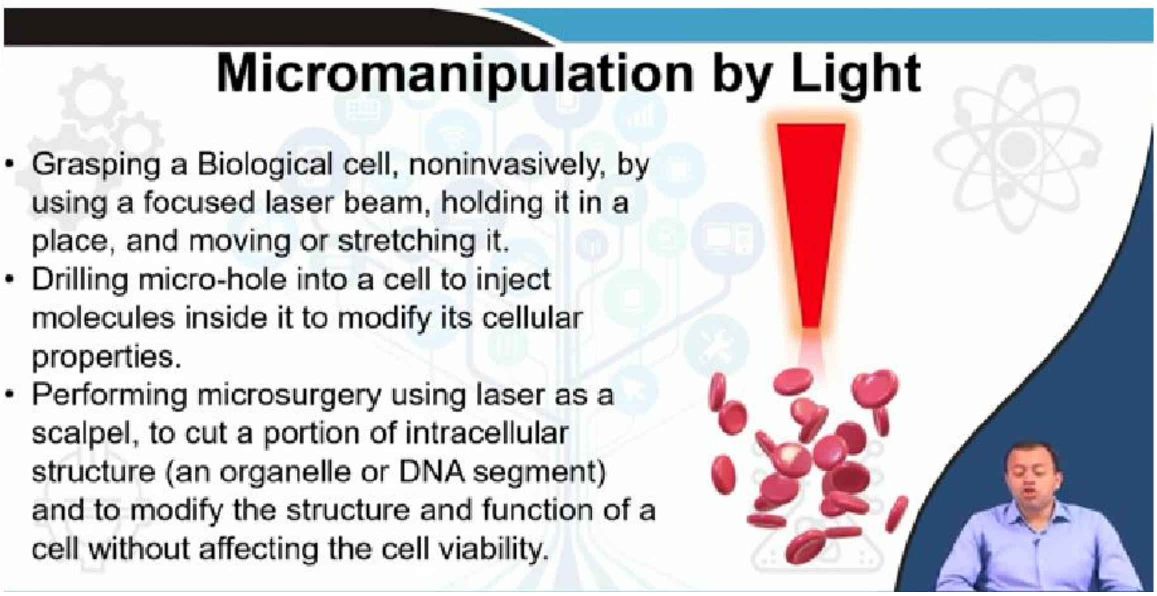
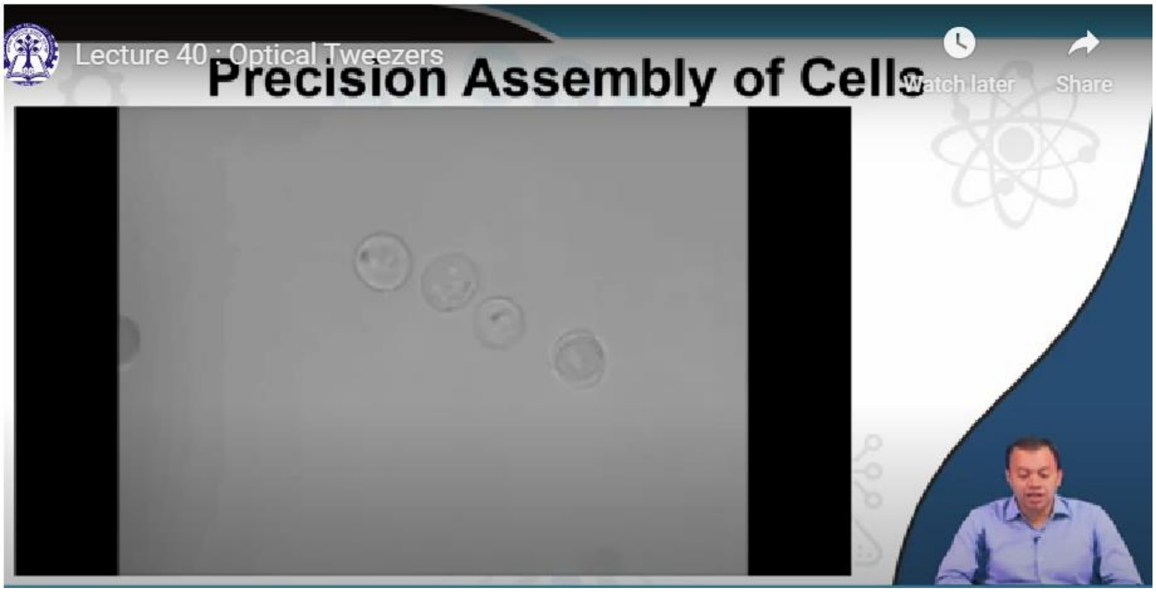
Nanobiophotonics: Touching Our Daily Life
Professor. Basudev Lahiri
Department of Electronics and Electrical Communication Engineering
Indian Institute of Technology, Kharagpur
Lecture No. 40
Optical Tweezers

