to this conical flask add a small amount of benzoic acid. Set this conical flask in the water bath to equilibrate for a minimum of 15 minutes. Ensure constant stirring during this process to aid solubility. In case the added amount of benzoic acid has dissolved, add little more to ensure you have reached saturation.

As always you must have a very detailed experimental procedure one as to follow the first step would be to standardize the sodium hydroxide solution against oxalic acid this I have already mentioned since oxalic acid is a primary standard and sodium hydroxide is a secondary standard you would have to end up normalizing the sodium hydroxide solution. Make sure concordant values are obtained.

This is something that we would have heard from our high school days where when you are doing titration concordant values must be obtained. The mere reason for getting same values multiple measurements is to ensure that you have repeatability. If there is a problem of repeatability it could be due to several reasons maybe there is a droplet of the solution or the burette solution that is the end on the conical which has not been properly added which will result in different end points.

And this different in end points would once again result in systematic error they get propagated throughout if you are able to realizing your standardizing propagating NaoH against oxalic acid of you introduce about a 5% error there keeps on propagating throughout your measurements making it less precise. So therefore one as to be careful doing these so concordant measurements are important in titration that you may end up performing.

And generally we would like to make tables like that table that we meet for the last class to standardize or to calibrate the burette. Here also we will make a tables so that the first step of this table would be the standardization of sodium hydroxide solution okay. Now having done that take a small amount of benzoic acid and grind it into small into fine powder using the mortar and pestle.

This is important one as to ponder why is something like it is has to be crushed you will soon realize that whenever something is solid and you want to dissolve it if you are able to increase the surface area that will you dissolve things better which is why we tend to like refined salt so that is simple granules which can be mixed same with the case of sugar where you end up adding it any solution it dissolves right away.

And there also another reason to which we will understand may go through the theory of experiment well step 2 is being performed set up a water bath to a desired temperature. So this is how you will be making sure the temperature equilibrated and therefore you will be able to measure a certain given value at any given temperature. So here we are saying set it at 30 degree's we will see that although water bath as certain setting in terms of the nobs one as to be careful using a thermo meter to ensure that you are indeed measuring that temperature.

That is exactly what is written here although the water bath claims as a certain actual temperature ensure the same with the thermometer. Otherwise again this is going to end up resulting in a systematic error and remember this need not be constant it could be proportion systematic error which cannot be redone unless you calibrate the water bath temperature. So it is rather than doing going through the complexity it is easier for you measure the temperature at which the water bath is so that you can make an analysis in a much more easier fashion.

Now to clean conical flask add about 200 mL of water and to this conical flask add a small amount of benzoic acid. So basically whatever benzoic acid you end up crushing to refine powder you end up adding to this 200 mL solution of water. And set this conical flask to equilibrate at least for a minimum time of 15 minutes. So here is where you are talking about the equilibration temp time. You have to make sure that the solution ends up reaching the equilibrium temperature acted dissolution of a benzoic acid.

Remember when you are dissolving benzoic acid it can be an exothermic or an endothermic process in case that it is an exothermic process what ends up happening is that you will be releasing some temperature solution which will increase the temperature at which you are making the measurement although you are assuming you are doing at 30 degree Celsius. So one has to be careful doing equilibration otherwise you might get erroneous results.

The same hose could for fact that is benzoic acid resolution is endothermic in nature if it is endothermic in nature it is going to reduce the temperature. So either ways be exothermic or endothermic one has to ensure that a minimum time of 15 minute equilibration is done. And this is also dumped to take here where you ensure constant stirring is done for this process so as to ensure at that given temperature you are completely saturated with the benzoic acid that you might want.

Which is the reason why you are committing on the total amount of benzoic acid that is required you are trying to say add as much as you want. You can actually add an excess so as to exploit the Le Chatelier’s principle of all the solids going into solution because you have too much of the solids. Of course there will be a tapering of point after which no more dissolution ends up happening. In the case of amount of benzoic acid let us say that you add up benzoic acid and all of it as got an dissolve then it is good idea to add a little more so as to achieve saturation.

So this is also another steps so there are multiple steps where one could go around here the measurement of temperature in the water bath be one of the reason why this that could be an offset that comes in a measurement one has to be careful in order to ensure that the solution reaches the equilibrium irrespective of endothermic and exothermic reaction and one has to also take care excess of benzoic acid is put in to place. So that the solution reaches saturation at that given temperature any of these steps are not followed you might end up having a certain error that comes up okay.

