**Chemical and Biological Thermodynamics: Principles to Applications**
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Lecture - 60
Summary of the course on:
Chemical and Biological Thermodynamics: Principles to Applications

Today we are going to summarize on whatever we have discussed in this course, which is on chemical and biological thermodynamics. Principles to applications thermodynamics is a very important subject, whether it comes to chemical sciences, biological sciences, pharmaceutical sciences and even in technology. We started this course from very simple concepts with an idea that if there are any confusions in understanding the fundamentals that should be removed. We decided that we will follow the science and conventions recommended by IUPAC international union of pure and applied chemistry So that there is no confusion in various equations which are used in describing different laws.

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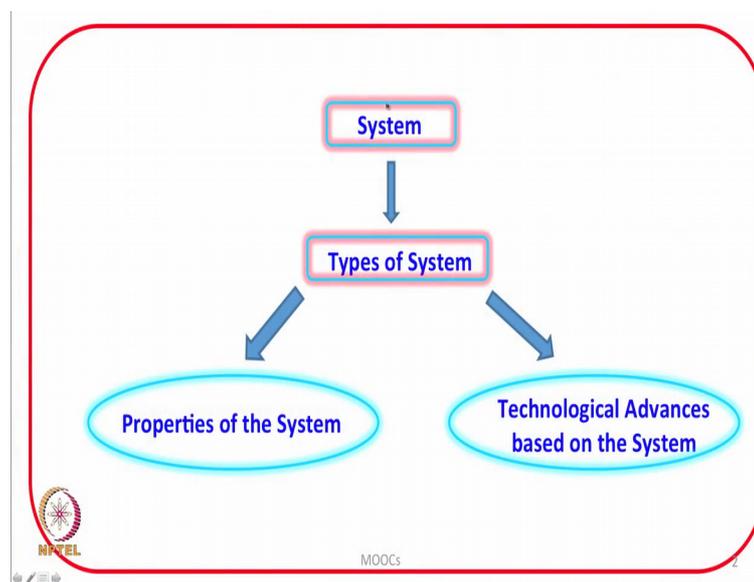
We started with the definition of system. System is the most important part of the universe, because it is the system in which we are interested in. And then we went on describing the various parts of various types of the system. Open system, closed system, insulated system and it is up to the scientists or a technologist to decide how to use the properties of the system. For example, it is the properties of the system which will decide

how the system will behave. And also it is the properties of the system that a technologist will use these properties to come up with the sophisticated instrumentation. So, that is why as commented on this slide the system was sub divided into different types of the system, and then the types of the system will decide the properties of the system. And the types of the system will also be utilized into developing technological advances which definitely depend upon the properties of the system.

So therefore, system has a specific significance when it comes to thermodynamics. It is the system which will decide that how we utilize it is properties. After system we introduced the concept of surroundings.

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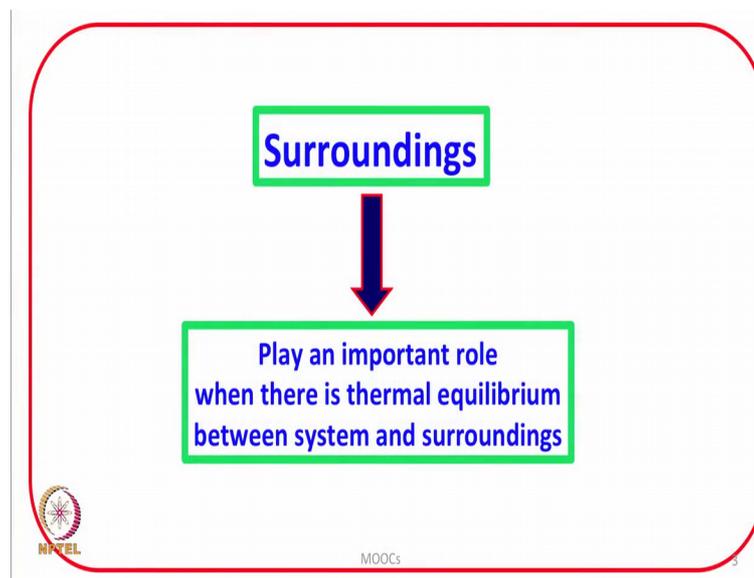
Let us take a look at the slide. As described over here surroundings play a very important role when there is a thermal equilibrium between system and surroundings. It is very important how we sense what is going on in the system. The observations can be made directly into the system, and observations can be made in the surroundings also. But if the observations are to be made in the surroundings then there has to be heat exchange between system and surroundings.

