Laser: Fundamentals and Applications
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Lecture – 35
Application of Laser: Enrichment of Isotope

Hello and welcome back. So, we have been looking into the application of laser in separating isotopes. So, we have seen that there are several isotopic separation schemes by using lasers and do we have broadly categorized them into 4 different classes. Now one thing I must tell here that no separation techniques lead to a complete separation of 2 products or to any 2, you know material under consideration. Similarly in laser separation technique also for isotopes it does not lead to completion of the separation. So, what it does essentially is the creation of an enrichment of one particular isotope of interest. So, it creates you know the abundance of one of the isotopes in much higher amount,

For certain applications suppose one of the isotope is needed then there is also a limit that if you have this much of relative abundance of isotope 1 over isotope 2 then you can actually process the you know or go ahead and do the rest of the job. So, this laser separation technique essentially does the same job they you know enrich the you know amount of one particular isotope over another, and then the following you know applications or processes they take place.

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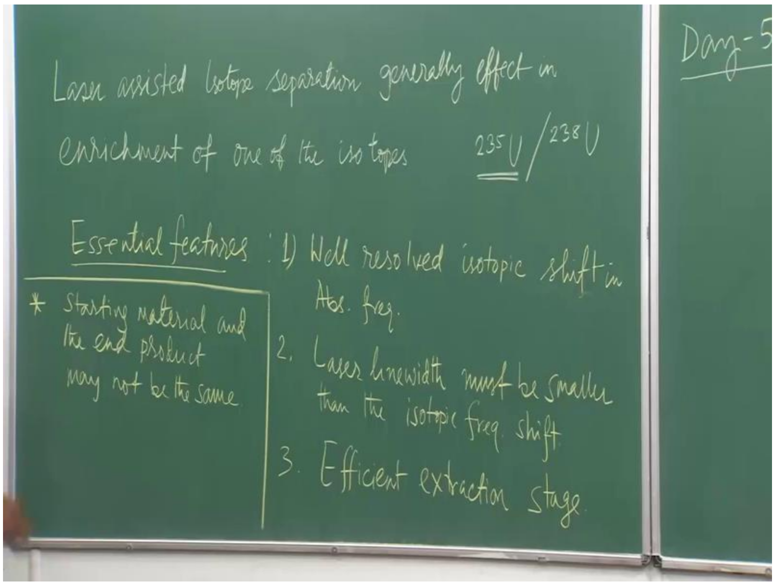

So, essentially I should mention that laser assisted isotope separation it generally effect in enrichment of one of the isotopes.

For example if I deal with uranium 235 and uranium 238 then my application may require that I must have in a more relative abundance of uranium 235 over 238. And my laser separation technique will give me that much amount of relative abundance of u 235 over u 238 and that is good enough for me. Because that is one I am now able to go ahead and do my job with uranium 235 and second most importantly I really did not have any other way to achieve that fine alright.

So, let us consider the essential features of this isotope separation. So, one thing is that one must have will resolved isotopic shift in absorption frequency or wavelength whatever you see. Second the laser line width must be smaller than this isotopic shift must be smaller then the isotopic frequency system as we as we said in the first clause. And third is we should have an efficient extractions stage what does that mean that whatever the laser do with the isotope. So, it will probably you know give you in terms of a different product having that particular isotope it can produce that in excited state. Whatever it does I must have a particular you technique to then take out that particular separated isotope. Or I must you know and also I must have a very efficient technique to do that ok.

So, if I have this 3 criteria fulfilled I am ready to go to do the isotope separation using laser. Now to one important factor here in this case the starting material and the end product during laser separation may not be identical, but that is not a big deal, because suppose I am looking at this radioactive isotopes. So, they may be in an atom or they may be in a molecule they will remain as it is correct. So, I do not care much about that one. So, I can always get my desired isotopes separated ok.

So now as I said earlier that they do not lead to complete separation, but they generally effect in enrichment of one of the isotopes, then I must have a way to quantify this enrichment. And that is what is the most important factor used in laser separation technique and this is called the enrichment factor which is given an symbol of beta.