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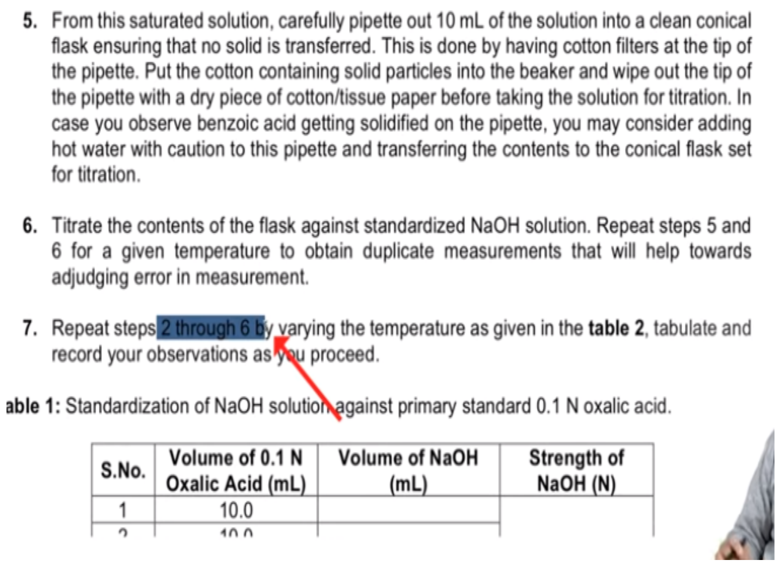

5. From this saturated solution, carefully pipette out 10 mL of the solution into a clean conical flask ensuring that no solid is transferred. This is done by having cotton filters at the tip of the pipette. Put the cotton containing solid particles into the beaker and wipe out the tip of the pipette with a dry piece of cotton/tissue paper before taking the solution for titration. In case you observe benzoic acid getting solidified on the pipette, you may consider adding hot water with caution to this pipette and transferring the contents to the conical flask set for titration.

6. Titrate the contents of the flask against standardized NaOH solution. Repeat steps 5 and 6 for a given temperature to obtain duplicate measurements that will help towards adjudging error in measurement.

7. Repeat steps 2 through 6 by varying the temperature as given in the **table 2**, tabulate and record your observations as you proceed.

able 1: Standardization of NaOH solution against primary standard 0.1 N oxalic acid.

S.No.	Volume of 0.1 N Oxalic Acid (mL)	Volume of NaOH (mL)	Strength of NaOH (N)
1	10.0		

Now from this saturated solution the next step would be to pipette out 10 mL of in a clean conical into a clean conical flask. So this is where this is the conical flask with which you will be performing your titration and when you are doing this unlike the last time where you might use a pipette in the simple direct way without having anything. In this case you would like to have cotton filters at the end of this pipette.

This is required because remember there will be some excess solid that will be floating around in your solution and by chance let us say you pipette that solid out it is going to be erroneous because you want to measure how much of benzoic acid is dissolved into the solution and not how much of benzoic acid is present in total. So one has to be careful about it due to which you have to put a cotton filter at the tip of it so that this is ensured.

And let us say that by mistake you get some solids into it you are going to introduce some error that goes into it and in this case it will be some kind of random error meaning that if you are cotton filter is not working properly or let us say you did not use the cotton filter you might have varying amount of benzoic acid you will be adding in different titration that you end up performing which will once again result in a huge error or even a gross error finally.

So one as to be very careful about it having transferred the solution then you have to standardize it again the sodium hydroxide solution remember one thing when you are doing the experiment at higher temperature after having carefully transferred only the solution from the equilibrate temperature to you conical flask you might see some solidification of benzoic acid this is not surprising because let us say your dissolving at 50 degree Celsius and you are performing titration at 25 degree Celsius it could be that some of the benzoic acid starts to solidify because you are at a super saturated solution at such a condition.

This is okay and it is different from the solid that comes from the solution previously mentioned because all that you are trying to take is the solution that has already been saturated at the higher temperature and when you are transferring it is solidifying from that solution and not from any other source so therefore that is okay then perform your titration repeat steps 2 to 6 at various temperature.

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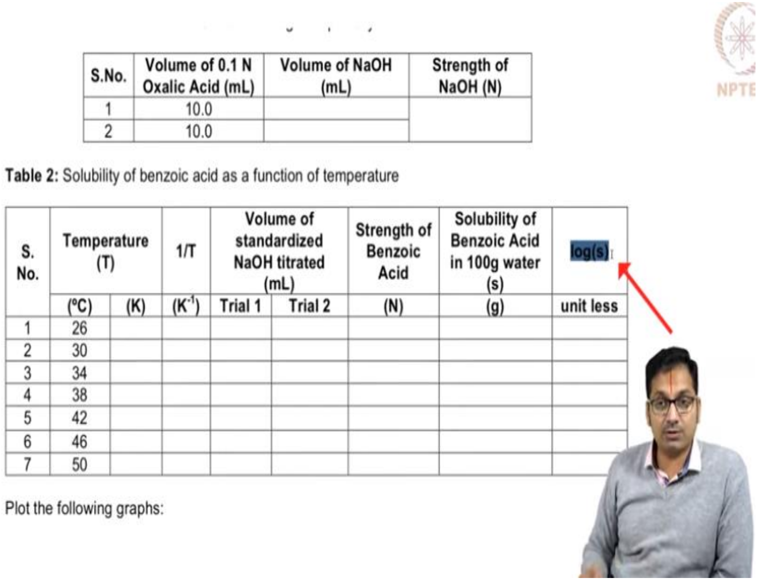