Let us remember the example that I took in the beginning of the lecture, that suppose if I am teaching in a classroom. And the walls of the classroom or door allows my sound to escape; that means, it is a closed system. The students cannot go out my voice can go out. Then a person who is standing outside in the corridor can listen to whatever I am

teaching and therefore, that person is a sensor whatever activity is going inside the system can be sensed outside. And therefore, the surroundings have a special role to play whenever there is an thermal equilibrium between system and surroundings; that means, if we are interested in very accurately determining the heat changes which are going on inside the system.

It is possible to be determine in the surrounding provided there is a thermal equilibrium. Therefore, surroundings play a very important role. Then we discussed the first law of thermodynamics. All the laws of thermodynamics are based on experimental observations. And based on experimental observations the first law was out forth according which the total energy is conserved. The total energy remains constant although it can be converted from one form to another. And this was put forward in the form of a mathematical equation that whenever there is a change in internal energy. That changed internal energy is used up in doing something, either in heating of the system or by doing work on the system.

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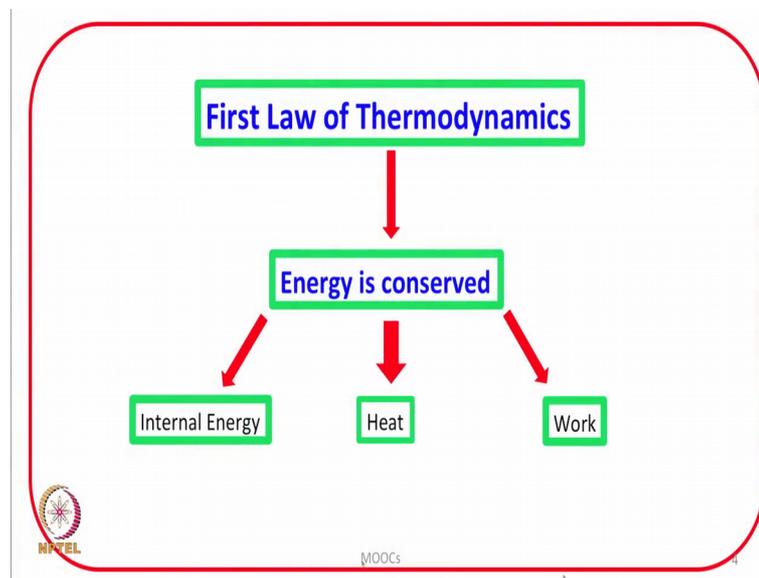
And that is what is represented in this slide. That the total energy of the system is conserved total energy is conserved. And this any change in the internal energy internal energy is the total energy of the system added up in all the forms.

The change in internal energy can be used up either in heat or by doing work, and that was the first law of thermodynamics. And after that we went on discussing the second

and third law of thermodynamics. Second and third law of thermodynamics have a special significant because second law which introduces the entropy is connected with the spontaneity of a process.

Remember we took an example of throwing a ball on the ground. If I just throw a ball on the ground after a special bounces it comes to rest. No work needed to be done in that case. Because when you just release a ball it is a spontaneous process no work is done. And whenever the ball was heating the ground it was generating thermal motion in to infinite atoms of the flow. And there we connected this spontaneity in the direction of generation of more disorder.

And therefore, this disorder this disorder is connected to entropy. That is why the changes in entropy play a significant role in deciding whether a given process will be spontaneous or not.