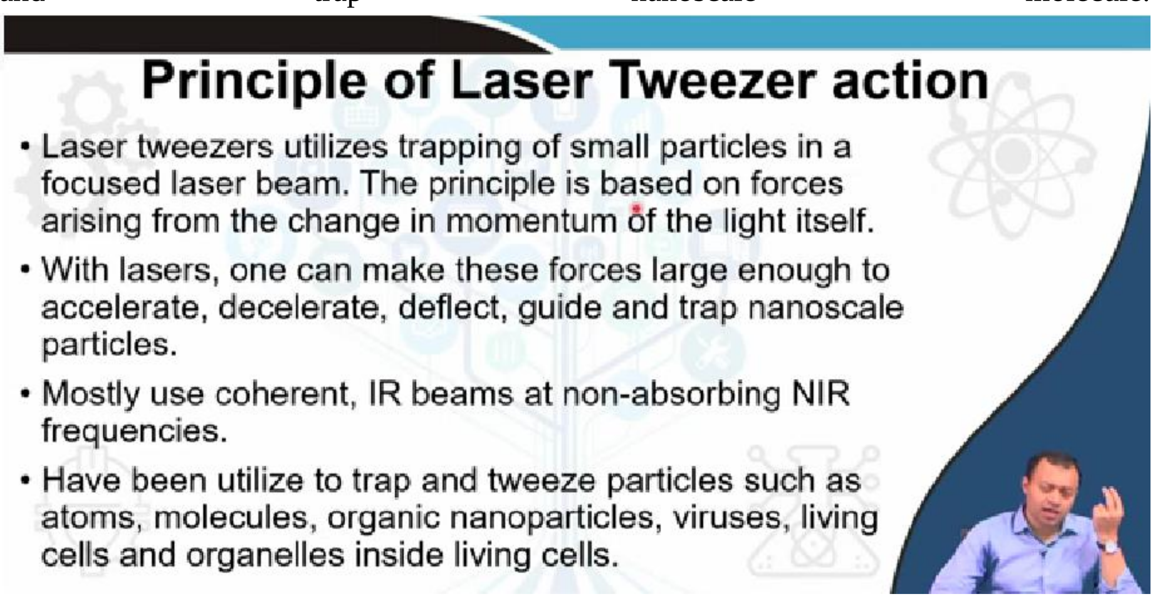
Welcome back. We are at the last leg of quantum biophotonics that is module number 8 and today I am going to tell something very interesting which is called optical tweezer. Do you think light has any force and enough force to manipulate nanoscale objects? Meaning simply can you use light to lift up lift up pick up some particles. Turns out actually you can especially in case of biological materials biological materials which are very small and you can manipulate their movement using light. So, micromanipulation by light is a very hot topic in which you can utilize light to grasp a biological cell noninvasively using a focused laser beam. You can hold it, you can move it, you can stretch it.



You can also utilize light to drill micro holes inside individual cells and thereby of course, perform microsurgery. Apart from these two topics in today's lecture we are mostly interested in how to grasp a biological cell using light. I have a video for you to show. So, see this is the dance of the cells.



All cells are being assembled they are made to move they are made to rotate these are individual cells 4 cells you are seeing in the computer screen and they are being made to move at specific direction you bring in additional cells and all of these are happening under the influence of light. There are no charge particles associated with it there is no mechanical application there is no tweezer there is no pH or pressure or anything like that it is simply it is simply the movement of the cells the assembly of the cells under the influence of light and that is precisely what we call as optical tweezers using light you make cells move into specific direction you assemble them. So, what is the idea behind it? So, the principle of laser tweezing action is that laser tweezer utilizes trapping of small particles in a focused laser beam. You use a laser beam you focused it to a very very precise area and several forces enact upon that particular area where light is being focused. With lasers one can make these forces large enough to accelerate decelerate deflect guide and trap nanoscale molecule.