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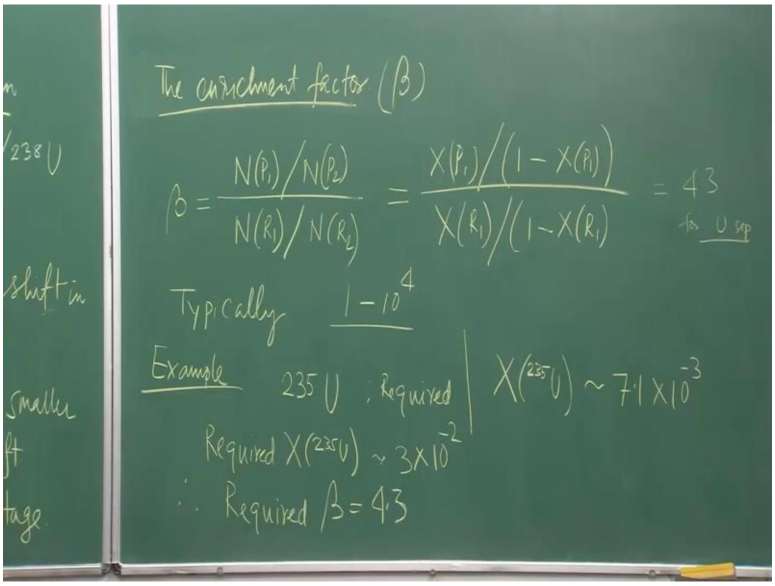

So, this beta is defined as or so here suppose I start with my 2 isotopes labeled as r 1 and r 2. So, my r 1 and r 2 are 2 isotopes that I would like to separate out. And suppose after the laser excitation my products are p 1 and p 2 and n s are their respective number of moles. And if I know the number of moles I can always calculate the mole fractions given by x s. Then this is the relation by which I get the enrichment factor ok.

Now, looking at the value of beta you know I can you know get that how much relative abundance of one isotope has been achieved over the others. And a typical number of beta and you can you can actually figure out that from this expression that beta must be greater than 1 to have a desired thing right if it is less than one then I have not achieved any you know enrichment there. So, typical value of beta it lies in a range of say one 2 10 power 4. So, I will give you one example. So, this example is about the enrichment of uranium. And uranium is used as a fuel in the nuclear reactors ok.

So, in nuclear reactors uranium 235 is required and this is the naturally occurring uranium. Now we have mole fraction that is naturally available of uranium 235 is approximately 7 into 10 to power minus 3 when I consider 235 and 238 isotopes now. So, we require 235 isotope and not only that if I want to really be able to use uranium 235 in the reactor the mole fraction that is required, required x uranium 235 is approximately 3 into 10 to the power minus 2 ok.

So, this is my requirement alright. So now, when I do this isotopic separation, in that case I will get my beta values with time and this requirement and knowing that this is the mole fraction of u 235 to start with I can get what is the beta actually that is needed. So, the therefore, the required beta is equal to around 4.3. So, when this equals to 4.3 for uranium separation, I am ready to go for using that uranium 235 in my reactor as a fuel and we call that we have enriched the uranium 235 sufficiently.

So, this is one of the you know very nice example of utilization of isotope separation. At this point if I ask you who will be interested in this kind of separation techniques using laser. So, there will be several industries who will be interested and one of them I do not have to tell you anymore after telling this one this is one of the you know really important thing for any government into this world right whenever you need energy you go to you know some nuclear reactor produce energy that solves the energy requirement for you know a large countries.

So, nuclear in that tea industry or some related industry who utilizes many of the you know byproducts in these things and you can separate them and then you can use them for further applications in different fields. So, the need of such technique is really fast alright. So now, let usquickly go through the different schemes that we talked about. So, we talked about selective photo ionization selective dissociation and selective photochemical reaction as well as selective photo deflection. So now, let us look at those things real quick.

