Rate Processes

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Module No. # 01
Lecture No. # 22
Fast Reactions (Contd.)

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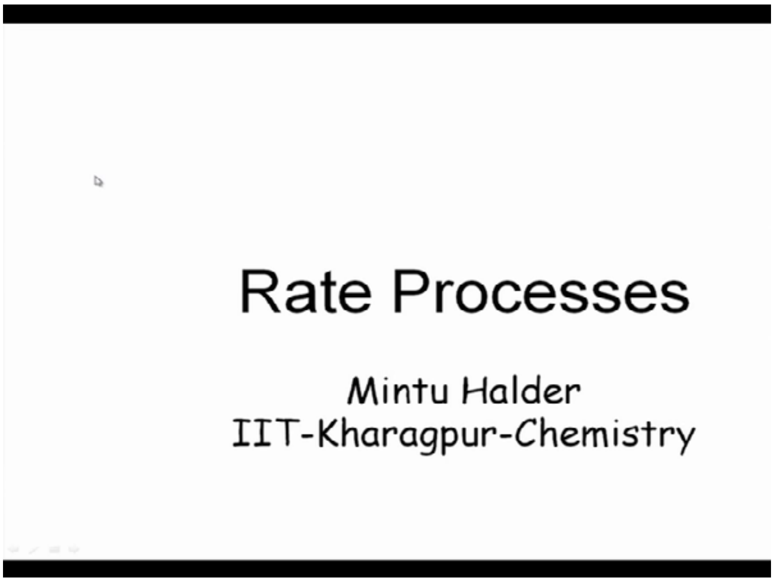

Hi, good morning everybody. So, we were discussing fast reaction; that is, techniques for fast reactions.

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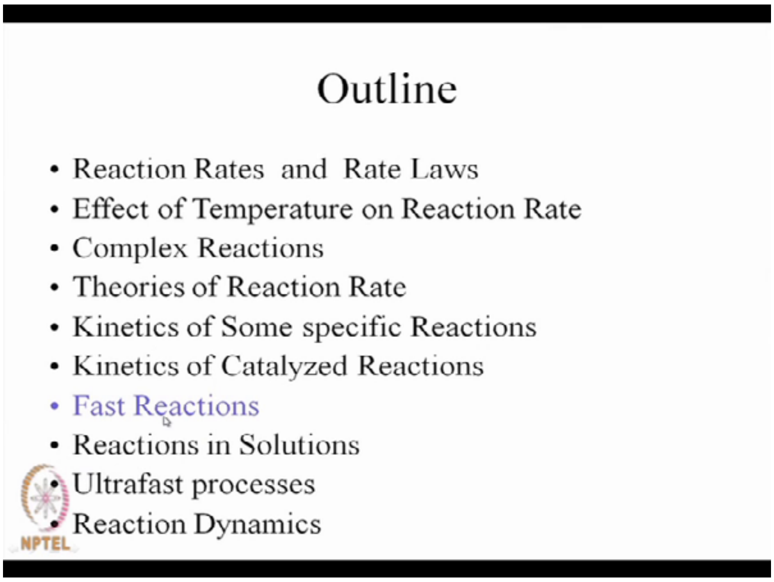

So far, we have talked about reaction rates, rate laws, effect of temperature on reaction rates, then complex reaction, theories of reaction rates, kinetics of some specific reactions, kinetics of catalyzed reaction. Now, we are here with fast reactions. Now, we discussed techniques like flow techniques; that is, a flow, continuous flow method or may be stopped flow method.

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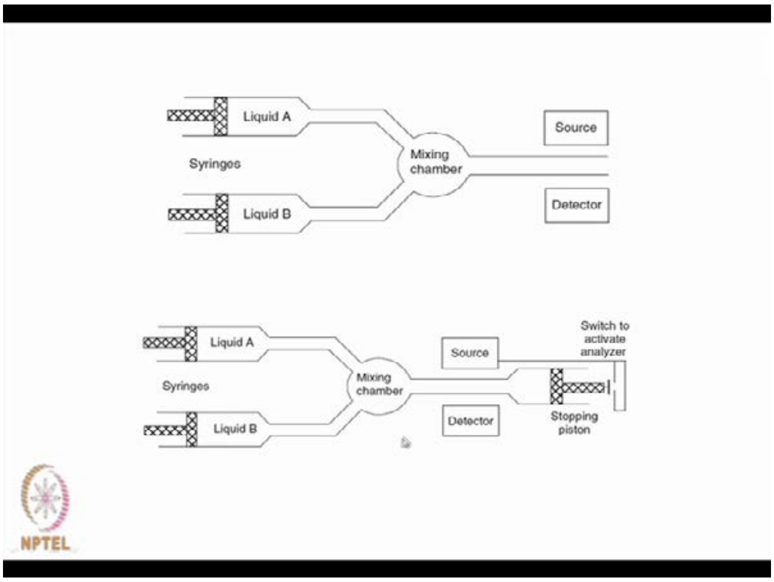

So, these are the typical diagrams of flow methods, I mean there are two syringes, there is a mixing chamber, and then there is a detector, and this detector may be movable or may be these syringes can also be movable. So with this, we can study fast or moderately fast reactions, not very fast reactions, it is not possible to follow the kinetics of those fast very fast reactions with this simple flow technique. So, for that, a modified version of flow method; that is, your stopped flow.

So, here also there are two syringes, there is a mixing chamber and you have got the detector. So, you have got the detector; that is, which detects, I mean the spectrophotometrically or may be fluorometrically, and there is a stopping piston and there is a switch, there is an electrical switch. The moment the stopping piston, this part; this electrical connection is completed, then source is illuminated and the detector detects the signal.

So, and in this case, this stopped flow technique, this does not require too much of volume, but here, may be it requires moderately larger volume of reactors. So, in this way, it is you know smarter than this one. Then you discussed this relaxation technique, shockwave method and lastly we talked about this flash photolysis.

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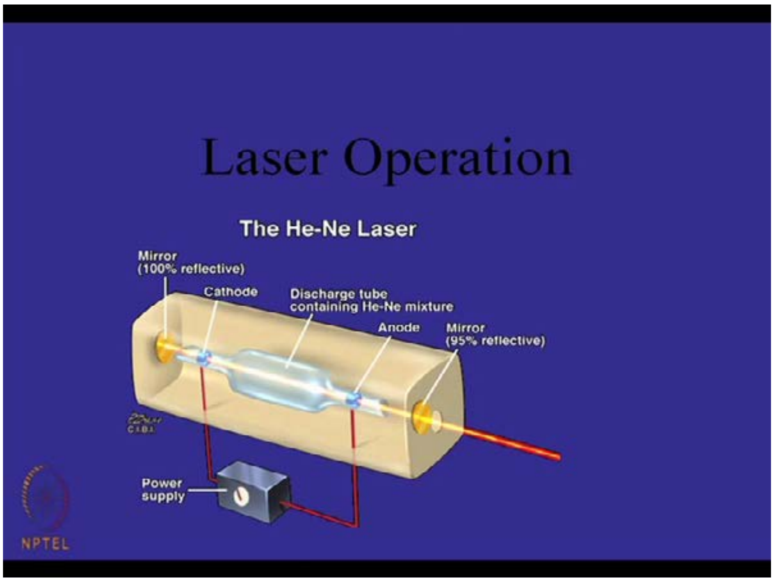

I mean talked about means, we just given an idea of this flash photolysis. Now this, when the term flash photolysis comes, then automatically you know this laser flash photolysis comes into our mind. Now before that, let us have idea of this flash photolysis. What is this flash photolysis?