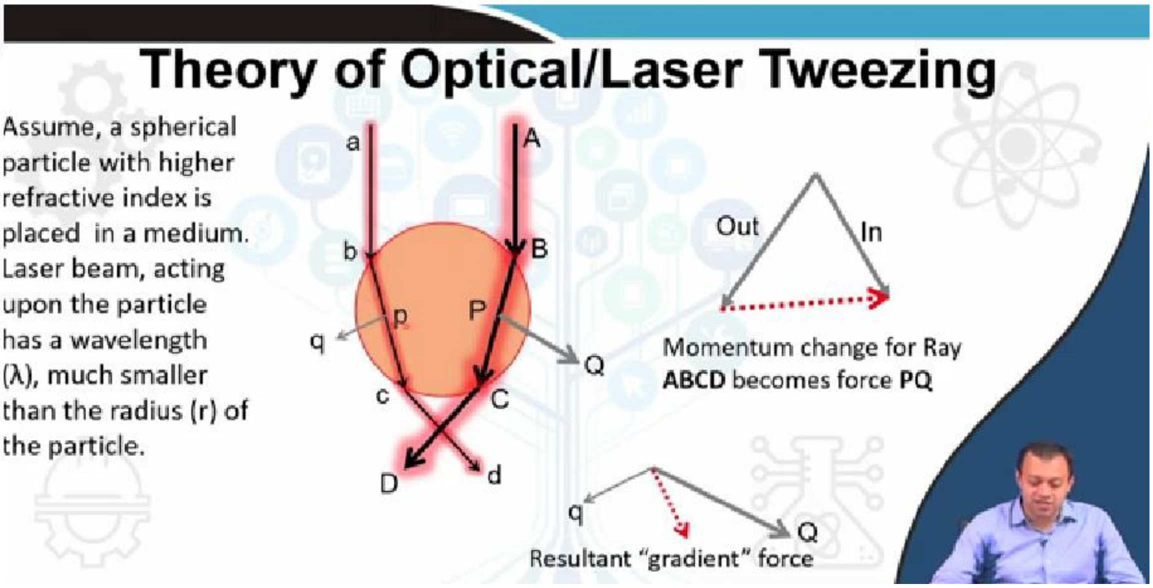


We mostly use coherent infrared beams and non-absorbing this non-absorbing is very important near infrared frequencies it has been utilized to trap and twist particles. What does this mean? So, let us understand the very principle of optical tweezers laser light contains millions of photons. Photons have linear momentum which changes as the photon change direction yeah. Whenever photon particles move go from a rarer medium to a denser medium yeah rarer medium to a denser medium refractive index change occurs you by this time you know all about refractive index. So, the photon has a different direction positive or negative it moves in a different direction.

So, change of direction meaning change of momentum you know mass into velocity momentum is a vector quantity. So, the linear momentum which change as photon changes direction the laws of conservation of momentum says that the total momentum has to be conserved. So, the difference between initial and final momentum is transferred to the particle and is responsible for the appearance of a force. So, force is rate of change of momentum with respect to time photon has a momentum it goes from rarer medium to denser medium according to Snell's law its direction changes its direction changes direction means the momentum changes, but the overall momentum of the whole process has to be same. So, rate of change of momentum this rate of change of momentum is converted into force and that force is inserted into the particle.

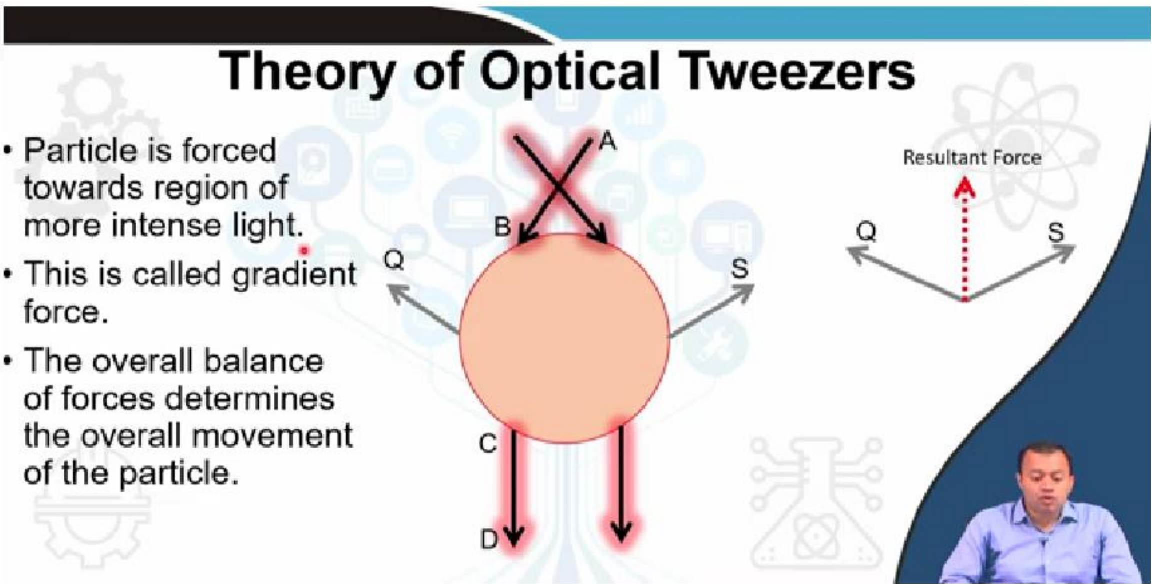
This is mass into velocity simple Newtonian physics P is momentum mass into velocity mass into velocity with respect to time what is velocity divided by time acceleration yes. Velocity divided by time is acceleration velocity is meter by per second acceleration is meter per second square g 9.8 meter per second square. So, this is mass into velocity divided by time it is mass into acceleration then because velocity by time is acceleration and what is mass into acceleration Newton's second law of motion the force of a body force inserted on a body is directly proportional to the product of mass into acceleration. So, force so, you have a force whenever light travels inside a body from a rarer medium to a denser medium it changes its direction, but obviously, this force is negligible few pico Newton few pico Newton.