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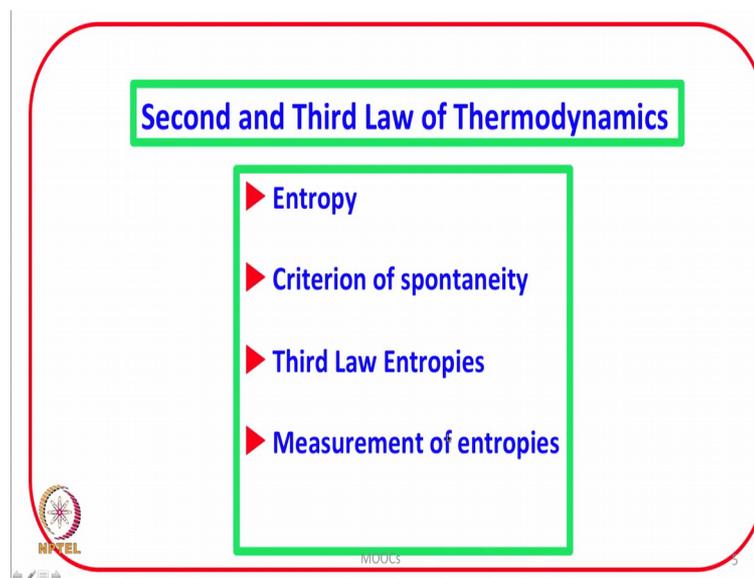
Let us take a look at the slide. In the second law we introduced the concept of entropy and connected the spontaneity of a process in the direction of generating more disorder. We further went on discussing the criteria of spontaneity. Criteria of spontaneity are very important, because we should know under what conditions a process will be spontaneous. We discussed that if you want to apply second law of thermodynamics in deciding whether a process will be spontaneous or not, we needed to calculate the

entropy change in system entropy change in the surrounding add up the both and if the total turns out be positive then the process is spontaneous in that direction.

That is why the second law states that the total entropy change in an isolated system always increases during a spontaneous process. We then further discussed that you can have the criteria of spontaneity in terms of the change in properties of the system alone. And then based on the cautious inequality we derived several criteria of spontaneity which were in terms of the changes in the properties of the system alone. Some of those criteria were a little tedious to obtain because maintain for example, maintaining the entropy of system constant is not in that easy.

But certain criteria of spontaneity for example, d G at constant temperature and pressure less than equal to 0 for a spontaneous process was very important. Because maintaining the temperature and pressure of the system is easy. And this criteria of spontaneity is widely used, whenever we say that the process will be spontaneous when the change in Gibbs energy at constant temperature and pressure is negative.

And we also use the criteria of change in Gibbs energy at constant temperature and pressure equal to 0 for that of the system at equilibrium. Then let us take a look at the slide again. We further discussed the third law of third law entropies. And these third law entropies were introduced after discussing the third law of thermodynamics. According to the third law of thermodynamics we discussed that entropy of each elibent is positive.

And it may become 0 at absolute 0, it does become 0 at absolute 0 in case of perfectly crystalline substances including compounds. We also discussed that if there is a configurational disorder at absolute 0, the entropy may not be 0 at absolute 0 and this we discussed by taking an example of carbon monoxide. We further went on discussing the technological applications of the third law of thermodynamics, and then we discussed by using adiabatic demagnetization process it is possible to obtain very low temperature of the order of picokelvin.

We further went on discussing how to measure entropies, measurement of entropies. Measurement of entropies is possible by using calorimetry. We took an example of finding out or determining the entropy of a substance a in the gaseous form at any general temperature. There we discussed that we need to make measurements from absolute 0. We need to account for all the phase changes. And then we discussed that it is

not possible to make measurements at absolute 0 because it is not possible to arrive at that temperature and that brought in discussion on d by third power law. And as I discussed earlier we did focused on the technological applications of the second and third law of thermodynamics.