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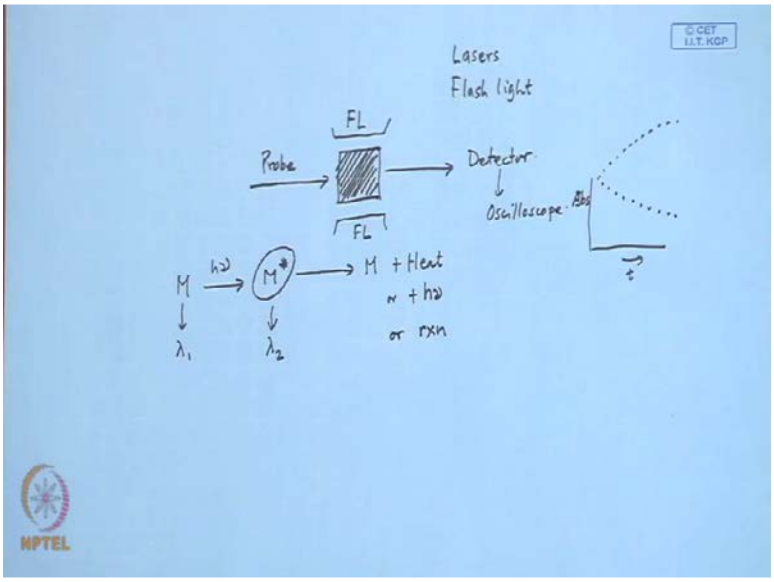

Now, suppose we have got a sample containing active spaces. Now the idea is that you have to shine with short pulse of light, maybe it is like flash light or may be laser light as well. I will come to lasers later on. So, this is an active material. So, suppose you have got the molecule m, when it is allowed to interact with radiation h nu, may be it goes to this to some electronically excited state, and then it undergoes further reaction. I mean the reaction may be it is photo-physical, may be some m and may be heat or maybe or maybe photon or maybe some chemical reaction. So, chemical reaction is also possible.

So, in this case, the active ingredient for the reaction is active material or the reactant is this one. So, by some means, and this is also not like ground state molecule that it stays for long time. It is not like that; this m star stays for long time. So, eventually it will undergo these processes.

Therefore, with time, this population of this m star reduces and suppose if it is the case like say, this one absorbs at say lambda 1, and say this one absorbs at lambda 2. So, the excited space is if it is absorbing at a different wavelength, then with the help of spectrophotometry, we can monitor the concentration of m star as a function of time.

So that means, this flash light is used to generate these active spaces, and you know there will be another light which is called the probe light which measures the absorbance of these spaces and maybe as a function of time. So, what you do? You have got your sample over. Here may be it is an equal solution or may be solution in some solvent, maybe methanol, maybe benzene and so on.

So, you have got your flash light over here; flash light and this side you have got your probe beam. It is a weak may be white light and you have got the detector, you have got the detector. The thing is that the moment this flash light is ON or it is flashing, electronically this detector becomes on, I mean getting a pulse from this flash light, a circuit is turned on so that the detector becomes active, and it starts to detect the signal at a given wavelengths lambda 2 and as a function of time.

So, this detector is plugged, I mean the signal from the detector is plugged into a device, maybe it is a oscilloscope; cathode ray oscilloscope or maybe oscilloscope. Nowadays these oscilloscopes are replaced with PC based oscilloscopes. So, what it does is, it records the signal intensity as a function of time. So, the signal strength decrease with time. So, it is the intensity or may be absorbance abs and it is time.

So, what happens is that that the probe light because of this absorption at immediately after this flash is on, what happens that this when the flash is on, this signal is minimum because immediately after the flash is on, this population is very high.

Therefore, what happens, if you just simply record the intensity of the emergent probe light at a given wavelength lambda 2, you will have a rising trend of your intensity because this species absorbing species is decaying with time. So, this way we can we can follow the concentration of m star.

Now sometime, this active I mean this sample does not have strong absorbance at a particular wavelength. It may have weak absorbance. So, in that case, if you can have a very high intensity light, then it is possible to have significant absorption at that particular wavelength and for that, this frozen light is replaced with lasers.

So, now we come to we will come to what is meant by lasers. So, it is the short form of the term Light Amplification by Stimulated Emission of Radiation; LASER. So, what is this light amplification? What is this stimulated emission? So, we will come to this. So, let us have a look into a typical simple laser. Say it is a helium neon laser, it is a visible laser I mean lasing frequency is visible and lasing frequency is visible.

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So, this picture is taken from some internet resource. Now this is a helium neon laser. It has got like you know there is an active medium, this is the power supply, this is cathode, this is anode, and it contains a mixer of helium and neon, and this mirror is 100 percent reflecting, this mirror is 95 percent reflecting.

Now, because of this electrical discharge, lasing action is generated. Now see this one is not 100 percent reflecting. So, it is giving this side is giving you know lasing, I mean laser light whatever we get from this box and this side is 100 percent reflective.

Now what is this laser action, suppose you have got like two level systems. Now in two level system, because of this Boltzmann distribution, the lower level is always populated higher than the upper level and since this these gap is electronic gap, so, always this one is having very high population; that is, most of the population is over here than here. Therefore, ordinarily you cannot have population over here more than over here.

Now, suppose if you have and if you have a population I mean like this level, I mean upper level higher than the lower level, then there is a possibility of lasing action. So, what is happening that suppose we got a third level, ordinarily this level is not populated. If this level is not populated and suppose if you excite, I mean if you pump the system with brief pulse of radiation, then what is happening that this excited species will rapidly move to this level so that if this is a metastable state; that it, is population remains finite for sometime, then at ordinary situation, this one is never populated, but because of this you know round about channel, this level gets populated.

So, what is happening is that eventually this level will have a finite population. So, compared to normal population, this level is I mean normal means under ordinary condition, this is 0; population is 0, but because of this optical pumping, this level gets some population. So, it is called the inversion of population with respect to when there is no pumping. And then this excited I mean this population in a some of the excited species, you know gets de-excited I mean because of your spontaneous emissive tendency, some of them will come down giving rise to photon.