S.No.	Volume of 0.1 N Oxalic Acid (mL)	Volume of NaOH (mL)	Strength of NaOH (N)
1	10.0		
2	10.0		

Table 2: Solubility of benzoic acid as a function of temperature

S. No.	Temperature (T)		1/T	Volume of standardized NaOH titrated (mL)		Strength of Benzoic Acid	Solubility of Benzoic Acid in 100g water (s)	log(s)
	(ºC)	(K)	(K^{-1})	Trial 1	Trial 2	(N)	(g)	unit less
1	26							
2	30							
3	34							
4	38							
5	42							
6	46							
7	50							

Plot the following graphs:

And these are the tables that we are trying to look at the first table shows you take a certain volume of oxalic acid and 10mL end up using 5mL in the actual experiment so that you are able to get Concordant value for measurement of volume of NaOH required that for you standardize sodium hydroxide solution having done that the next step would be to set up an elaborate table to get things going.

So if you are able to remember some concept of equilibrium concept which we will introduce in a moment since benzoic acid solid is in a pure state water is in the pure state. Once can associate the equilibrium constant directly to the amount of benzoic acid that has been dissolved in solution that you are having. So what will end up happening if you are able to relate the

Wendroff of equation as i showed earlier lon of K2 – K1 is delta H naught divided by R times 1 / T2 – 1 / T1 you are able to see you are having 1 / T that you are varying and you are able to get lon or log of K.

So if you are able to plot the log of K as 1 over T your delta H naught will come up as the slope itself. So let us quickly take a look at what is that you are trying to do.

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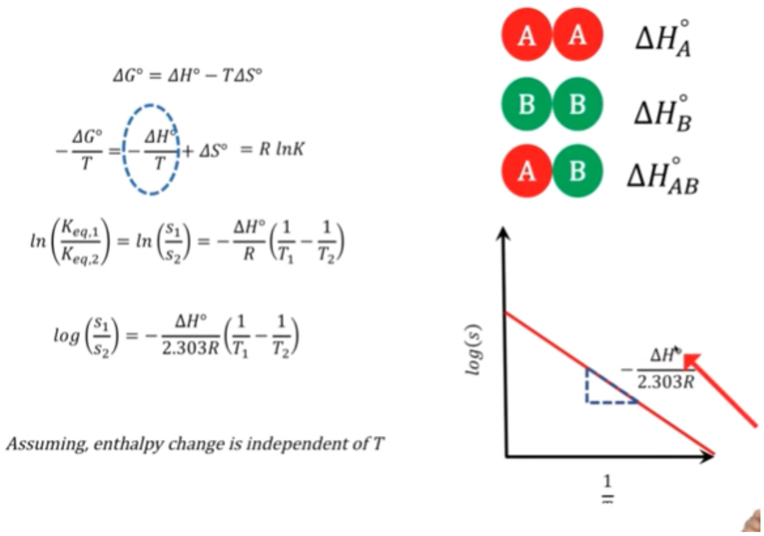

$$\Delta G^\circ = \Delta H^\circ - T\Delta S^\circ$$

$$-\frac{\Delta G^\circ}{T} = -\frac{\Delta H^\circ}{T} + \Delta S^\circ = R\ lnK$$

$$ln\left(\frac{K_{eq,1}}{K_{eq,2}}\right) = ln\left(\frac{S_1}{S_2}\right) = -\frac{\Delta H^\circ}{R}\left(\frac{1}{T_1} - \frac{1}{T_2}\right)$$

$$log\left(\frac{S_1}{S_2}\right) = -\frac{\Delta H^\circ}{2.303R}\left(\frac{1}{T_1} - \frac{1}{T_2}\right)$$

Assuming, enthalpy change is independent of T

So the point that you would like to measure here is what is the delta H naught of this process. And remember the spontaneity process is given by change in free energy which is the some of the enthalpy change to that of the entropy change or multiplied with the absolute temperature. Here you are only trying to see what is the enthalpy change that occurs? So although you might have a process that endothermic it could still be spontaneous because of the change in total entropy of the system.