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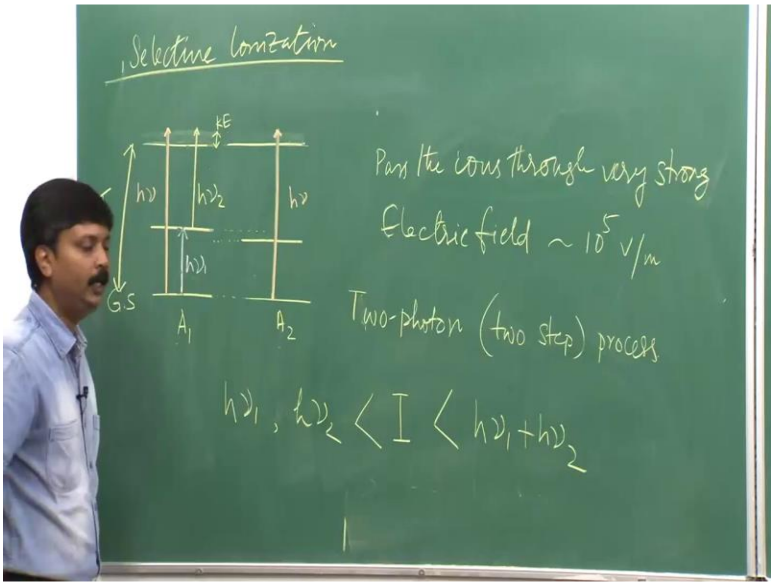

So, when I talk about when I talk about photo ionization, selective ionization. So, what do we understand about ionization? So, if I have a molecule present in the ground state and they may have some excited state here and then this is the limit beyond which the ionization will take place. So, this is the continuum. So, I can have this is for say my atom or my isotope 1 and then I have my isotope 2. So, the dissociation level and the ground state they are same ok.

Now, if I think of the conventional dissociation using a single photon absorption then what do I have? I have a transition like this when I come with a photon called h nu and if I do that same thing here what I will get I will get the same fate. So, this is also h nu and this excess energy for both of them which matches with this we will give me the kinetic energy of the ionized product and the electron. So now, what do I get out of this photo ionization suppose I have 2 isotopes I bring in my laser and I heat it with a photon energy such that one photon will take the system you know to the ionization limit. Then essentially both of the isotopes will behaves in the same way. So, we have a problem in this case.

Now, what I can do I can you know do this particular photo ionization in 2 steps, how? So, if I bring a particular energy say nu 1 which causes a transition between the ground state and this first excited state here and I have this is h nu 1. And in the following step I have a second photon which takes this molecules to this ionization beyond this ionization limit, then what will happen? If A 1 you know has the state such that it matches with this nu 1, and if I use the same laser light to do the same job in A 2 it will not work. So, it will work only for A 1 it will not work for A 2 that is what exactly I want because here this energy is right for this transition while this energy is not the right one for this transition correct.

So, therefore I will not have a transition here I will not have then a photo ionization for A 2 if I use nu 1 2, this 1 h nu 2. So, then I will ionize one of the isotopes selectively. After I ionized them selectively what I can do? I cannot pass this ions through a very strong field. So, through a very strong field strong electric field as strong as say like 10 power 5 volt per meter. Then I can selectively collect them right. So, then I can do whatever the things that I want to do right.

So, this is a very fantastic scheme where you are using you know A 2 photon essentially 2 photon and also this is A 2 step process. Only thing I have to be careful about is they the frequencies that I am using this nu 1 or nu 2 this should not be such that they themselves you know they them self create the ionization. So, my condition will be let h nu 1 or h nu 2 must be less than the ionization energy I, which should be less than the sum of this. This is very easy to understand because nu 1 plus nu 2 is more than the ionization energy.

So, this is my ionization energy. So, individually nu 1 and nu 2 must be less than that of the ionization energy, while together nu 1 and nu 2 will be more than ionization energy. So, we you know you use something like a di laser which is tunable and tune your wavelength to match one of this you know states. So, that you know excited states will be different in 2 different isotopes, because that is what my requirement also says that that is shift in the absorption frequency must be there and they must be you know quite well shifted with respect to my you know line width of the laser. And if I have that condition then I will populate only one of the you know and isotopes not the other. And hence in the next step I will ionize only that isotrope not the other.

So, I have only one ionized I sort of product then separate them using a particular field and then go to the next step whatever you want to do with that particular you know isotope ok.