What is happening is that if you can fit this photon back to here, then it will stimulate another system to come back. So, it is a cascade action and therefore, all the population will all on a sudden come down giving rise to a huge number of photons and which is called basically lasing and this lasing you know it has got specific characteristics. So, which we will come to you know one by one.

Now, lasers it is one more important point that it is a three level lasing case. I discussed. We may have four level cases also like here, three level case it is you know; these two levels are never populated under ordinary condition, but if you do pumping like this, you will have population finite population over here compared to this one. So, it is again against the normal case; that is, Boltzmann distribution. So, population is getting inverted. Therefore, we can expect lasing between these two levels.

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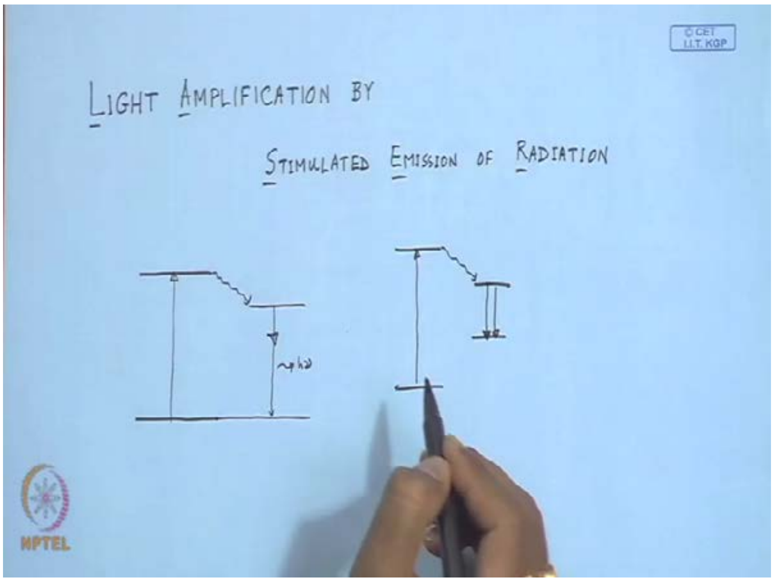

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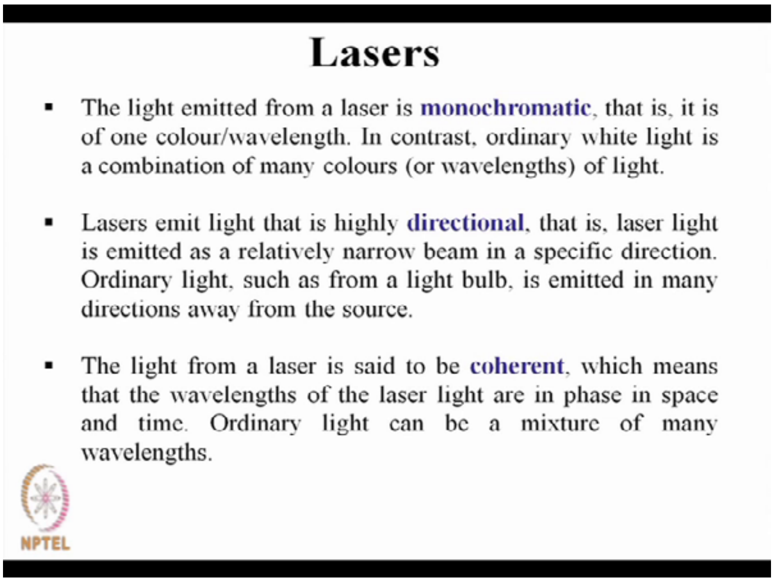

So, let us come to the characteristics. So, light emitted from laser is monochromatic, that is it is of one colour and wavelength. In contrast, ordinarily white light or may be yellow light. Yellow light may be a combination of a band I mean a band of frequencies. It is not a single frequency, but for laser, it is a monochromatic; that is, one frequency is there. Why it is that because lasing occurs between two definite levels; that is, a pair of level, these two are definite. Therefore, the gap between these two levels is fixed. Therefore, we may expect we can expect you know only one frequency.

And lasers emit light that is highly directional. Why highly directional, because as I told you that because of this spontaneous emission, this one I as I told you earlier, that because of this spontaneous emissive probability, this comes down to here diving rise to a photon and if you can have this photon within a pair of mirrors, then what will happen is suppose in between these two mirror, there is an active medium like this. Say this is the active medium. So, this active medium means that is it has got the excited n symbol.

So, excited n symbol means this n symbol, this one. Therefore, the moment this single photon is emitted due to spontaneous emission tendency, this may fall on to maybe this mirror or may be the other mirror. And if this spontaneously emitted photon falls onto this mirror vertically, vertically this way, then it will it will be reflected back and pass through this active medium. So, pass through this active medium means it will go back and forth between these two mirrors and giving rise to a standing wave pattern. So, a standing wave will be generated and the more it will go like this, it will stimulate other excited I mean I mean other excited molecules or excited systems to come down.

And there is a kind of average weak down like all the I mean the excited n symbol will together come down to the ground state giving rise to photon. And only those photons which are exactly or very close to the vertical situation compared to this mirror will remain within the within the cavities. So, this you know you know region in between this two mirrors and the active medium is called the cavity. So, it will remain within the cavity. So, within the cavity means those beams I mean those rays which are exactly vertical to this mirror will oscillate within the cavity.

And as I told you, in the earlier diagram that one mirror is 100 percent reflecting and the other mirror is less than 100 percent reflecting; means some of these oscillating photons I mean waves, some of these oscillating photons within the cavity will exceed the cavity through this less than 100 percent reflective reflecting mirror. Therefore, whatever light we are getting as a lasing should be exactly you know very directional because it comes out of this two parallel mirrors. These two mirrors have I mean have to be very specific like they have to be parallel to each other.

Therefore, it is highly directional and laser light is emitted as a relatively narrow beam in a specific direction. Ordinary light which I mean ordinary such as bulb light is emitted in many directions I mean all the possible directions, but lasing is a very directional thing. The light from a laser is said to be coherent which means that wavelengths of the laser light are in phase in space and time. Ordinary light cannot it can be mixture of many wavelengths because as I told you, the standing wave pattern is generated means when this standing pattern remains there, the situation is that if they oscillate in phase, if they do not oscillate; these waves do not oscillate in phase, then there will be destructive interference.

Therefore, those waves which will survive within the cavity to form the standing wave pattern; these should maintain a constant phase difference or they should oscillate in phase; that means, whatever waves are there within the cavity forming the standing wave pattern will be in phase. That is why the laser light which is coming out of the cavity is coherent, that is, the constant phase differences maintained or maybe they will oscillate in phase I mean like this, same way.

If this one is one wave, this is another wave. So, they have to oscillate in this way or maybe there will be a constant phase difference. It is never like one is going this way, other is going that way. So, in that case, the destructive interference will stop everything. So, therefore, therefore, this makes laser light coherent.