So now what ends up happening is that in order to understand the entire process is little more easier and also to motivate why is that you want to determine the delta H naught. Let us divide this entire equation by minus absolute temperature –T on the left hand side you end up having something like minus delta G naught / T which is equal to minus delta H naught / T + delta S naught. Since delta H naught is change in entropy of the system minus delta H naught / T becomes the change in entropy of the surroundings.

So if you are able to determine what is a delta H naught and at that given temperature you would be able to say what is the change in entropy of the surrounding. So you know for the fact that delta H naught for endothermic reaction is positive so if delta H naught is positive negative of a positive makes it negative so this term ends up being overall negative which indicates the entropy of the surroundings have minimized.

Basically you are able to imagine is that if you are able to add some salt and dissolve it in water the outside becomes cooler that just indicates the fact that outside entropy as dropped. So now have after having understood what is the influence of the entropy of the surroundings you would like to relate it with the equilibrium constant this is what we are measuring? So one is able to understand a 1 over T dependence on the equilibrium constant so therefore for a constant delta H naught as a function of temperature you would be able to measure equilibrium constant as a function of temperature and determine what is the enthalpy change for such a process.

So now what all dictates the entire process is that when you are having benzoic acid you have solute-solute interactions that as a certain free energy or rather that as a certain amount of enthalpy that has to be provided in order to break the interaction between them. As you would know one breakage requires energy this process of breaking the solute-solute interaction is actually endothermic in nature.

And this is also distortable from the fact that within benzoic acid you have the fennel groups which ends up packing on top of each other and the carboxylic groups which might form intermolecular hydrogen bond. So therefore in order to break the interaction between them and also the amorphous solid that might have end up forming you have to break the interaction between the solid particles.

So providing energy is also obtained by the mortar and pestle with which you are trying to make a fine powder of the benzoic acid. So we are able to realize that breaking AA interactions is generally endothermic and the next thing that would that one has to remember I thing to the solute-solute interactions that one as to break one also as to break the solvent-solvent interaction in this case you are having water as a solvent and you know for a fact that water ends up forming stable hydrogen bonds and therefore you also have to break those interaction.

And what could results in A being properly dissolved and B is to form favorable interactions between A and B. And in this case you are able to realize that carboxylic acid might end up forming hydrogen bond with water while that is the favorable interaction you also have the fennel group which is hydrophobic which might not be happy in water. So basically this is also another term that over all comes up.

So these 3 terms have to kept in mind for this experiments where there is a change in enthalpy that comes for breaking solute-solute and solvent-solvent interactions and the enthalpy change that associated in forming the solute solvent interaction. So one is able to realize that going from this if you are able to get the delta H naught 1 should be able to understand some information across these 3 different processes coming up.

And of course if you are able to measure this and one way or the other if you are able to measure this in some other way and if you are able to get the total enthalpy change from this experiment will be able to estimate what is the enthalpy change that comes up for AB interaction being favorably formed. So this experiment is nothing but determine the equilibrium constant as a function of temperature which have repeated couple of times and this is just reiterating the fact that if you are able to plot the solvability as a function of 1 over T in principle the lon of solubility as a function of 1 over T you are going to be getting a curve that will help you to fit a data and determine the delta H naught from the slope itself.

Of course that is a basic assumption that goes in this experiment that the enthalpy change in this process is independent of temperature. I am not going to be alluding you to this but if you are able to take a look at the Kirchhoff’s law which says how enthalpy change for a process changes the function of temperature you would understand not for all the processes you can assume the same but in this case this can be assumed.

The reason why I am also enumerating the assumption here is that any data analysis is contingent upon the assumptions that you are forced. In the case that this assumption does not fall in place the whole data analysis is could be biased. But that does not mean you cannot have any assumptions in your experiment because some of the experiments have an inherent limitation in that you cannot afford a measure the changes that might end up happening. For instance this case probably we are insensitive to the changes of delta H naught is the function of temperature or may be delta H naught does not change at all.

So not going into further detail I would like to make you guys aware of fact because be aware of the fact that the assumptions might end up deciding your final result in the outcome of the experiment which could end up introducing a biased by itself. So be aware of what all assumptions you are having and what assumptions are held good and sometimes your data might say that is not fair assumptions and you can reintroduce the approximation by going and redoing the model that you used to fit.

But for this experiment let us assume that the enthalpy change is indeed constant function of temperature. So now if you plot the log of S as a function of 1 over T you get a straight line of course the straight line gives the slope. The slope will help you understand what is the enthalpy change associated the process since R is universal gas constant and we assume it to be having no error you would be able to release that the error in the fitting of the curve would result in the final error in the delta H naught.