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Then we discussed Gibbs energy G hemholtz energy A. And we further discussed that if we are interested in knowing the maximum work which can be drawn from a system we have to calculate delta A. And if we are interested in knowing the maximum non pressure volume work then we have to act upon delta G. So, this delta A and delta G are very important changes in thermodynamic properties. Because we are always interested in knowing how much were we can draft from a system and id we want to talk about the total work inclusive of pressure volume or non pressure volume work we must always act on A and calculate delta A and if we are interested in calculating in knowing the non pressure volume were which sometimes several books described as extra work or other work, then we have to calculate delta G. And one such example is electrical work.

Therefore, delta A and delta gare very important changes in thermodynamic properties; we also discussed that why delta A is called the change in Helmholtz free energy, we discussed what is free in this free energy. And then we went on discussing the properties of G and A and their connection to volume and entropy. You remember that equation d G is equal to v d p minus s d t that connects the changes in j. And we also discuss the

equation for d a. So, that the changes in G and A can be connected to other important thermodynamic properties.

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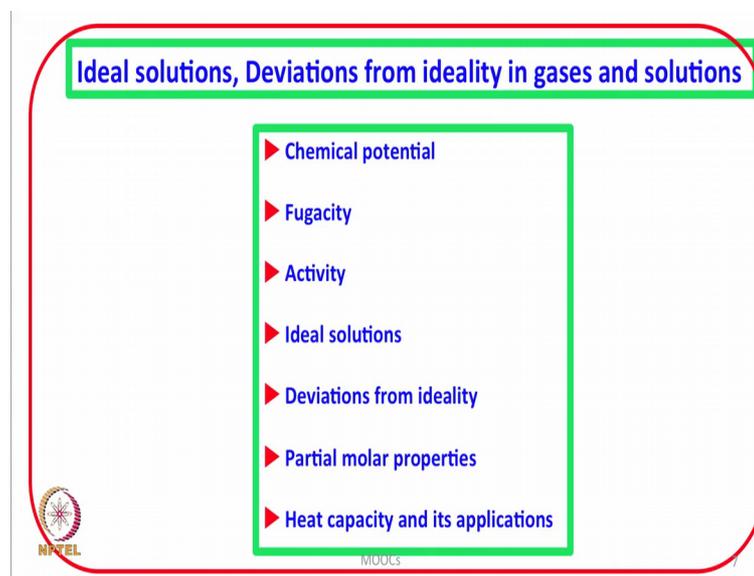
Then we started discussion on ideal solutions, deviations from idealities in gases and solutions. We introduced chemical potential. Chemical potential is central to chemistry when it comes to discussion on equilibrium. So, any advanced discussion in physical chemistry when it comes to equilibrium, should be done in terms of chemical potential.

Then we started discussion on fugacity and activity. Why fugacity and activity are important to discuss? We discussed what is an ideal gas we discussed what is an ideal solution. When an in ideal gas there are no inter molecular interactions whereas, in ideal solution there are intermolecular interactions because if there are no intermolecular interactions then the solution will not be formed or 2 liquids will not be miscible. In an ideal solution formed by mixing liquid a and liquid b the average a, a interactions and average b, b interactions are as same as average a b interactions.

We also know that most of the systems do not follow ideal behavior. The difference in intermolecular interactions in solutions or the intermolecular interactions in gases bring in non ideality. In order to account for non ideality in gases fugacity was introduced fugacity is effective pressure or escaping tendency of the gas molecules. And then we discussed activity, activity we discussed as effective concentration. And that brought in a discussion on the fugacity coefficient or the activity coefficient. The fugacity coefficient

or activity coefficient captured the deviation, or the extent of deviation from ideality all the deviations from ideality are captured by the activity coefficient. So therefore, whenever we are making some measurements, we must use the activities or fugacities unless the solution is So dilute and the gas is such a low pressure that the molecules can be considered very, very far apart and the activity can be equated to concentration or activity can be equated to molality or more fraction or fugacity can be equated to the pressure of the gas.

