Introduction to Fluid Mechanics
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Lecture - 01
Motivation of studying fluid mechanics

Welcome to the course of Introduction to Fluid Mechanics and Fluid Engineering. This particular course will be spread into various lectures, and today we will have the Lecture 1. Before going into the course I think what is important for all of us, is to recognize that there is a motivation behind learning fluid mechanics. So, we will first go through a few examples that will illustrate us the motivation, and then we will get in to the fundamental topics that we intend to cover.

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Now, fluid mechanics is almost everywhere in human life. And let me give you some examples to illustrate what are the important applications of fluid mechanics. Let us think of automobiles: when we think of automobiles, I mean automobiles are the basic elements which many times motivate young minds to study fluid mechanics. And really there is a whole lot of challenge in designing automobiles based on the requirements of fluid mechanics, based on the constraints given by some considerations of fluid mechanics.

For example: if you want to design a car, design the shape of a car. The shape of a car should be such that it should minimize the drag force or the resistance force. We will come in to what is drag force and how it can be minimized later on in our course, but it gives one of the important motivations.

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Now when we think of vehicles, not just automobiles which run on land are important but we have also watercrafts, boats, and ships. And as you can see here in these visualizations that there can be nice flow patterns, very interesting flow patterns that can be generated as the watercrafts are propelling in water. And there can be again a whole lot of analysis that can go on in the background to make sure that one can minimize the resistances against the motion of the watercraft.

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Now, we come to the third example which deals with spacecrafts. Spacecraft are the most fascinating of all the examples that we intend to highlight. And you can clearly see that; let us say that when a aircraft is taking off or landing or when a space shuttle is moving. So, you can see nice visualization of flow and this nice visualization of flow is a very natural way of visualizing the flow. So, what is happening is that the smokes or products of combustion are coming out, and these are basically highlighting the flow patterns that are surrounding the aircraft or the spacecraft.

So, this is a very nice way of visualizing the flow not just qualitatively but one can get a quantitative insight on the details of the fluid flow that is taking place. And again, the very basic principles of motion of these aircrafts or spacecrafts rely on fluid mechanics. Many times again the issue of not just a drag force but a lift force that is important, because the lift force pulls the aircraft up in the sky. And many times one may need to use fundamental considerations like say law of conservation of linear momentum and some other basic principles or Newton's Laws of Motion, and some modified versions of these which can be used for fluid flow analysis.

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Now, similar to the concept of flow around automobiles and watercrafts and aircrafts, we can have interesting interaction between fluid flow and sports balls. And all of us experience that sports balls under certain conditions can spin or can swing, and there is a interesting fluid dynamics that goes behind the swing of spin of sports balls. It is a very involved topic, and in one of the lectures later on in this course we will discuss in details about the sports wall dynamics.

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Coming to the material world, I mean in engineering we deal with lots of industries. And industries many times are basically comprising various plants power, plants and process plants for example. So, you can see that there can be interesting flow patterns that can be observed, because of emissions of products of combustion from the chimney. That you can see in one case and maybe also similar flows can be visualized in process plants as well, like effluent treatment plants.

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Now fluid dynamics; it is not just in the material world of automobiles, and power plants, and process plants like that. Fluid dynamics is there in nature, and it is such a beautiful pattern or gallery of patterns of fluid flow that can be visualized if we really observe nature in a vivid way. And what you can see here is that in tornadoes, in rivers, in raindrops, what interesting flow patterns can be observed.

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Now, nature is not just made of inanimate objects. There are animate objects, like animals and you can see interesting flow around butterfly, snake, fish, and all these are really giving rise to very intriguing fluid flow pattern which can be observed in nature.

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Now when we discuss about nature, I mean we basically come in to the domain of biological sciences and a life sciences. And one of the important follow ups is signs of human bodies or signs of living systems or medical science. The human body for example, is a paradise for fluid mechanist to make their own analysis for studying the respiratory system, pulmonary system, cardiovascular system, swimming of sperms and all these are very intricate. And if one gets a complete understanding of this it gives rise to not only a fundamental physical insight, but also maybe strategies to combat various life threatening diseases.

And, I will just give you one example to illustrate the complicacies involved, like let us think of flow of blood through arteries and veins. Like this is a very common thing in human body mechanics. Now, think of an analog in a industrial system, like flow of water through pipes. Now can you tell, what are the basic differences between flow of water through pipes and flow of blood through arteries and veins? You will immediately come up with some obvious differences like blood is a much more complex fluid than water, but the complexity of blood as the fluid is a not a mystery now I mean it is somewhat appreciated and understood not to the fullest extent, but to some extent it has been well understood.