And this error in the fitting would come up due to the fact that you are going to be having different measurement basically the solvability is error comes from the fact how of is the standardization of NaOH. The inconsistency in temperature could come due to the thermo meter or the water bath that has not been properly said or that you have not let the solutions reach equilibrium or that you have not found a saturated solution.

So this are all the reasons where you could get error in the different data points and when you fit those errors will come up in the fit in the error and that will result in overall error for the delta H naught.

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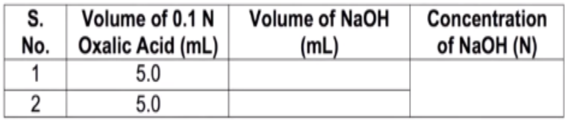
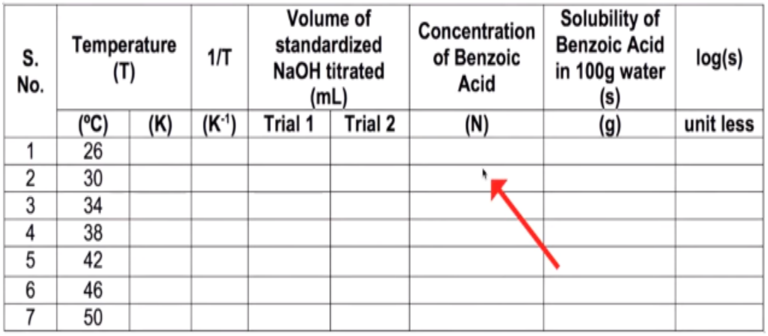


S. No.	Volume of 0.1 N Oxalic Acid (mL)	Volume of NaOH (mL)	Concentration of NaOH (N)
1	5.0		
2	5.0		



S. No.	Temperature (T)		1/T	Volume of standardized NaOH titrated (mL)		Concentration of Benzoic Acid	Solubility of Benzoic Acid in 100g water (s)	log(s)
	(°C)	(K)	(K^{-1})	Trial 1	Trial 2	(N)	(g)	unit less
1	26							
2	30							
3	34							
4	38							
5	42							
6	46							
7	50							

So as always let us take a look at the tables that one might end up preparing so this is the first table where you will be standardizing that this is the table that one has to be using from the temperature you can determine the absolute temperature in kelvin and one over temperature is therefore calculated and the volume of NaOH that you would be standardizing benzoic acid again to be done to trial in order to get Concordant values and the concentration of benzoic acid can thus be determined.

And from that you can determine how much amount of benzoic acid is dissolved in certain amount of solution and from their get a log of S and plot log of S as a function of temperature. Since we have already seen this tables let us try to take a look at how this experiment is indeed perform.

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As you see here this is the mortar and pestle and we are adding a large excess of benzoic acid into it and you will realize that using the mortar and pestle you are trying to make fine powder of the benzoic acid do as much as possible so as to increase the surface area of dissolution. Here we are able to see the conical flask that as 200 mL of water to which you will be adding the solid benzoic acid and ensure that the entire solution is immerse within the water.

And use another conical flask which is also filled with the 200 mL of water into which you will be adding your thermo meter and both these solutions have to be equilibrated into the water bath that you are trying to see at a given temperature and the temperature all though it is listed here it is better idea to have a separate measurement so as to ensure that you are actually measuring the temperature that you want to measure at and to the clean water conical flask add excess of benzoic acid as shown here and once you have added the next step you are able to realize the solid is all at the bottom of this conical flask.

So this also results in the trouble that the benzoic acid is not going to be properly dissolved so therefore use a glass rod and stir as much as possible in order to make sure the interaction between solute A and solvent B is done. And now we are trying to show you an example where you are taking the pipette and how you will be adding the cotton cloth to it to ensure when you are trying to take some solution out of the conical flask minimum amount of solid comes up.

So you take the cotton and use a rubber band and fix it around it so as to make sure that all the solid even if it comes gets stuck in this cotton use a rubber bulb never use a suction from your mouth as the source because it could be harmful. So once this is done we end up once again stirring the solution make sure you have left the solution there for at least 15 minutes or more and then you carefully pipette out at volume of benzoic acid in this pipette.

This matters a lot any error that might end up coming from pipetting will also results in final error bubble should come up so be very careful about it or ensure that even if bubble comes we have certain amount of volume that you require add that into the conical flask as shown here carefully and now you might find some solids here that is not a problem as you might realize from 56 degrees it is going to lower temperature you are going to have some solids that come up.

You might also realize some of the benzoic acid and might have solidified in the pipette itself it is a good idea indeed to wash the pipette with hot water so as to make sure that you are getting all the benzoic acid out. And to this conical flask add as minimum as possible of phenolphthalein as it is very sensitive dye and then titrate it with the standardized NaOH solution towards to end point. And the end point is nothing but the appearing of the pale pink color.