So, most of the time you are simply ignoring it a very very small amount of pico Newton is inserted femto Newton is inserted whenever light enters from lower level from a rarer medium to a denser medium pico Newton force is not enough to do any specific damage anywhere except in nano materials except it materials whose size are 1 nanometer 2 nanometer 3 nanometer what are the weight of those materials nano particles what is the weight what is the mass of individual cell how many grams do you think one cell measure what is the weight of one of your red blood cell what is the weight of one of your DNA yeah few pico gram few femto gram few nano gram. So, will a force of few pico Newton be able to lift a mass of few pico gram that is exactly what is happening that is exactly what is happening in laser tweezer. So, assume you have a



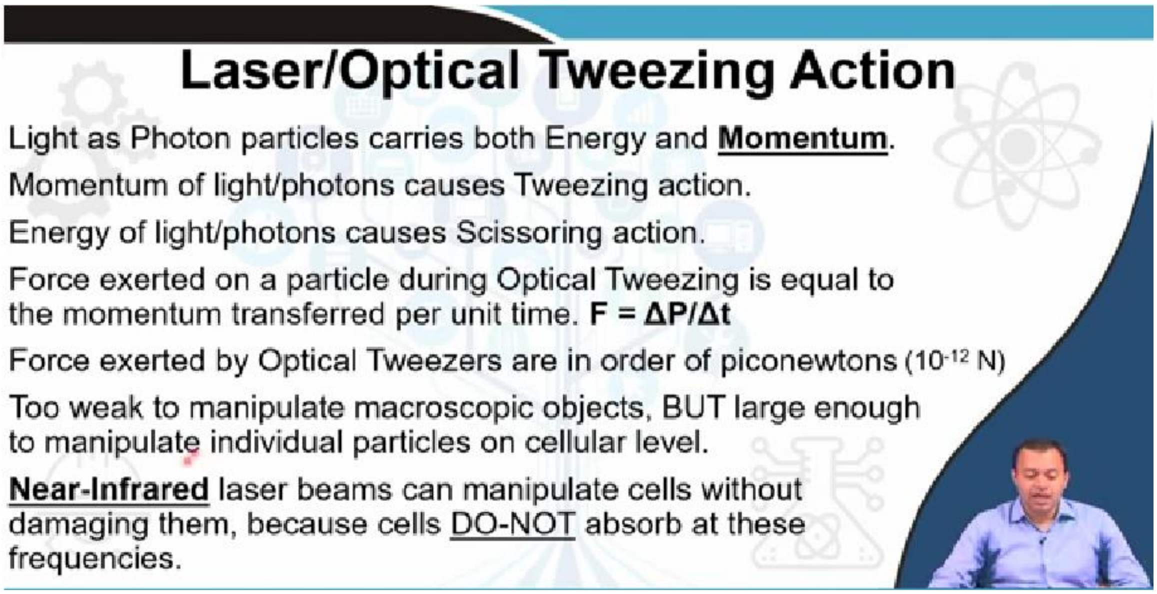
spherical sphere of few nano gram weight you have two laser lights falling onto it this is a smaller intensity this is a higher intensity they should not be absorbed here the exact opposite they should not be absorbed and they should be transmitted as they transmit their change of direction happens because of change of refractive index light moves from rarer medium to denser medium. So, change in direction happens this change in direction exerts a particular force the overall conservation of momentum happens the conservation of momentum results in the formation the total momentum is conserved the difference between initial and final momentum is transferred to the particle and is responsible for the appearance of the force it produces a force in q direction you have another photon coming up higher intensity photon capital A and capital B it also goes through similar paths and produces are overall fourth force of q now you know you have a small q you have a large q combination of force factor multiplication this will take you in minus x direction this will take you in plus x direction the overall result depending on the magnitude of this particular force versus this particular force you have a gradient force you have a gradient force moment change for a a b c d is given by this you have a resultant gradient force this is the direction in which a particular particle this particular sphere of nano nano scale size nano scale weight will move. So, this laser being acting upon the particle has a wavelength much smaller than the radius of the particle.

So, here the wavelength has to be much much smaller than the size of the particle and it should not be absorbing if it absorbs then heat is generated if heat is generated no output light is coming up then the force and everything goes somewhere else the photon is consumed electron moves up the molecule starts their own dancing and that is a different problem things happen internally inside the molecule we do not want anything internal to happen we want this entire sphere entire molecule to move entire particle to move entire cell to move we do not want a particular area within the cell to heat up yeah or emit light I do not know you just want the entire thing to move. So, you insert group of lights group of frequency group of photons which particular frequency that are not not absorbed that simply simply changes direction change of direction result in change of momentum rate of change of momentum is force that is the enough force under the influence of force any body moves you are moving your particle simple. So, the particle