But the problem is that it is not just the issue of blood as a complex fluid, but think of blood vessels. These blood vessels are flexible; their diameters vary with local blood pressure. And till now it is a mystery in fundamental science that how the diameter of a blood vessel should vary with locally with blood pressure. This is not yet fundamentally completely understood; I mean one can go through empirical formula to express this, but it is not yet fundamentally well understood.

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So, you can well appreciate that an apparently an elusively simple problem, like flow of blood through arteries and veins can he rise to very complicated considerations in fluid dynamics. Now coming from human body mechanics to something let us consider as an example of not so humanistic, like nuclear explosion. So, you can see an example like off the flow that is taking place, because of nuclear explosion in the view graph that is being presented.

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Then like when there is a fluid there is also an interacting structure that is interacting with the fluid. So, there is often a very interesting interaction between fluid and structure. And critical situations may occur when there is a fluid let us say wind blowing past a beach with imposed frequencies that impose frequency matches with the natural frequency of the structure. Then there is something called as resonance, and because of this resonance the structure may oscillate or vibrate vigorously.

And there can be failure of the structure. In this example the bridge has totally collapsed and eventually it is going to collapse in this view graph. And that collapsing of the bridge, collapsing of the structure is because of the intricate interaction between the fluid and the structure. So, fluid structure interaction is also a very important and interesting modern day topic.

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Let us come to more common day to day examples like food or drinks. Of course, we need to understand that; I mean this issue we will discuss later on. That sometimes it is very difficult to demarcate between a food and a drink right, whether it is a fluid or its a solid or it is something in between fluid and solid, these kind of questions come and hard demarcations are many times difficult.

For example gel like matters, now what we call them? Should we call them fluids, should we call them solids? I mean of course, there are very standard descriptions and theories to describe these matters, but these are important and interesting topics in fluid mechanics which deal with the constitutive behavior or the behavior of the substance as it is. And typically it belongs to the study of Rheology of fluid flows.

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Even something not so fluid: now looking in to this particular view graph that is being shown, can you tell what does it represent? Yes, you are correct; it is traffic. So, if you visualize the traffic from altitude you will see that the traffic in a typical city will be moving like this. So, traffic flow although it is not the physical flow of fluid has some resemblance with the physical flow of a fluid. And there is a lot of research that is currently going on and has in the past being going on in the area of traffic flow.

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Now, the issue is that should we study fluid mechanics just because there are so many applications in the industry, in the nature and so on. But sometimes we may study fluid mechanics just because we are fascinated with beautiful flow patterns. So, you can see these examples, these flow patterns which are being demonstrated here. These flow patterns are so interesting and so fascinating that if one is interested to study the structures of these flow patterns, demonstrate these flow patterns to experiments it is like fluid mechanics gives us a structured way of understanding this pattern.

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To summarize this discussion that we had had so far, we can conclude that fluid mechanics is everywhere. Fluid mechanics is not just in inanimate objects or in animals, but fluid mechanics is everywhere in the world. So, there is a lot of motivation in studying and understanding fluid mechanics.

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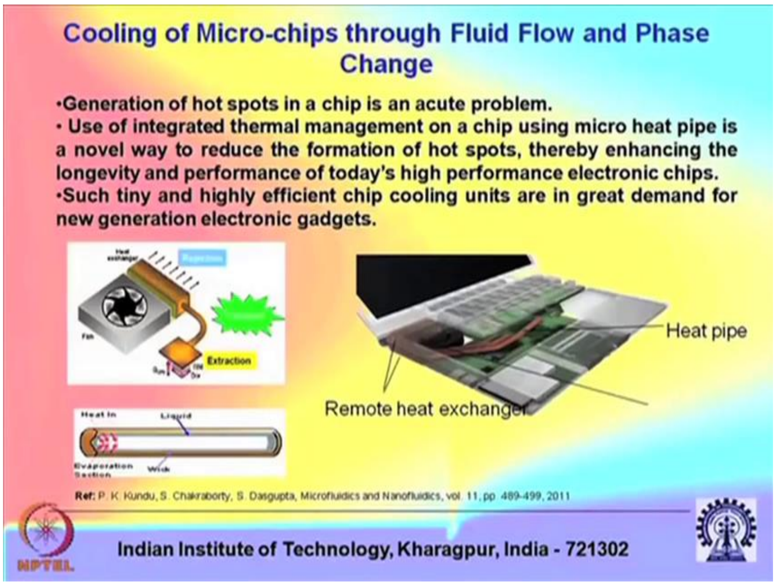

Now, when we say fluid mechanics is everywhere, and we have given certain examples. The examples that we have given so far are somewhat traditional. Now we can give some more examples where fluid mechanics in a different way is relevant for modern day applications. Like, the first example that I want to give you is cooling of microchips through fluid flow and phase change.