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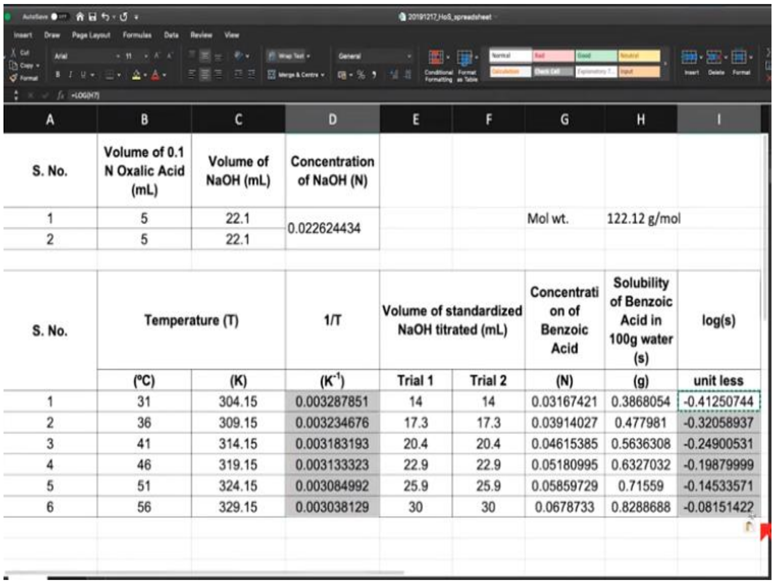


S. No.	Volume of 0.1 N Oxalic Acid (mL)	Volume of NaOH (mL)	Concentration of NaOH (N)				
1	5	22.1	0.022624434			Mol wt.	122.12 g/mol
2	5	22.1					

S. No.	Temperature (T)		1/T	Volume of standardized NaOH titrated (mL)		Concentration of Benzoic Acid	Solubility of Benzoic Acid in 100g water (s)	log(s)
	(ºC)	(K)	(K^{-1})	Trial 1	Trial 2	(N)	(g)	unit less
1	31	304.15	0.003287851	14	14	0.03167421	0.3868054	-0.41250744
2	36	309.15	0.003234676	17.3	17.3	0.03914027	0.477981	-0.32058937
3	41	314.15	0.003183193	20.4	20.4	0.04615385	0.5636308	-0.24900531
4	46	319.15	0.003133323	22.9	22.9	0.05180995	0.6327032	-0.19879999
5	51	324.15	0.003084992	25.9	25.9	0.05859729	0.71559	-0.14533571
6	56	329.15	0.003038129	30	30	0.0678733	0.8288688	-0.08151422

Okay so now let us take a look at how a spread sheet software could be used towards recording and analyzing your data. So in this measurement the scientist finds that he gets concordant values of 22.1 mL required for the standardization of a carefully prepared 0.1 normal oxalic acid. So then the normality that will end up coming here would be V1N1 = V1N2 so this is going to be since you added 5mL of 0.1 normal oxalic acid divided by the total volume that you end up getting here.

So you get the normality of sodium hydroxide around 0.2262 normal so once that comes up the next part is to do the solubility as the function of temperature and you are able to realize this student as performed it across 31 degrees to 56 degrees and you have to first convert degrees Celsius to degree kelvin since you are having these numbers quiet easy to do this where you add 273.15 to this given value.

You are able to realize this simple sum is given by the addition of 273 to that given cell and you should be able to copy and paste all of this so that this value that you are trying to determine is nothing but an athematic sum of 273.15 to this given cell. So now having obtain the next step would be to determine what is 1 over temperature so one can do that by just doing 1 over that given cell and that is copy and paste this over here.

So what ends up happening you have 1 over T measurement and this data is nicely analyzed if you are as a scientist doing all this by calculator you might end up introducing some errors here which does not happen. Now these are the values concordant values of the solution of NaOH that was used to standardize or to determine the concentration of benzoic acid. As you are able to realize what will end up happening here is that you are going to have a concentration that goes in the fact that it is $V1N1 = V2N2$ again.

So what you are trying to do here is to determine the amount of benzoic acid that has been dissolved in order to get this you will take the product of volume and concentration of sodium hydroxide divided by the total volume that you have taken you are able to realize this is the volume of sodium hydroxide and this is the concentration of sodium hydroxide divided by the total volume which you ended up by taking as 10 ML.

So therefore you get the normality of benzoic acid of course do not be in hurry to copy paste this because you are going to have a problem that okay this cell starts taking the concentration from the wrong cell which does not make as we have seen in the last class it you want to not change a given variable then what you end up doing is to write the same formula with a dollar in front of it. So what you would like to do is write it D dollar 2.