We talked about the ideal solutions, deviation from ideality and then we started discussing partial molar properties. In fact, chemical potential itself is a partial molar property because chemical potential is change in Gibbs energy, when one mole of a substance is added at constant pressure and temperature keeping the other components at same concentration. And we also discussed partial molar volume and partial molar adiabatic compressibility. For example, partial molar volume is an extremely important thermodynamic properties is a very important thermodynamic properties if we are interested in understanding intermolecular interactions. Because volume not only depends upon the mass and density the volumes also depends how a substance interacts with other components in a mixture.

For example if you are talking about an aqueous solution, and then when we add a substance into water how it affects the structure of water will very much decide the partial molar volume of that substance in aqueous solution. And the partial molar volume of transfer from water to mixed aqueous solution can tell us about the nature of intermolecular interactions operating in that system. And therefore, the partial molar properties play a very important role when it comes to a understanding the intermolecular interactions operating in solutions.

And then we discussed heat capacity and it is applications, we discussed that heat capacity is a very important connector between various thermodynamic properties from one temperature to another temperature. Not only an important connector, but also heat capacity is an indicator of the strength of a system, because if a system is very strong then it heat capacity will be more. And if the system is very soft it is heat capacity will be less.

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And therefore, this property can be used in discussing about the strength of a system. We went on discussing chemical equilibrium, equilibrium constant which is very important in discussing the optimization of a process. And we further went on discussing the applications of equilibrium constant it is role in chemical and biological processes, equilibrium constant is very important thermodynamic property, because equilibrium constant decides the yield in a reaction.

It is not just a number, but it gives important information on how much the product is formed. It also gives information on how a ligand interacts with a protein ad how the ligands interact in biological systems under what conditions and it has played an important role in rational drug design as we discussed in several chapters.

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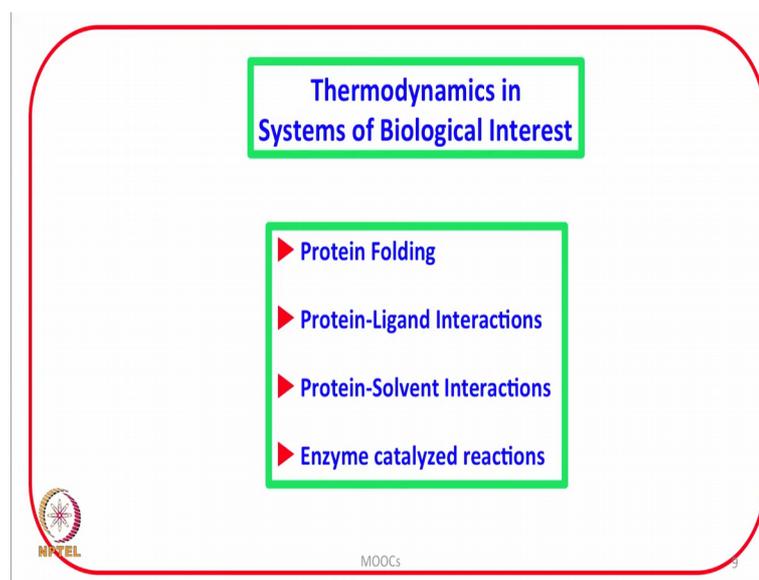
We further went on discussing biological standard states and pH. Later on we switched over to thermodynamics in systems of biological interest, specifically with a focus on protein folding, protein ligand interactions; protein solvent interactions and enzyme catalyze interactions. Protein folding which is how a primary sequence of amino acid takes up a unique 3 dimensional functional form of a protein is called the protein folding problem. We discussed how thermodynamics is important in this process and how the use of calorimetry has given important information on the forces which hold the protein pre dimensional structure of the protein intact.

We also discussed how thermodynamics is important in protein ligand interactions, protein solvent interactions and enzyme catalyzed reactions. Let us take a look at the slide.

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We discussed that more than 50 years we have spent in addressing the protein folding problem and still we do not have an answer to why a unique 3 dimensional fold is obtained from a given primary sequence. Although the computational chemist claim that they can give the folding court for small peptize, but for larger proteins we do not have the protein folding court.