The motivation of this is as follows: as we have come to the modern era what we find is that the sizes of the electronic devices are getting smaller and smaller. Despite the fact that sizes of the electronic devices are getting smaller and smaller the power dissipation is not getting progressively reduced. So what it means is that the power then dissipation per unit volume is getting significantly increased, because of reduction in volume and that makes the devices overheated. So, you may not be surprised to know that many of the electronic devices actually fail not because of the failure in electronic design, but failure in thermal design. That is those materials cannot withstand that high temperature.

So, how can we address this? Of course, you may say that we can employ a fan. But yes, we have to understand that if we have a small miniaturized device, your entire parts purpose of miniaturization will be lost if you have a very small device and to cool that small device you require a large fan. So, you require a compatible cooling arrangement. So what you can do, you can for example employ various strategies. One particular strategy is you can employ change of phase. So, you can have a liquid which takes heat from hot spots of the electronic device and can change its phase. The liquid can flow through our micro channel which is a very small channel, a channel of the order of micro meter dimensions, and then when this liquid gets evaporated the evaporated fluid moves to a different place in the channel and can get condensed.

So, there can be an evaporation condensation simultaneously going on to complete the loop and this mechanism is used even industrial applications this is known as heat pipe. And in a miniaturized environment this is known as micro heat pipe. So, there is a lot of interesting fluid mechanics that goes behind. We do not have scope for discussing that at this moment, but it is just to let you know that these kinds of interesting applications do exist.

There is also another technology which is called as Droplet Based Microfluidics. So, what you can do? Basically you take small droplets, you arrange for small droplets and these droplets will go and sit on hot spots on the electronic device and absorb heat from that hot spot. So, it is very interesting to design the movement of droplets so that they can move in an optimal path. And in the shortest time they go and sit on the right hot spot and take away heat from that hot spot.

We have to understand that fluid dynamics is so interdisciplinary as a subject that it is not a subject just within the jurisdiction of mechanical engineering, chemical engineering, aerospace engineering, civil engineering like that. If you are interested to design an optimal path and make chips for transmission of the droplet according to that optimal path design then you require to interface with electrical engineers and computer scientists. So, it is really emerging as an interdisciplinary subject.

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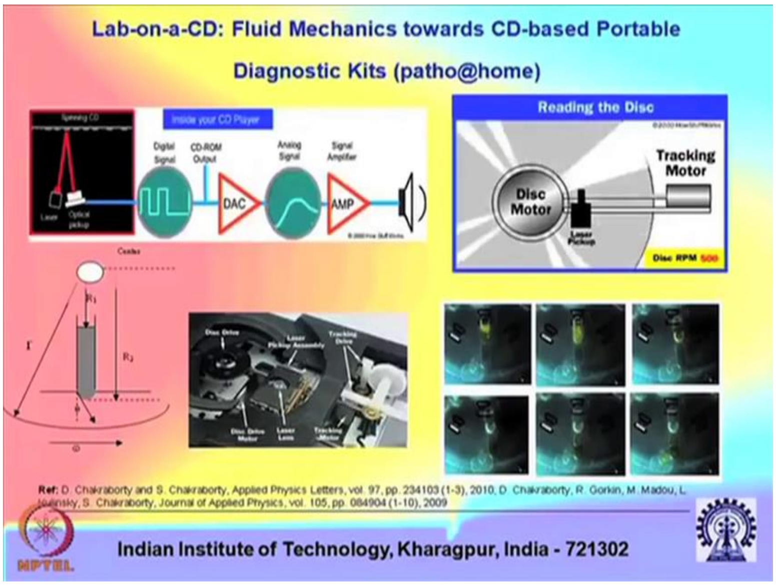

Now, I will give you a couple of; sorry, I will give you a couple of more interesting applications and these applications essentially deal with a health care engineering. Now what is health care engineering? Health care engineering is an interface of health care with engineering. And let us see that how fluid mechanics plays a role towards that.