So this will ensure that when you copy and paste it while this cell gets arrayed meaning that you want to pick the value from the volume of sodium hydroxide this cell does not change. And of course you want 10mL so that can also be input and put into another cell and called up on as a formula. So now you got on the concentration of benzoic acid in normality I would like to make you understand here we are casually using normality in this experiment and not molarity because you are able to realize now you can compare oxalic acid to sodium hydroxide 1 to 1 because the equivalence is already been put into the normality okay.

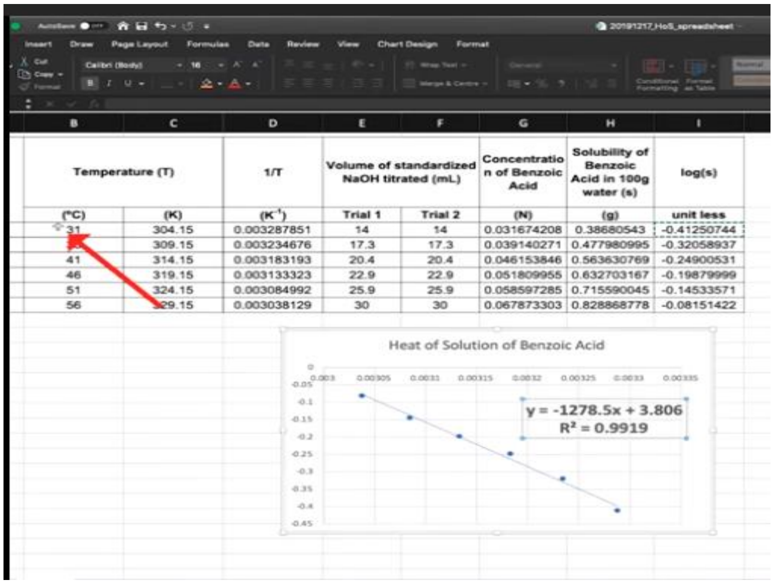
So now what ends up happening here for benzoic acid is that you want to determine the about a benzoic acid dissolved. So therefore how does normality go? Normality is nothing but number of moles divided by the volume of solution in liters the whole multiplied by the number of equivalent since a equivalence is 1 in this normality is equal to molarity and therefore what you are going to end up doing is to take the product of the normality to that of the volume of solution in this case you are saying 100 grams of water assuming that addition of benzoic acid does not change the volume of water.

It is a fair assumption in this case because this is all we can do so the second assumption that we are put into place. So 0.1 liters as what we are going to end up adding here remember you have to multiply this by the molecular weight of benzoic acid because finally you want to get how many grams of benzoic acid you have dissolved. Molecular weight of benzoic acid is 122.12 grams per mole so now this we can copy paste again. So this ends up saying how many grams of benzoic acid we have dissolving in water as a function of temperature.

Let us start to make observation right away you remember that in Le Chatelier's principle we learnt if it is an endothermic process increase in temperature results in more of the forward reaction we are able to see something of that chart meaning that as you keep increasing temperature we are able to see the fact that in solubility in amount of grams dissolve increases. So this already hints at the fact that you are probably looking at an enthalpy of the reaction being endothermic okay let us not jump to conclusion let us take our time.

So now there are 2 ways of doing it whenever you are doing a log measurement to carefully look at library felts that exist generally log indicates it is log to the base of the e the natural logarithm which many times we say as lon LN. But in this case you would like to get log of 10 because you are already factored that n or we can do the calculation with lon itself so let us try to do it both the ways since what we get up okay. So what you finally end up getting is that from the solubility you get log of the solubility the last step that is involved right now is to plot solubility as a function of temperature.

(Refer Slide Time: 31:15)



Temperature (T)		1/T	Volume of standardized NaOH titrated (mL)		Concentration of Benzoic Acid	Solubility of Benzoic Acid in 100g water (s)	log(s)
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[illegible]	309.15	0.003234676	17.3	17.3	0.039140271	0.477980995	-0.32058937
41	314.15	0.003183193	20.4	20.4	0.046153846	0.563630769	-0.24900531
46	319.15	0.003133323	22.9	22.9	0.051809955	0.632703167	-0.19879999
51	324.15	0.003084992	25.9	25.9	0.058597285	0.715590045	-0.14533571
56	[illegible]29.15	0.003038129	30	30	0.067873303	0.828868778	-0.08151422

So you just select these 2 and then say insert scatterplot. So now you are able to realize the 1 over S you can always add legends so that people are able to understand what that we are writing so in the Y axis you have lon of 1 over S and in the X axis you have 1 over T that is independent variable and lon f S is a dependent variable that nicely able to see almost linear curve.