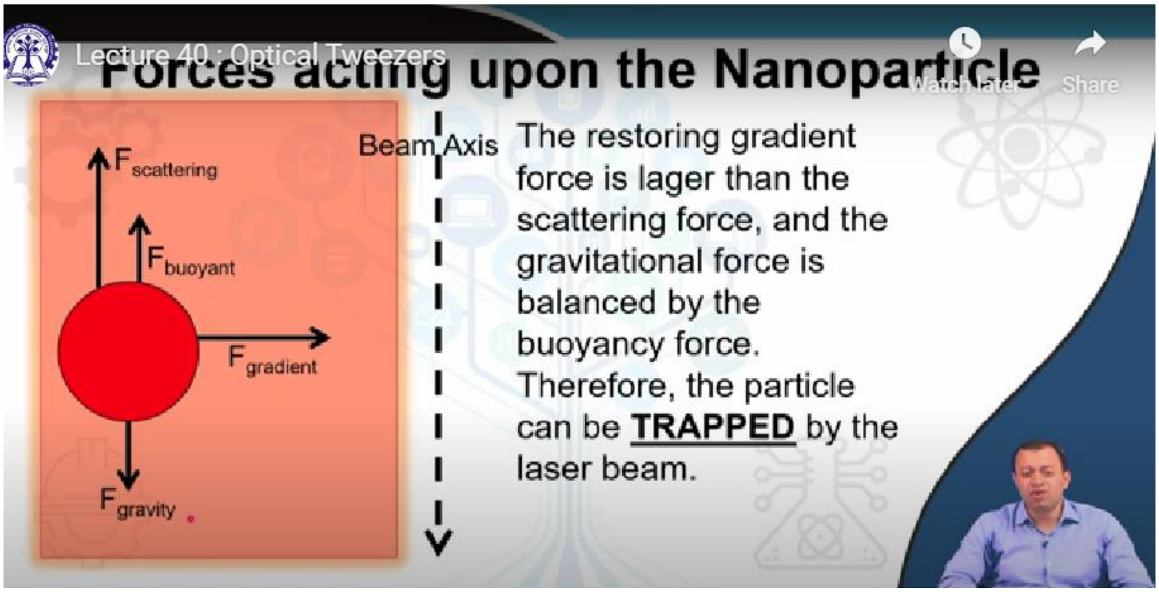


is forced towards the region of more intense light this is called gradient force the overall balance of force determines the overall movement of the particle. So, this is moving in this direction this is moving in this direction you have Q and S a combination of Q and S in whatever direction it is will move the particle you control the movement of the laser light control the movement of the photon through the particle in different direction you have a resultant force the resultant force allow you to manipulate the direction of your sphere what if what if these two light beams A and B are different direction opposite direction, but of exact same intensity exact same power everything same opposite direction one is going in x one is going in minus x what then I E Q and S the force exerted are also same, but in two different direction what will happen then what if some person pulls you in east and another person pulls you in west where will you go you will stand still both forces are balance each other. Obviously, it can break apart, but if you are clever enough if you are not inserting that amount of force when two of your friends is pulling you one is pulling you in the east one of you pulling one of them pulling you in the west direction where will you go you are suspended you are suspended you are stuck you are simply stuck in a particular position we can thereby optically optically make a spherical cell or something like that stuck suspended in thin air or a thin fluid simply by having two equal, but opposite forces into different direction it will simply suspend in thin air it will float it will suspend in thin air like you see in some sort of a magic show something is floating in here something is suspended in here magic.

Well actually science the overall balance of forces determines the overall movement of the particle if the balance is same or opposite and equal there will be 0 movement you have suspended you have stuck you have stuck the particle in thin air thin liquid. So, again light as photon particle carries both energy and momentum of light and



photon causes tweezing action energy of light photon causing scissoring action it can cut it off force exerted on particle during optical tweezing is equal to the momentum transfer per unit time force is equal to momentum per unit time force exerted by optical tweezers are of pico newton 10 to the power minus 12 newton too weak to manipulate macroscopic object, but large enough to manipulate individual particles on cellular level near infrared laser beams can manipulate cells without damaging them because cells do not absorb at this frequency particular frequencies have to be figured out where the cell is not absorbing if it is absorbing then you have heated up the cell and the cell is going bad. So, what are the force if you have put in a liquid medium is usually fluidic medium