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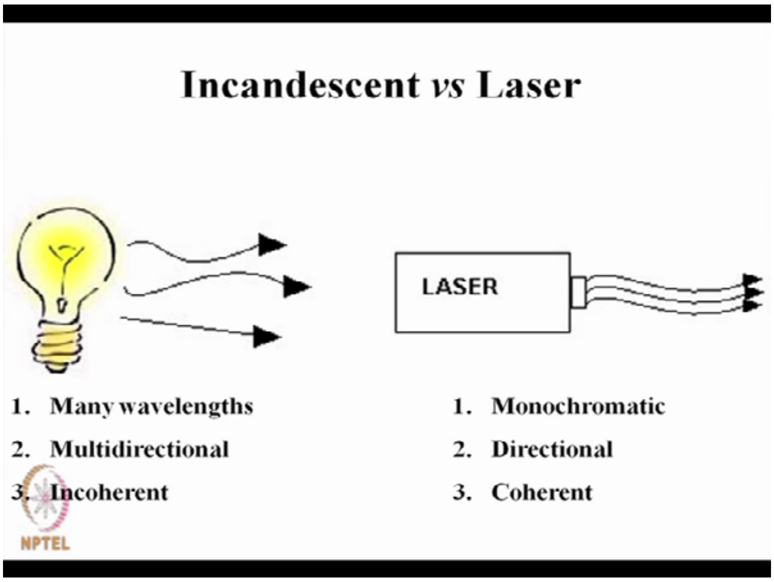

So, it is a comparison between bulb ordinary bulb and laser. So, it has many wavelengths, the laser will have broadly one wavelength; that is monochromatic. But mono-chromaticity does not necessarily mean that only one one wavelength. It also depends on the time scale. So, that part I am not going to discuss, anyway and for incandescent, it is a multidirectional, but for lasers, it is directional because it comes out of two parallel mirrors. Therefore, therefore, it is highly directional.

And also I told you that it is coherent, why coherent, because of this standing wave pattern is the requirement because if standing wave pattern is not there, then those photons will leave the cavity and when the photons I mean photons from this spontaneous emission of this excited n symbol is leaving the cavity, they are no longer no longer able to stimulate the excited n symbol to come down giving rise to photon. So, that is why coherence is coming, but for incandescent; that is ordinary light, it is incoherent.

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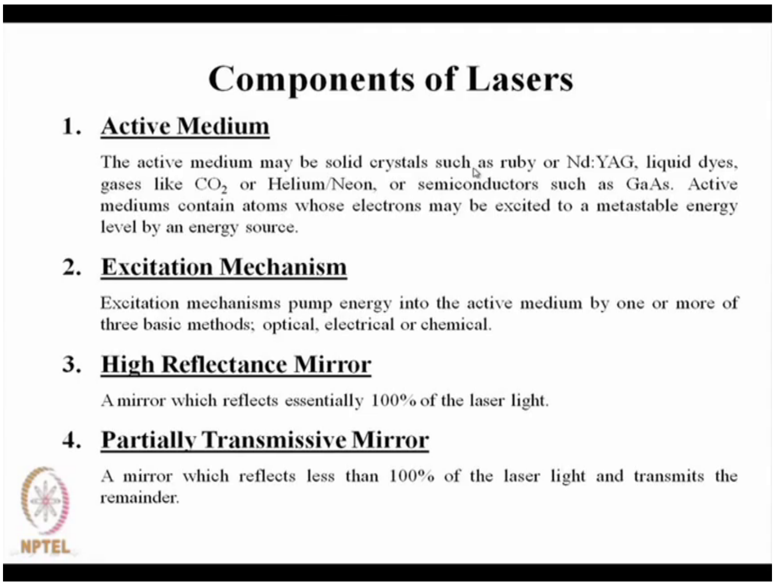

So, this is you know this is all about incandescent and I mean with respect to properties. So, component let us come to components of lasers.

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Active medium; first one is called the active medium, like let us go back to this picture, this is the active medium. It may be like helium neon as I have shown over there; helium mixer of helium neon. It may be ruby. It may be neodymium, yttrium, aluminium, garnet crystal. May be liquid dye or you know gases like carbon dioxide or like helium neon or may be semiconductor like gallium arsenide. An active media you know that contains atoms whose electrons may be excited to metastable energy level as I told you by an energy source.

So, metastable state is generated by means of may be electrical pumping or may be optical pumping. Electrical pumping is also possible, optical pumping as I have discussed with two level systems or may be three level systems. So, for you do helium neon case, there is electrical pumping. Excitation mechanism; it is called the pumping process like pumping water from the ground level to the top level. So, pump energy. So, excitation mechanism pumps energy to the active medium like optical method, may be electrical method or may be by chemical method.

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So, there must be a wheel to pump energy from here to here by this route. Then high reflectance mirror; high reflectance mirror means if you have you know a lasing cavity, you have got this active medium, you have got this mirror, there is another mirror. So, one mirror will have to be 100 percent. You have pumping, pump energy. It may be optical; it may be electrical and so on.

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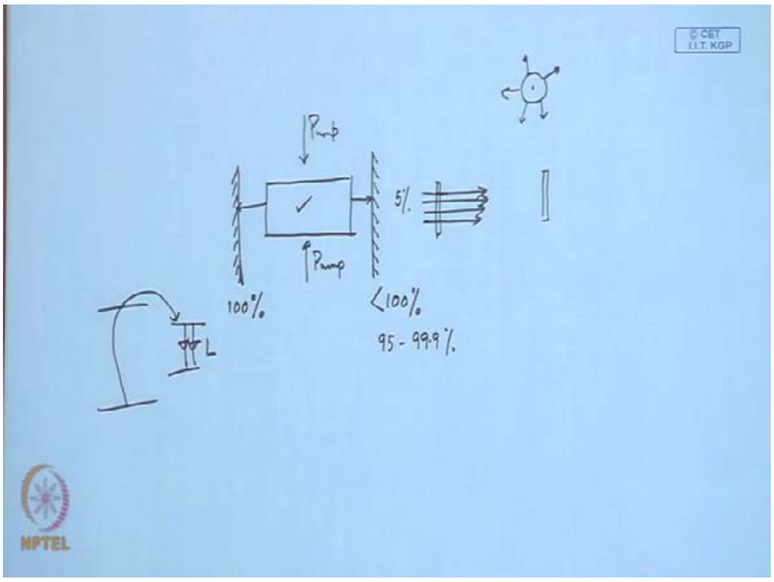

So, this is 100 percent reflecting mirror and these two mirrors need to be parallel, may be parallel. If one of them I mean if they fail to become parallel, then you would not be having you know lasing. And there is another mirror or maybe it is called the partially transmitting mirror. So, it will be less than 100 percent reflecting, may be say 95 to 99.9 percent. So, what happens is that this reflects all the photons which are falling onto this mirror, but this reflects maybe 95 percent I mean suppose 100 photons are falling on this mirror. So, what is happening in that out of 100, 95 photons are fed back, I mean returned to this cavity, and may be 5 percent I mean 5 photons are coming out which you see as lasing.