Since we know for a fact that the model that we are trying to look at is lon of S is a function of 1 over T gives us –delta H naught by R we can actually go ahead and fit it right away to a trend line and then you set it as a linear trend line and you can look at the equation and the R square. Let me make this a little bigger so you are able to realize that you have a slope of -1278.5 since you are doing the lon plot and it is 1 over T be careful of units that we are trying to talk here so that for what ends up happening is that if you are using R in whatever units you are going to get the delta H naught in similar units.

And temperature is already in absolute kelvin so this is all fine and if you are able to see the R square which gives you the goodness of fit you are able to see that is very close to 1 and we are able to adjust the same when you take close attention to the dots and to the line that is splitted through it saying at some points that are above the line and some points that are below the line. So this indicates that the fit is trying to satisfy all the data points and this is what I met by error small errors that had come in your measurement due to certain differences cropped up due to may be extra benzoic acid solid that ended up coming which will introduce error into a measurement.

Nevertheless you are able to realize that you are slope is -1278.5 now let us go back and try to see what is the that we want to measure. What has happen is that excel seems to be using log as log 10 itself so basically you are having something log of K2 over K1 you are going to have a 2.303 which comes up as change in the base from log E to log 10. So now your slope that comes up from this which is -1 278.5 can be used to determine what is the delta H naught.

And if you are able to realize since the entire term is negative here and this is also negative value you are able to design the delta H naught is indeed positive indicating that it is an endothermic process and you know that delta H naught for this process is going to be 1278.5 times 2.303 times 8.314 Joule per kelvin per mole. So this is going to be equal to 24479 Joules this is approximately equal to 24.5 kilo Joules per mole.

So one is able to realize that if you are trying to dissolve benzoic acid in water the surrounding becomes cooler and this is not a new observation one has to remember that in thermodynamics we only want to ensure that the delta G naught is observed not to delta H naught meaning that there are processes which are endothermic yet spontaneous for instance if you are trying to dissolve sodium chloride which is your common salt into water even that is endothermic process.

That does not mean it does not happen basically there also happens because entropically there is something else going on with the system which ensures that the overall free energy changes it is still negative although your delta H naught is positive. The same observation is done here what you are able to realize is that we have enumerated 3 processes where you want to break the solute-solute interaction solvent-solvent interaction and from solute-solvent interaction and you are able to realize the first 2 processes that is breaking the solute-solute and solvent-solvent interactions are endothermic.

Then if the solute-solvent interactions where exothermic and more exothermic than breaking the interaction as I mentioned previously then the overall process becomes exothermic this also happens it is a nature if you are trying to dissolve sodium hydroxide in water what ends up happening is that it releases a lot of heat. And for this purpose one has to be very careful when dissolving something like sodium hydrazine because it might introduce so much heat that the vessel in which you are dissolving it could actually break.

So what we end up understanding from this experiment is that okay in order to measure something which is of interest to us in this case of heat of solution one can set up a smart experiment such that this can be reliably measured and one as to have a very clear systematic stepwise protocol and what as to be done. Why this step wise protocol is written up one also has to aware of the systematic error that would come up where all it could come and what could end up in a final larger that comes up.

Here I am still not discussing that error that comes up in the delta H naught which you all discuss in the forthcoming lectures but one is able to understand the final value or the error that comes up in which ever decimal is contingent upon all the different errors that are propped up. One way of doing this is by repeating the measurement such that you will be able to get some value similar and if you are able repeat it several times you get an average and standard deviation from such a measurement.

On the other hand one could use the different points had they have measured and introduce a random error assuming a certain amount of error that comes from other processes and therefore get an error for the fit that comes up. These are different phase of doing which we will discuss as we go forward but I hope you have understood how to enumerate a different steps in the process that might end up giving error in your measurement.

So in the first 2 classes in this week we have seen how to use software to just input your data and we saw how to use different functions within the that spreadsheet functionality meaning getting average getting standard deviation getting minimum getting count and features of that salt in today’s class we extended it by trying to go for a very simple system which has a linear relationship meaning that you change something the parameter that you would like to measure various linearly in this log of S where is linearly as a function of 1 over T and therefore you are able to measure a parameter delta H naught.

In the next class we will be trying to take a look at how kinetics can be still measured and documented using spreadsheets software and how rate constants can be derived from such a measurement. So basically we are just increased complexity from simply putting in numbers and analyzing the data and the spreadsheet to a very simple linear depends problem next would be an non-linear dependent problem from which we will be able understand how software is extremely useful to document large piece of dataset.

And I hope this will help you understand how important is even documenting data in software so this can be disseminated and also shared with the community so that they can also learn and understand where there values come from and how different they are. In the next class as I said we will be taking look at rate kinetic changes using excel and probably even going towards another software platform called Matlab thank you.