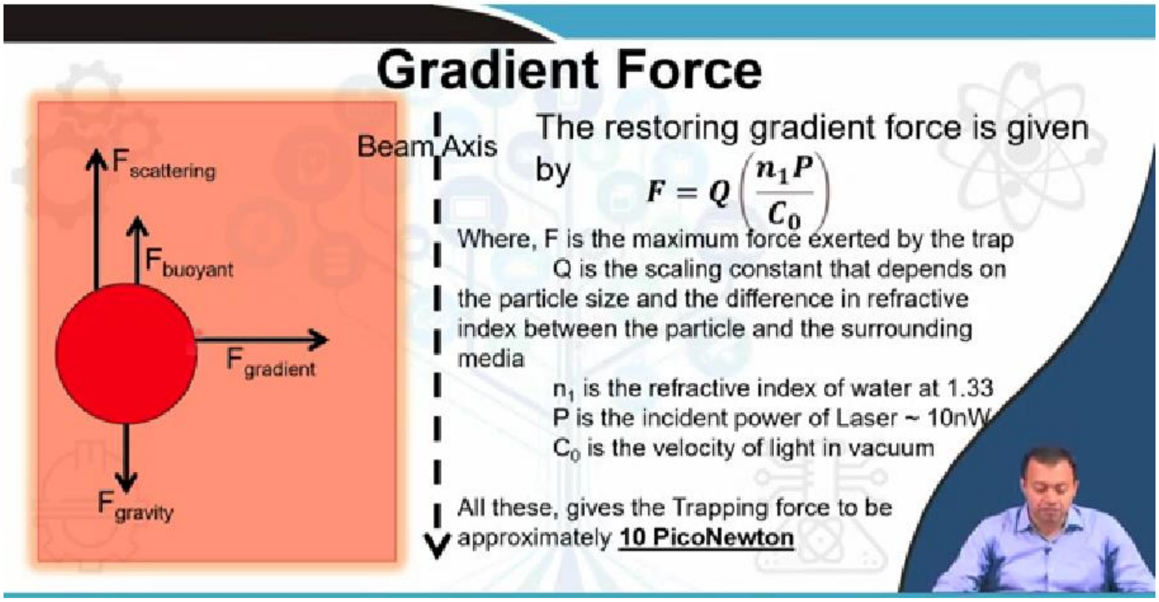


water is a much better instead of suspending something in air it is easier to suspend something in water. So, there are several forces along with the light force that will enact upon the particle that you want to tweeze there will obviously, be gravity anything is affected by gravity. So, gravity will pull it down there will be the buoyant force any fluid has a buoyant force argument is principle and what not some of the frequency of light will come here and it will be scattered it will simply be reflected.

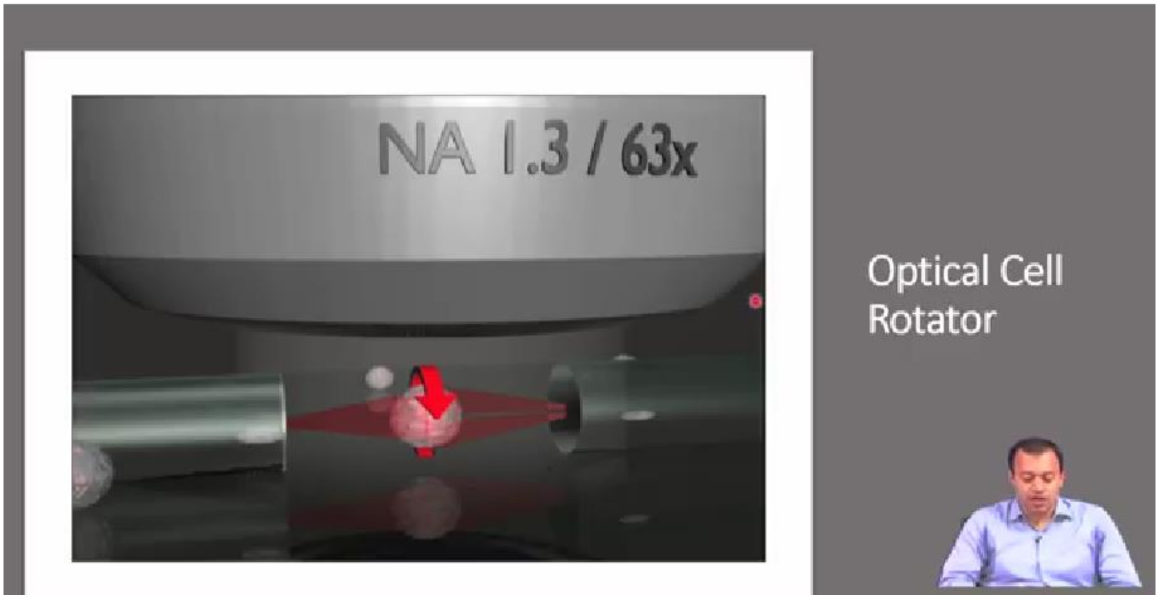
So, so this this this this light will not penetrate they will simply be reflected or scattered out. So, that will have something and then the gradient force then the overall gradient force because of the presence of the light beams that are that are crisscrossing it that is transmitting it. A combination of all of these forces in different direction plus minus if this is minus then this is plus then this is something else the combination of all of these forces allows you to control the direction of the movement of the particle. Yes, the force of gravity on it will be obviously, there will obviously, be there, but you are putting it in some sort of a you are trying to balance the gravitational force by putting it into some kind of a fluidic medium water as I said for it to be buoyant. So, that the buoyant force allows it to float and not sink into the bottom of the surface like anything floats.

So, buoyant force is there to cancel gravity there will be scattering and then there will be a gradient you are clever enough with the gradient and you have chosen your particle carefully you have simply trapped it you have simply suspended it you are simply manipulating it like I show you in the video in few slides before. The restoring gradient force is larger than the scattering force and the gravitational force is balanced by the buoyancy force therefore, the particle can be trapped by the laser beam. So, the scattering force the is is that the gradient force is restoring gradient force is larger than the scattering force and the gravitational force is balanced by the buoyancy ok, opposite movement any