So, and since these light is coming because of this two parallel, I mean out of these two parallel mirror configuration, so, these being photons will be exactly parallel. Their divergence is less than 1 radian or even very less than 1 radian. So, very low degree of divergence. Contrary to our or I mean ordinary lamp case where I know light is emitted in all the possible directions.

And intensity falls off rapidly with distance from the source, but here, it does not fall that much I mean it does not fall that much with with with separation or I mean if the intensity over here is having some value, may be here also that value is very close to this value. So, active medium; this one is an active medium. Excitation mechanism; pumping energy, pumping energy from may be here to here and then lasing.

High reflectance mirror and partially reflecting or may be partially transmissive mirror. So, these are the basic parts of a laser.

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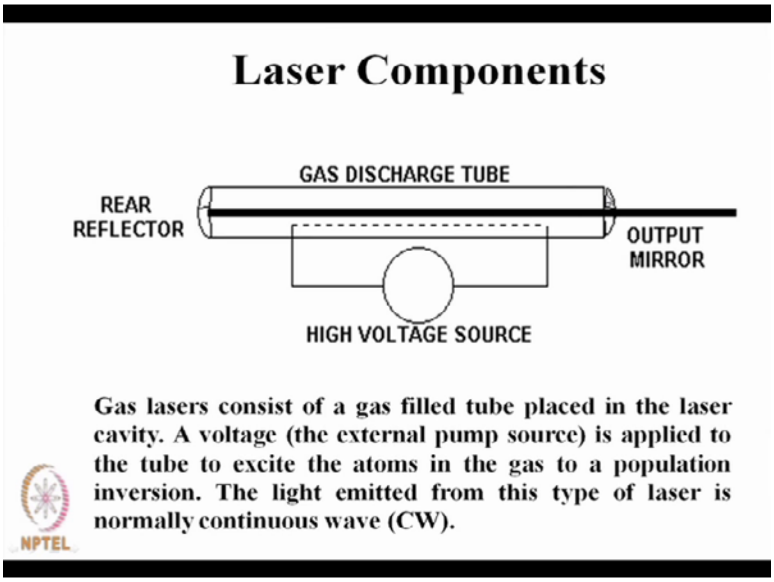

So, it is a typical gas laser description. This one is a rear reflector, this is actually called output coupler OC; output coupler means it is partially transmissive mirror and gas discharge. Through gas discharge, your excited n symbol of molecules are created, and then through this rear reflector, 100 percent reflector and output coupler, the beam is coming out.

So, gas lasers consist of a gas filled tube placed in the laser cavity. So, like it is it is the active medium. A voltage; the external pump source is applied to the tube to excite atoms in the gas to a population inversion. Population inversion is a must.

And light emitted from this type of laser is normally continuous wave. Continuous wave means it is not like a flash light. It continuously remains I mean it is intensity remains constant with time. It is called the continuous wave gas. Generally these gas lasers will give rise to CW mode; continuous wave mode.

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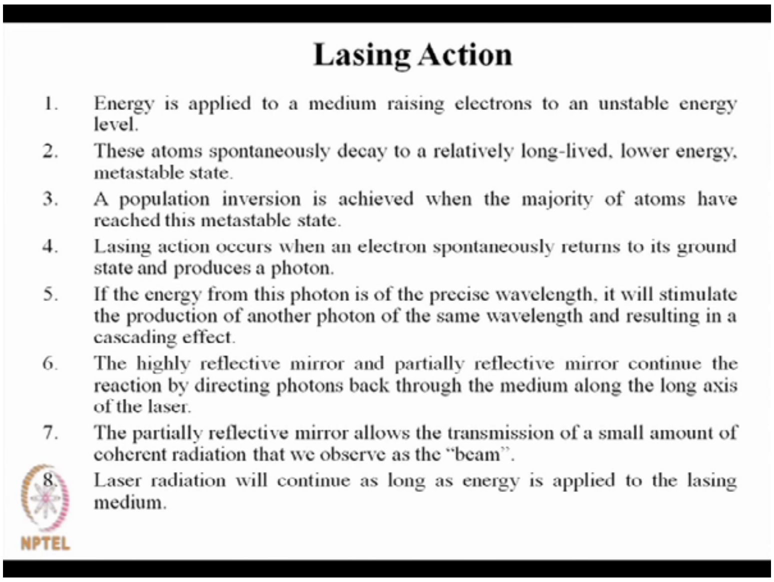

So, lasing action; let us say in points. Energy is applied to a medium raising electrons or may be may be molecules to an unstable energy level. So, like here. See this one is unstable energy level. This is your unstable energy level. Then maybe it is because of this electronic excitation it happened or may be some other means. May be collision could be another way of pumping way to I mean collision by collision, you can I mean because of energy exchange, excited n symbol can be created. These then what happens, these atoms or excited n symbol spontaneously decay to a relatively long lived low energy; this is your metastable level.

Your population inversion is achieved when majority of atoms have reached when majority of atoms have reached majority atoms have reached this metastable state. Then, so, majority of atoms when made this transition, then there is a sufficient population built up. Then lasing action occurs when an electron or may be an excited n symbols spontaneously returns to the ground state and produces a photon. May be because of the electron de-excitation from here to ground state or may be or may be a molecule comes back. This is called then molecule comes back to the ground state; may be electronic transition or may be by some other transition; vibration or may be some other transition. So, it comes back and giving rise to a photon in the appropriate frequency.

If the energy of this photon is of the precise wavelength, it will stimulate the production of another photon of the same wavelength and resulting in a cascade effect; that is, if this energy of these emitted photon is exactly matching with this energy gap between these two lasing level, then what will happen is that it will stimulate another excited molecule to come back resulting in another photon.

So, one photon makes another photon, then these two photons will make four photons. So, this way cascading effect happens. The highly reflective mirrors partially reflect I mean highly reflective mirror and partially reflective mirror continues the reaction by directing photons back through the medium along the long axis of the laser.

So, as I told you that this things photons are fed back into these active medium, and only those photons which are falling onto the mirror exactly perpendicularly will remain through back and forth, back and forth reflection and will make standing wave pattern. Then the partially reflective mirror allows transmission of a small amount of coherent radiation that you observe as beam.

So, because of this partially reflecting mirror, a little percentage is coming out what you see as lasing. You see if 100 percent could have been directed outside, then we could have got huge intensity, but in that case, we will lose the cavity. So, that is why keeping the cavity on, we have to have most of the radiation within the cavity. A laser radiation will continue as long as energy is applied to lasing medium I mean as long as pump is there. So, this is the brief story about lasing.