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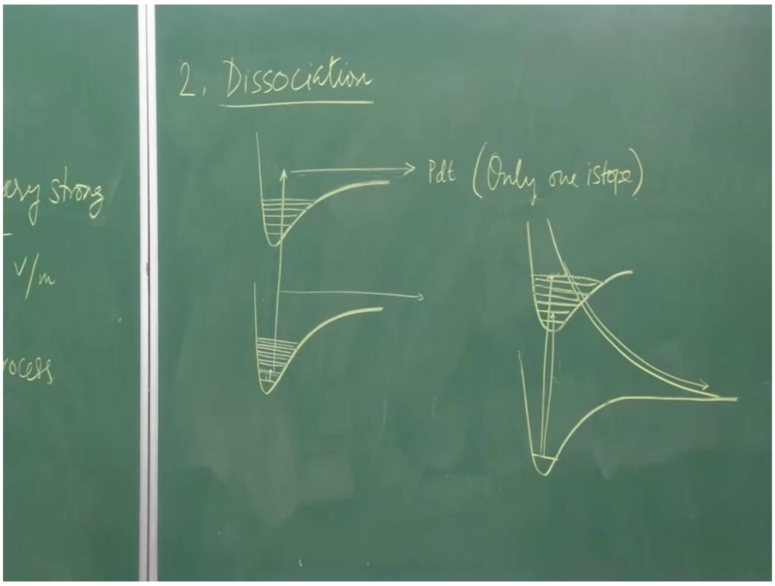

So, this is one technique that is used in case of isotope separation. There are other techniques as I said second is dissociation. So, this is pretty much like the ionization process while we took the help of multi step ionization process and that is also a kind of resonant enhanced in ionization photo ionization.

So, here when we talk about the dissociation what we see it can be you know one can excite the molecule up here and that will go and dissociate. So, this is within the same level you can do that. Also what you can do that you can put over here and the molecule will be dissociating correct. Now what you normally do to separate the isotopes the different isotopes will have their you know vibrational labels shifted from each other. So, here also if you use A 2 step process, in the first step you use an infrared laser having a very very long wavelength or you know very low frequency light and excite the vibration level of one isotope only.

So, then and if I use a different color in the same scheme to show that you know isotope levels they have different energies. So, the yellow color is for one isotope while the white color is for the other isotope. Then if I bring in an infrared laser which will populate say only the yellow one. Then in the next step if I bring an UV laser light and then excite it over here and then I get dissociation product. And this dissociation product will call contain only one isotope because I am selectively exciting one isotope and other remaining silent. So, in this way I can do it instead of using 2 photon process A 2 step process we can also use a single photon process in certain cases where I have a case of pre dissociation ok.

So, for example, if I show it separately, so this is a dissociative state. So, if I excite here I will not have any problem. Because this will just come down and at max it can come here and then it can dissociate, but if I excite to say high energy then the molecule vibrate in this level and then it will come to this particular dissociative channel. And then I will have a dissociation product along this one. So, in this case if my isotopic level states are you know separating energy such that I can use only one single photon and have a pre dissociation beyond a certain energy then I can use a single photon also to do the isotopic separation ok.

So, the third one is the reaction which is very well known for many of us laser induced chemistry actually plays the role here. Now by using a suitable wavelength of light and because this is very narrow having very narrow line width one can you know excite a particular isomer to a particular state while the other remains silent. So, this has been used a lot in case of separating you know you know isometric products having isotopes as the constituent and also you know many occasions it is actually the laser induces an isomerization which then is easy to separate out and this happens in case of one particular isotope why the other remain silent.

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And last thing I will talk about is the photo deflection. So, photo deflection is that photon when it hits particularly the laser light it transferred the momentum also ok.

So, suppose my molecules are moving in this direction suppose for example, something like in a supersonic zit expansion. And if my laser light it is a perpendicular. So, this is my laser and this is my molecules or containing the isotopes. Then what will happen? Due to this momentum impart on this particular molecules going here they will start deflecting. So, it involves quite a lot of thing. So, we do not we are running out of time today. So, I will finish this part in the following class and then move on to some other topics.

Thank you very much.