And that is why now still there is a need for experimental evidences for the funnel model which is used as one of the best model to describe protein folding problem. And thermodynamics plays a very significant role in this because a minimum energy configuration is; what is the final fold of a protein.

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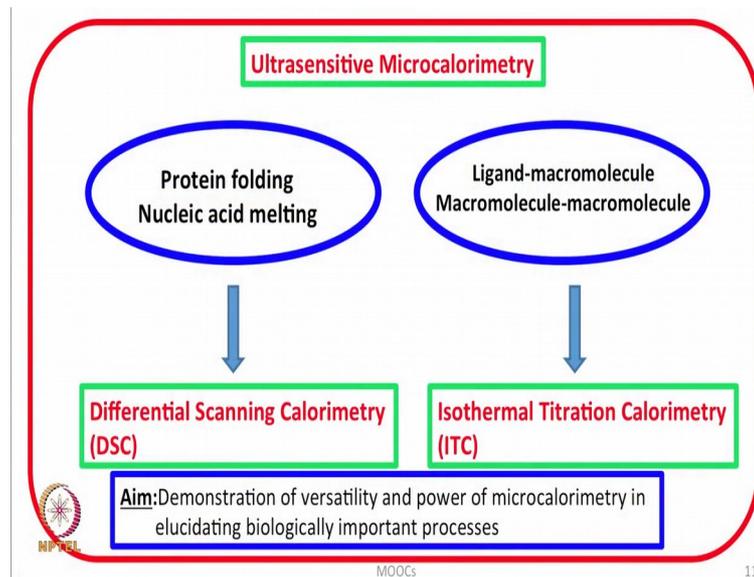
At length we discussed the ultrasensitive micro calorimetry. It is use in protein folding, nucleic acid melting which is differential scanning calorimetry has played an important role in this. And ligand macro molecule or macromolecule interactions we discussed with the use of isothermal titration calorimetry.

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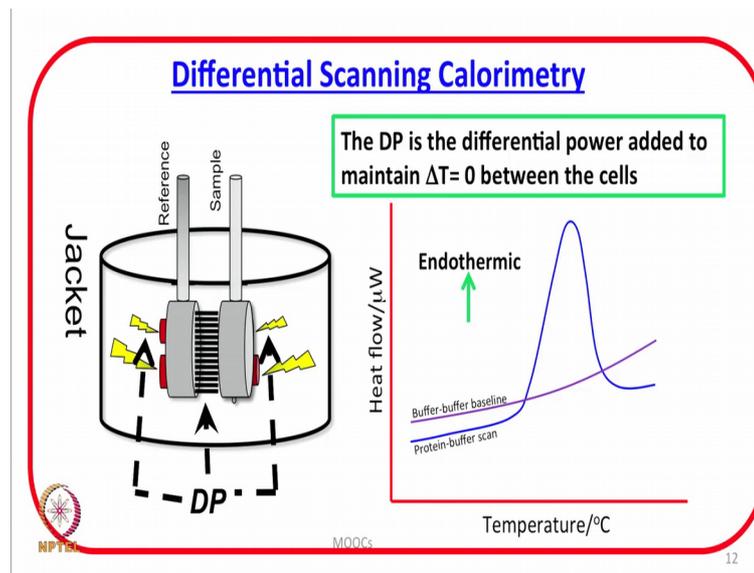
And the aim was demonstration of versatility and power of micro calorimetryin elucidating biologically important processes. We discussed the principle of differential

scanning calorimetry and the applications of differential scanning calorimetry in the area of protein folding pharmaceutical sciences and many other areas.

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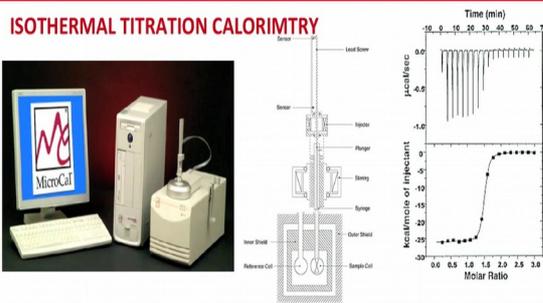
We also discussed isothermal titration calorimetry it is principle and it is huge applications in addressing the interaction of ligands with variety of biological macromolecules.