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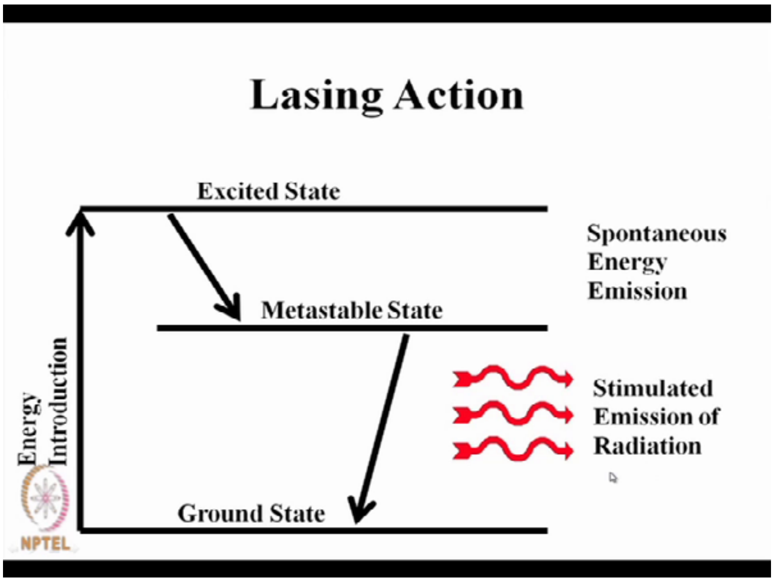

So, you see energy introduction, excited state, metastable state, I mean it is a non radiation by a non radiation transition you know non radiative transition metastable state is generated, then metastable state to the ground state. It is shown as a three level case, but it may be four levels. So, then it is your stimulated emission of radiation. This is the schematic of lasing action.

Laser output like you know as I told in case of your helium neon laser or gas laser, it is a continuous wave output, but for pulsed laser, it is I mean you know, it is coming as a pulse like energy, you know a packet of energy is given in a very short duration. Here may be here, then here, and of course, the gap between successive pulses is constant.

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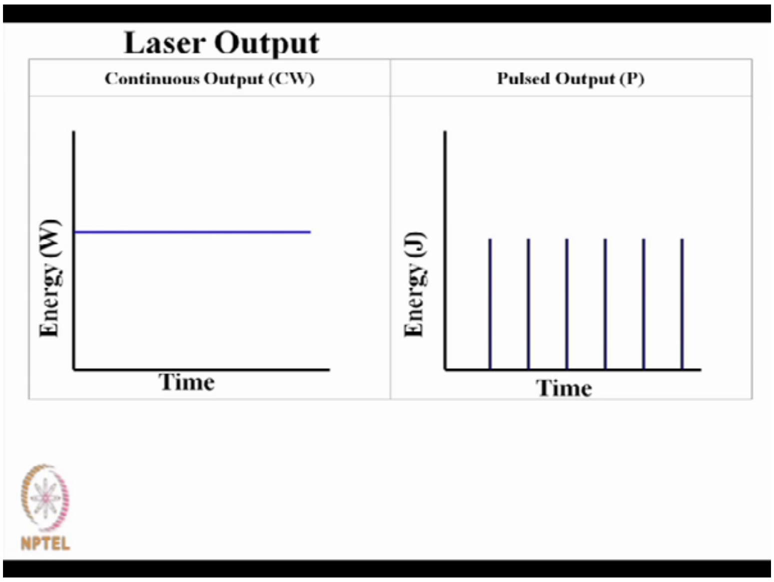

So, it is a pulsed output. When that pulsed output is possible by means of a mechanism that if you if you can rotate the 100 percent reflecting mirror at certain frequency, I mean rotational motion, then lasing action will be there only when you know the second mirror is exactly parallel to the partially reflecting mirror. So, like if it is like this, little tilted, you would not get any lasing. So, this way it will it will continue to rotate I mean like this. Say this is your mirror; it will continue to rotate like this. The moment it is exactly parallel, then lasing. When it is not parallel, it is not lasing.

So, that this way, you can you can get pulsed output. So, pulsed output is a means of you know is a means of getting bunch of I mean a packet of energy and the energy is I mean packet of packet of photons and energy is huge compared to continuous case. And you can generate by means of this mechanical way or may be other optical way. You can generate pulsed output. So, that I am not going to discuss in detail here because it is outside this scope.

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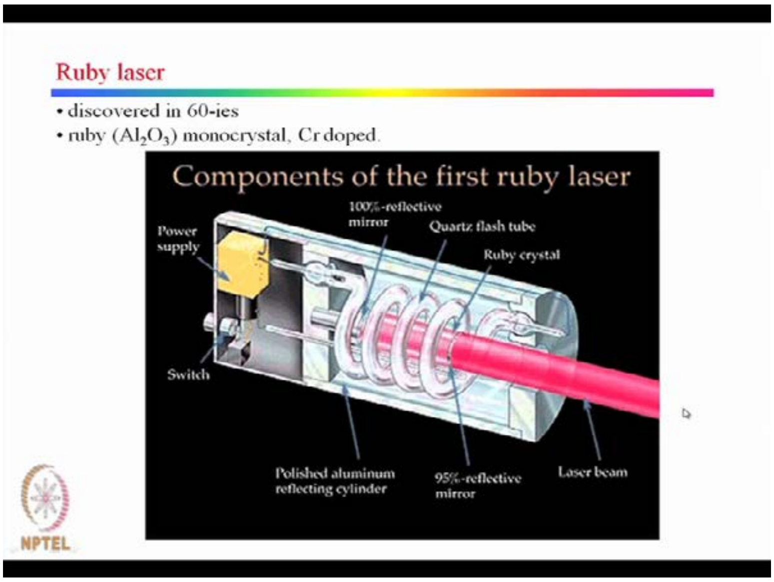

And this is the typical schematic of a ruby laser, that this is your active medium and this is your quartz flash lamp, and this one is 100 percent reflective mirror, and the other side is partially reflective mirror, I mean this side is partially reflective mirror; this side, and you know ruby lasing beam is here. It is discovered in sixties.

And it is the power supply that is a source of energy that is supplied here, you know there is energy pumping is done by means of electrical energy is now converted to photonic energy by means of quartz flash tube. That flash tube excites you know n symbol from the ground state to the metastable, and then from metastable to the ground state; this transition generates your lasing. It is a aluminium mono crystal doped with chromium. It is called the ruby.