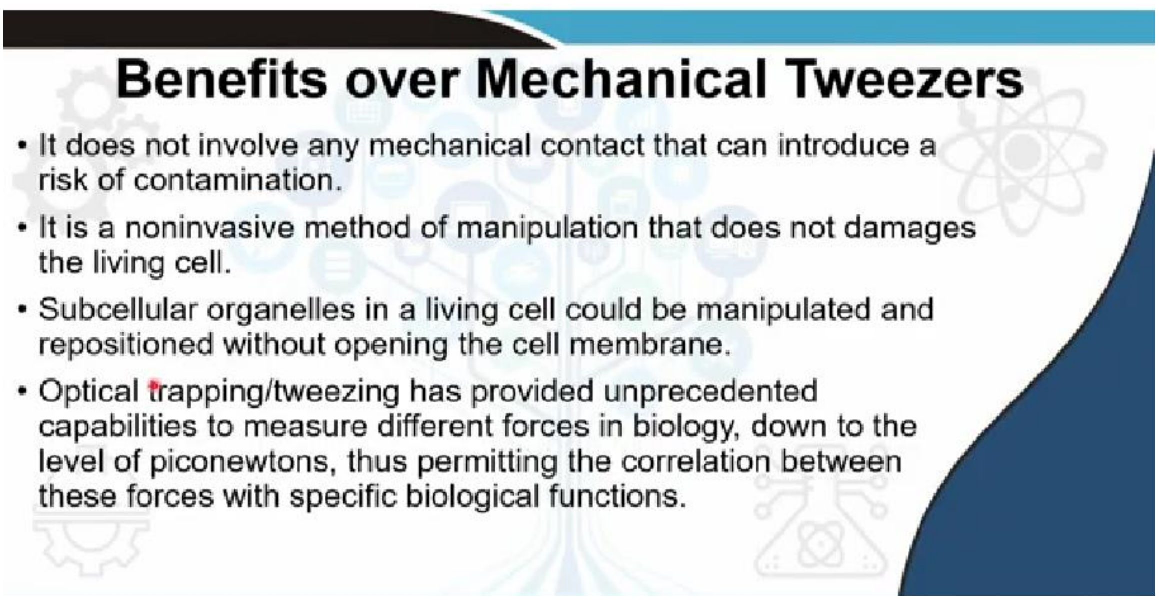
any any fluid does it air also does it, but we are too heavy for it, but some animals some insects can glide through air. So, the restoring gradient force is given by this particle. So, the value the formula for the gradient force the restoring gradient force under whose influence the particle moves are given by this particular formula.



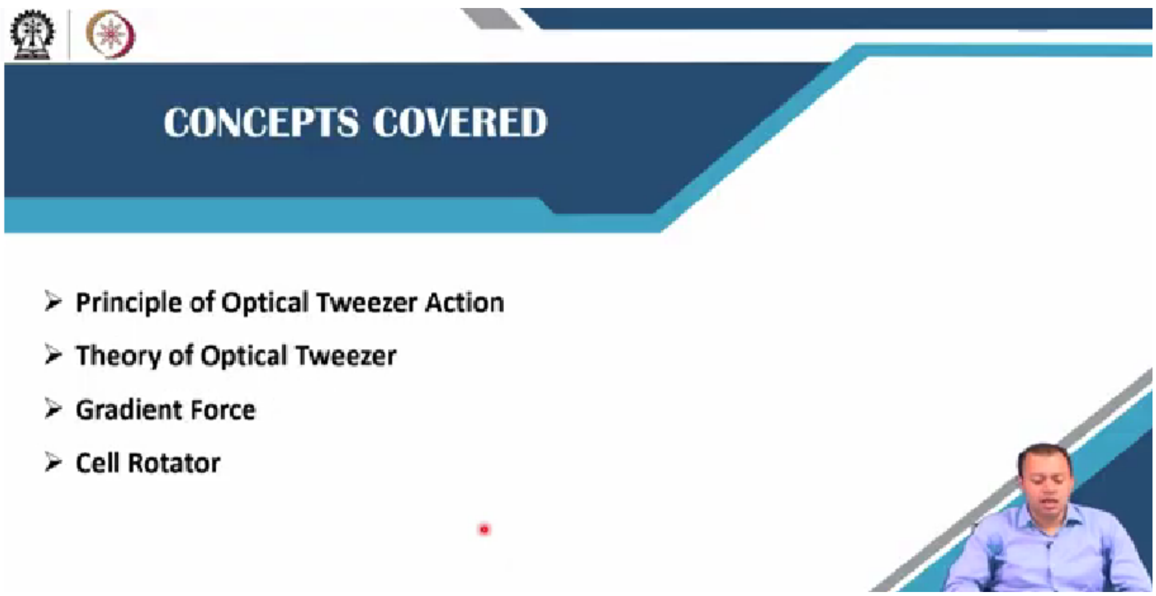
If is the maximum force exerted by the trap q is the scaling constant that depends on the particle size and the difference in refractive index between the particle and the surrounding media. So, this has a particular refractive index this is a particular refractive index difference between that will help you give q n 1 is the refractive index of water 1.33 p is the incident power of the laser usually 10 nano watt see how low these powers are c naught is the velocity of light in power all these gives the trapping force the tweezing force to be approximately 10 pico newton 10 into 10 to the power minus 12 newton you will have no effect on it, but a single cell of your body might have effect on it. If you put it in some kind of a buoyancy medium and put it like this using the gradient force that you can calculate you can put the sample in with a specific refractive index a particular power of the laser particular frequency of the laser particular energy of the laser on your hand you have got yourself a optical tweezer something that could manipulate simply a nanoscale object without touching it you are not touching the material at all it is noninvasively manipulating individual particles right. So, this is the optical cell rotator I do not think the animation will work, but all you are doing is moving the axis of the laser beam this is your microscope the laser particle the the particle is just below it this is the laser source and the laser is moving and you have suspended your you have trapped this cell and you are rotating it.