We also discussed that ITC is not just important in addressing the biological systems of interest, but even in several non biological interactions. We discuss that obtaining thermodynamic signatures from the technique isothermal titration calorimetry are very important.
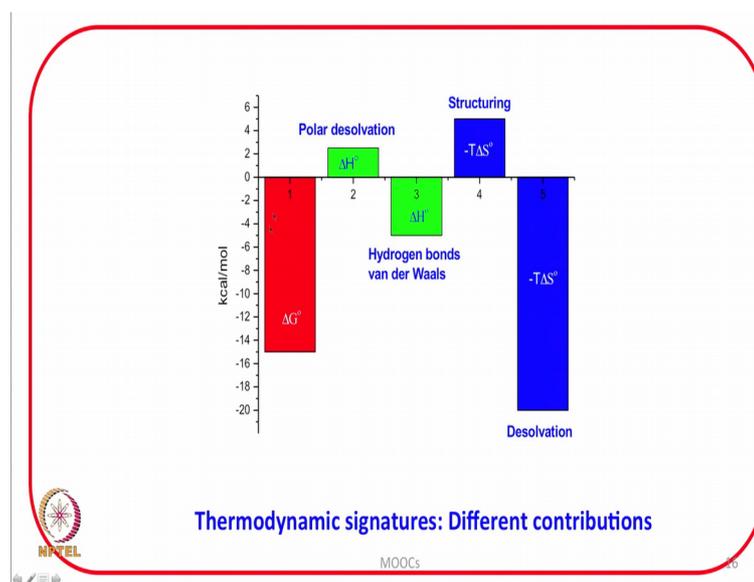
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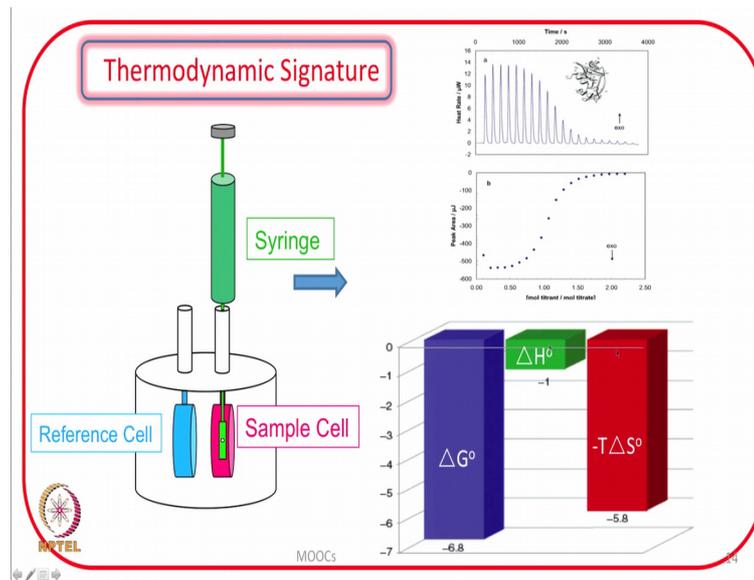
And such thermodynamic signatures can be obtained in a single experiment, which play