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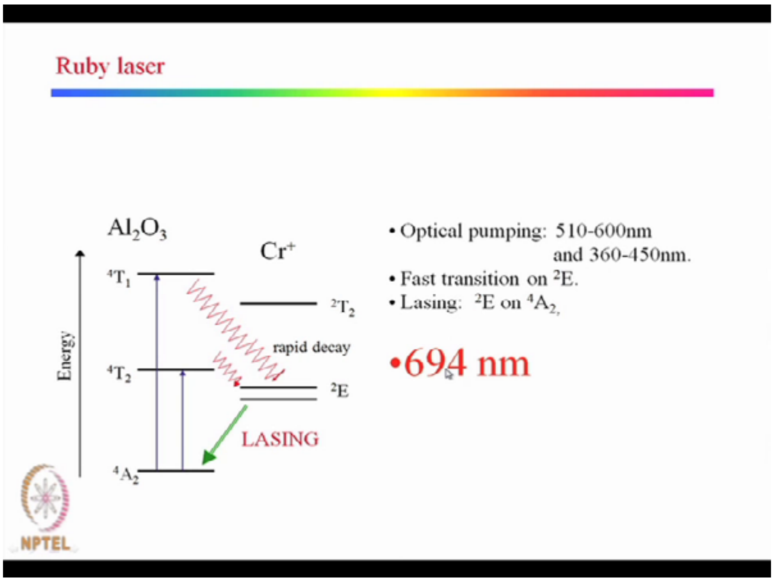

And this is the schematic of the levels; that is, you know these are the level and lasing occurs over here and its frequency is 694 nanometre. An optical pumping is done in this region and lasing occurs in 694.

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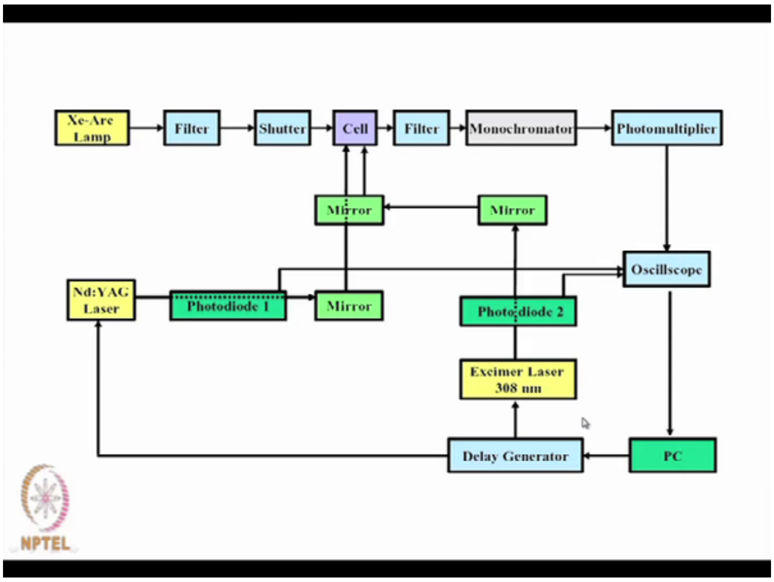

Now, we will come to the actual discussion of this laser flash photolysis. It is the modified version of your just flash photolysis that in this case, in place of flash light, laser light is used; laser source is used, light amplification by stimulated emission of radiation. So, here what is happening is that, this is your sample where your molecules are there. This is xenon arc lamp that is used for your probe beam. It is a weak; it is not as you know intense as your laser.

So, what is happening is that you have got your cell over here having molecules, xenon arc lamp, there is a filter that filters the unnecessary radiation or may be filter to select the frequencies for your probe beam. There is a shutter which may be sometimes shuts off your radiation. This is your cell and filter because this is your probe beam.

So, after the cell, there is a filter to select the specific frequency and then mono-chromator to further sub divide the frequencies, and then there is a detector called the photo multiplier. The signal from photo multiplier is given to the oscilloscope for digitization, then to PC. And here the excitation source; excitation source means I mean the molecules are fast. They have to be excited or maybe they will be given energy, so that further molecule, I mean further reactions can take place.

So, it is a four level Nd-yag laser. Then this four level Nd-yag, light is fed into a mirror, then you know another mirror, then to this to the cell that that initiates the reaction. This mirror is a partially transmitting and partially reflecting mirror at some specific angle. So, any way.

So, this light is falling on the cell, it generates the excited n symbol of molecules and then what happens is that the original xenon arc; the moment this is laser is falling on your sample, a portion of your Nd-yag laser light is fed into photodiode to turn on the oscilloscope; turn on the oscilloscope means that time the oscilloscope will accept the signal from your photomultiplier because photomultiplier is already on. The moment laser light falls on; a portion of that light is triggering the photodiode to trigger the oscilloscope so that oscilloscope gets the signal and then this signal is fed to the PC for generating you know a decay pattern like this.

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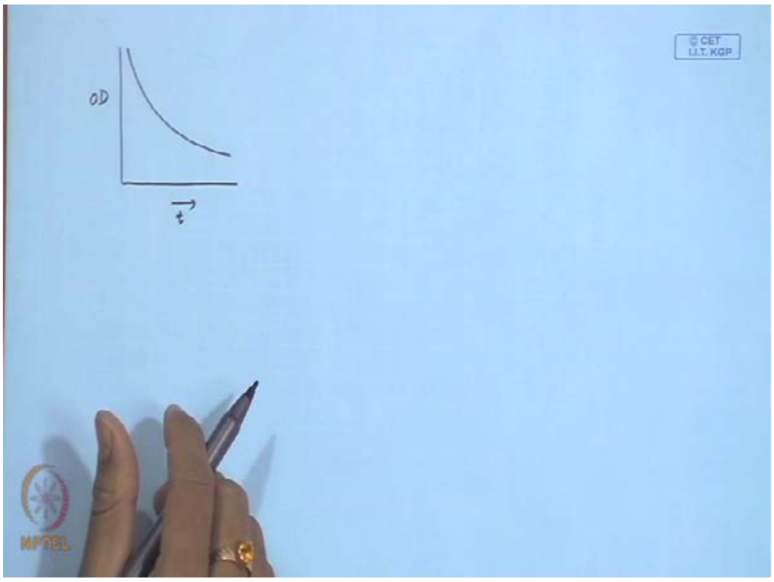

This is the decay pattern. This is your OD; optical density as a function of time. So, this will analysing this decay profile, I mean will get us the time constants and you know decay factors. So, in a typical example, you know this is your you know other case this is a another you know simplified description that this is your xenon arc lamp, this is your detector, and this is your reaction vessel.

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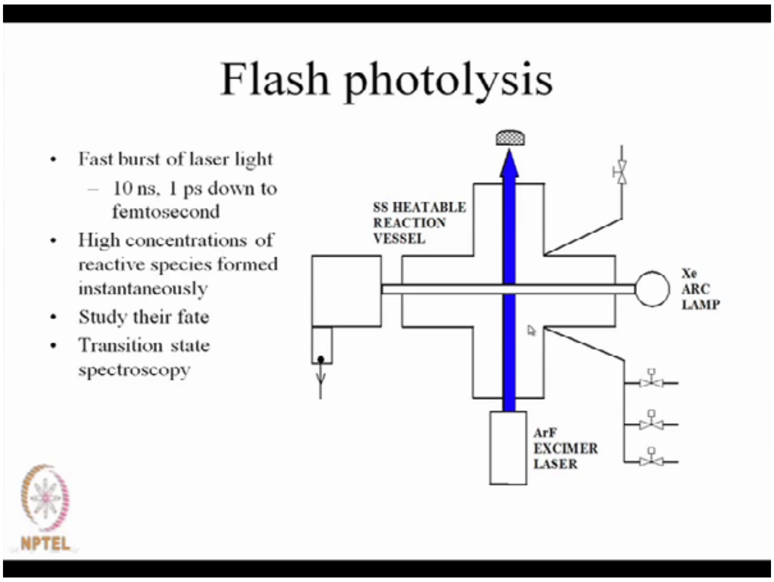

It may be heated or it may not be heated, and this is your laser light so that they are in perpendicular geometry; that is, your probe beam and the laser beam is perpendicular geometry in some cases because you see, there is a little interaction area that a little portion of your active I mean photo excited molecules are detected by your xenon arc you know this beam.