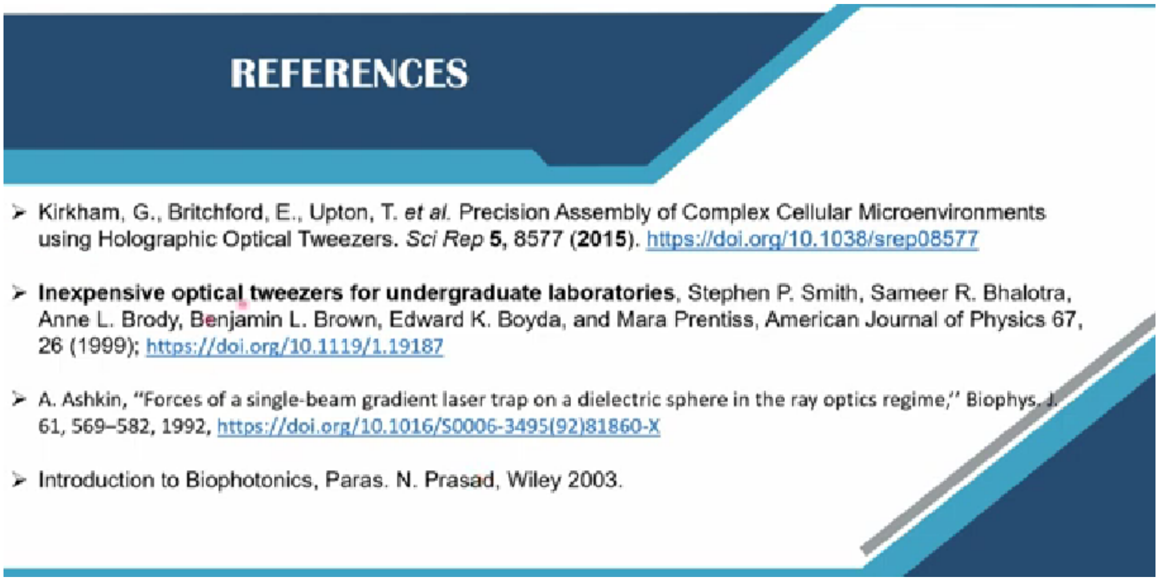
Usually in a microscope when you are measuring or when you are imaging you are only getting the top surface image, but what if you want to see it in a full 3D rotatory image you do it like that and you have your answer you do it like that you have your answer the cell the lasers axis is rotated this gradient force this gradient force is is is is is being rotated. So, the sample also will rotate on its axis this is the optical cell rotator there are 1001 benefits over mechanical tweezer most importantly you are not touching it thereby



not contaminating it they do not involve any mechanical contact can introduce the risk of contamination it is a noninvasive method of manipulation that does not damages the living cell subcellular organelles in living cell would be manipulated and reposition without opening the cell membrane optical trapping tweezing has provided unprecedented capabilities to measure different forces in biology down to the level of pico newtons thus permitting the correlation between these forces with specific biological function. When a virus is attacking a particular cell attaching itself with a particular area of the cell the spike protein is attaching itself with a particular area of the cell there is some force involved right there is some force a mechanical force that is being by which it is capturing a particular area of the cell you use your laser to you know trap a particular virus or a group of particular virus and and and and take it out and if you understand you have measured the force by which a cell is being attacked like two magnets they are holding, but you bring in another force to pull it apart you have calculated the force you have understood the force now you produce some sort of an environment inside the cell. So, that the force is disturbed you can easily disturb the force a magnetic field force I am just giving an analogy heat it up etcetera etcetera as long as it survives you break the force you do some kind of a condition charge anything anything and you are able to expel the virus from that particular cellular environment think about how technology is going in what particular direction it is going. So, these



are the concepts that I covered in today's lecture theory of optical tweezer optical tweezer is very easy to make all you need microscope and bunch of lasers within few lakh rupees Indian you can get an optical tweezer already done.
So, based on that you can get it. So, I I heard certain colleges if you have the capacity to utilize a optical tweezer make it up the formula or the mechanism to create optical tweezer is available in various social media it is very easy all you have to do is focus a laser beam and the optical the microscopes focus has to be aligned and and and it is mostly easy and you can thereby do wonderful things all of these could be said as quantum technologies.



So, with this I ask you to look into these papers as my reference where they have inexpensive this is a particular interesting topic inexpensive optical tweezer for undergraduate laboratories they give you step by step method of how to if you have an existing microscope in your laboratory just by having few LED based laser systems you can create a you can create an optical tweezer in your lab right. So, I will see you in the next class. Thank you very much.