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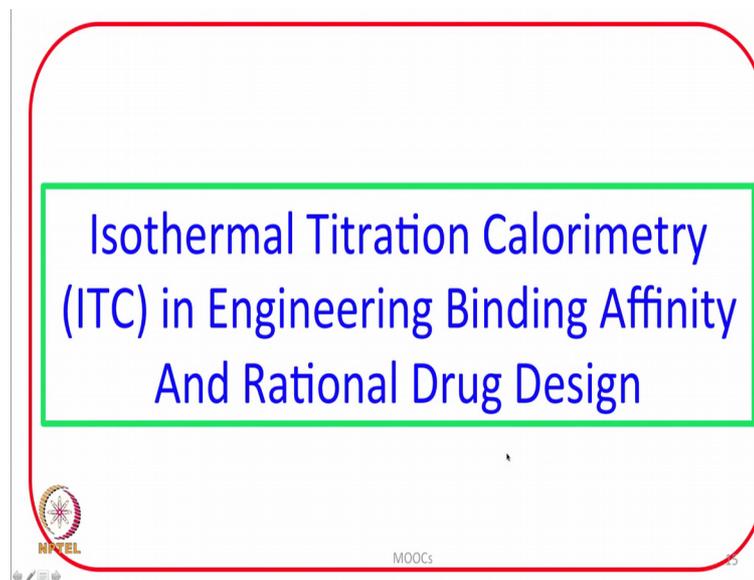
An important role in engineering binding affinity and rational drug design.

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Thermodynamic signatures: Different contributions

Because the thermodynamic signatures help us in identifying the various causes which help in deciding how to engineer binding affinity in a given molecule in a given potential drug, because delta G has to be negative when we want to achieve an affinity. We discussed how polar d desolvation can be costly and how hydrogen bonds and van der waals interaction can contribute in the negative value of delta G and Also we also talked about the desolvation how desolvation can also contribute in negative value of delta G naught and on the other hand structuring can also needs to some penalty.

So, these final discussion helped us in discussing that how to improve the functional groups in a given molecule which is already existing on in novel synthesis of new molecules or newer molecular entities which should have a desirable effected desirable affinity if our aim is having more exothermicity. Then in what kind of functionality should be introduced and also that here it should be introduced So that it should not lead to enthalpic penalty if obtaining exothermicity is the major court.
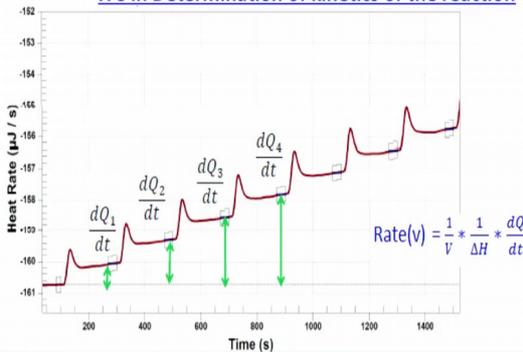
We further went on discussing that if the binding is very, very tight and beyond the determination by isothermal titration calorimetry or other equilibrium methods. Then differential scanning calorimetry can be used in estimating t ligand binding constant or affinity constant associated with the ligand binding of the order of 10 raise to the power 20 or higher 10 raise to the power 20 10 raise to the power 30 10 raise to the power 40 or even higher.

And we discussed how differential scanning calorimetry can be helpful in addressing the thermodynamics of the process from folding unfolding to ligand binding. Not only in addressing the thermodynamics of a process we further discussed that isothermal titration calorimetry is very important in determination of the kinetics of the reaction. The rate of the reaction is connected with the enthalpy change and also the heat rate that is the rate of flow of the heat, and from the isothermal titration calorimetric measurements it is possible to address the kinetics of the reaction.

To summarize the significance of understanding thermodynamics of the process lies in variety of areas. Let us take a look at some of those important areas.

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Chemical sciences, biological sciences, pharmaceutical sciences, chemical industry, pharmaceutical industry and research in chemical and pharmaceutical sciences; I am sure that the concepts which were covered in this course and their connection to the applications in variety of areas will be very, very helpful not only in explaining or in obtaining the deeper insides into the phenomena into the process under investigation, but also in various types of industries in various industries such as chemical industry pharmaceutical industry specifically when we talk about the rational drug design.

As listed in this slide that from chemical sciences, to biological sciences, to pharmaceutical sciences chemical industry, pharmaceutical industry the deeper understanding of thermodynamics will very, very be helpful in all of these areas

including research in chemical, biological and pharmaceutical sciences. Wish you all the best.

Thank you very much.