So, that is why, now a days, it is a perpendicular geometry. This is your laser, this y and this y is your probe beam, but other geometries are possible. That may be this is your probe beam, this is your sample, and this is your lasing; laser light. So, that the interaction area I mean is a little more. So, you can get better signal.

So, depending on your need, whether this sample is absorbing or not, you can choose the geometry of interaction, may be for your laser flash photolysis, it may be a perpendicular geometry or may be a almost collinear geometry. In some cases, may be the angle can be further reduced also.

So, what is happening is that let us have a concrete example that let us take benzo-phenone. It is a widely studied molecule. ((No audio from 44:32 to 44:48))

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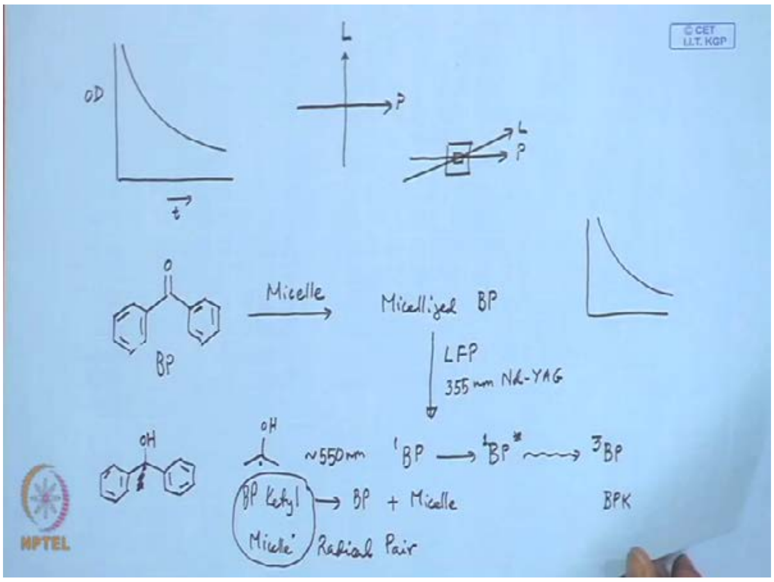

So, what happens that in a micelle medium, if we if we solubilise this benzophenone in c t a b micelle or maybe s d s micelle, it gets solubilised. So, micellized benzophenone. So, micellized benzophenone; then if this micellized benzophenone is excited, it is excited with say a laser source, I mean it is flash photolysis; I am talking about laser flash photolysis LFP, and the frequency is say 355 nanometre of Nd-yag. So, BP will go to BP star, similar b p star excited. This is also this is ground one. Then it will go to BP triplet, then this triplet benzophenone will abstract one hydrogen from micelle producing benzophenone ketyl. What is that benzophenone ketyl is this, benzophenone ketyl. ((No audio from 46:36 to 46:48))

So, benzophenone ketyl radical. So, it is like here, one hydrogen, one hydrogen and may be like that. So, here or may be like I mean it is better to write in this way. So, this hydrogen may be here, dot over here. So, this way. So, this dot over here so; that means, so, we can follow this ketyl 1, we can follow this ketyl 1 like it has got a specific absorbance at say around 550. So, around 550 nanometer, it will absorb.

So, if we monitor at monitoring wavelength is 550; that is, if we put the monochromator, this monochromator I mean at 550 nanometer, and then take the signal, will be getting you know this decay of the benzophenone ketyl.

So, this way, we can follow, we can follow the reaction in the excited state using this technique which is called your flash photolysis technique, and this is possible only when you know when your excitation like Nd-yag source or maybe your flash light is there. If there is no flash light, then the excited benzophenone will not be produced to do this ketyl one.

So, therefore, it is very important it is very important and also one important point; this one dot is over here and the other dot is on micelle side, and then what will happen with time? Again this hydrogen is given back to the micelle may be some cases; if it does not undergo further reaction, this hydrogen will be given back to your micelle. So, benzophenone BP ketyl will produce BP plus your micelle.

So, benzophenone ketyl and your micelle dot is called a radical pair is called a radical pair. That is why this (( )) and also this radical pair can undergo several reactions which are very which are very interesting and this radical pair will since it is radical pair, so, radical pair can have radical pair can have you know singlet state, singlet situation or may be triplet situation depending on depending on their spin arrangement.

So, and in presence of some external magnetic field, in presence of some external magnetic field, you can expect you know a modulation of their spin state. So, it is very interesting you know, may be in later part of our of our discussion, may be in next lecture, we can we can talk about this you know behaviour of this spin pair, I mean radical pair as a function of time in presence of an external magnetic field.

So, this will be interesting and radical reactions are very interesting anyway. So, I will talk about this radical pair mechanism may be in the next lecture, but let us try to finish off this part. Therefore, we do flash photolysis laser flash photolysis and you know study this fast reaction may be which happens in microsecond or may be in nanosecond time scale. So, this is a typical photograph or I mean description for your flash photolysis.

So, with flash photolysis, we can you know detect and specially laser flash photolysis, when absorption is less, you do not have much signal, then if you use a high intensity light source like laser, if you use a high intensity light source with laser, then you generate a finite or definite population of your excited n symbol and you know you can expect more signal.

Therefore, flash photolysis can be a very useful, specially laser flash photolysis nowadays can be useful and selection of excitation source or pump source is very important. So, you pump energy into the system and then do your study. So, selection of excitation source is very important. So, you excite your sample and then you do further action.

So, excitation source in the in terms that here in case of benzophenone, we have used 335. May be in other case, you can use 532 nanometer or maybe IR radiation or may be a 266 nanometer. So, and now a days we have got many choices for selection of your excitation source to initiate the reaction. Therefore, flash photolysis and laser flash photolysis is tremendously important tool for studying you know transients their fate.

So, with this, we will conclude today. So, in the next lecture, we will talk about this spin chemistry a little bit, give you an idea about what is going on with this radical pair case, I mean this spin chemistry can be or spin dynamics or magneto kinetics; it is called also called the magneto kinetics that that can be followed using a laser flash photolysis technique. So, we will discuss that in the in the next lecture. Till then that is all for this lecture. Till then, have a nice time. Thank you.