So, in health care engineering many times what we require is rapid diagnosis of a disease. And this is a classical problem; it is a problem relevant in many countries especially in the underdeveloped countries. That let us say that a person is suspected to have a certain disease. Now the person cannot go to a pathological laboratory, because he or she does not have access to high class pathological laboratories. So, it takes time to take the blood sample, let us say as an example and that blood sample is tested in a sophisticated laboratory. By that time the result of that test comes and it is quite expensive to get the result of the test, this time consuming. And by the time the result of the test comes the patient may be under very serious condition.

As an alternative one can go for various technologies. So, one can have small devices which are called as lab-on-a-chip or a device which is like a rotating disk that is called as lab-on-a-CD. It is like the compact disc for external data storage in a computer. So, what we can do is, you can have micro channels or small channels are cut in the disk and you put a droplet of blood, just a small droplet of blood not a huge volume of blood drawn from the patient. And then you spin the disc in a small motor and that is the portable system so that can be taken to the patient itself this is called a point of care way of handling medical diagnostics.

And then this blood sample is dropped, and then within the channels there are various reactants, and because of reactions there can be a for example change of color of the blood sample. And a particular change of color can give rise to the indication of a particular disease. Here fluid mechanics comes in a big way, because you need to have a proper design of what is the rotational speed of the compact disc for most efficient transport of the blood sample. So this is one example, there can be several other examples given.

And then once the test result comes, immediately this test result can be conveyed to a medical doctor maybe through SMS in the mobile phone system. And then the medical doctors can immediately advice for a treatment. And this entire process can take place within a few minutes. So, it is very rapid, it is inexpensive, it is portable, and if this kind of system comes in to the market it can really solve some of the challenging problems in medical diagnostics in many places in the world.

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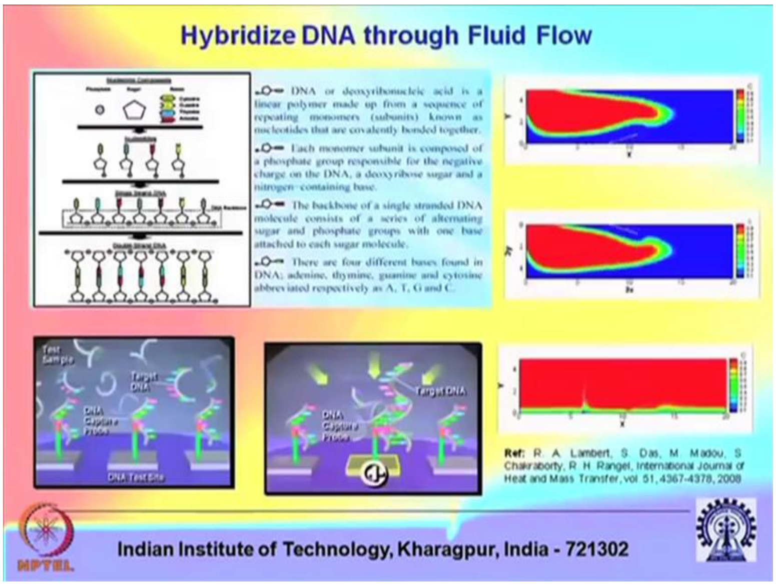

Another example like which is related to the medical sciences is DNA hybridization. And DNA hybridization basically refers to like, identification of a particular sequence of bases in a DNA which can indicate the existence of a certain disease. Like, all of us know that DNA is a linear polymer made up of a sequence of repeating units known as nucleotides. And each monomer is composed of a phosphate group which is schematically shown in the view graph, which is responsible for a negative charge on the DNA, deoxyribose sugar and a nitrogen containing base. So, there are four different bases found in DNA: A. T. C and G.

So, if you want to identify a particular disease it may be related to the sequence of base, a particular sequence of bases like A A T T G G C C like that. And it is known that A and T want to get combined with the help of hydrogen bond and G wants to get combined with C with the help of hydrogen bond. So, A is complementary to T, and G is complementary to C. So, if you want to identify whether a particular sequence of DNA bases is present in a DNA sample then what you can do, you can put a complement of that interrogating sequence on the wall of a small channel and pump a DNA sample with single strands.

So what you can do is that; first you break the cell, which is called a cell Lysis and bring the DNA out of it and then you heat the DNA sample so that double stranded DNA gets broken in to single strands. Then you pass the sample through a fluid flow. When you pass the sample through a fluid flow there is an interesting interaction between fluid dynamics and the transport of DNA. And that can control effectively that how fast you can achieve this hybridization reaction. And if you can achieve this hybridization reaction fast, then it is possible to get an answer whether a particular DNA sample base sequence is there in a DNA sample or not and a rapid diagnosis of certain diseases can be made.

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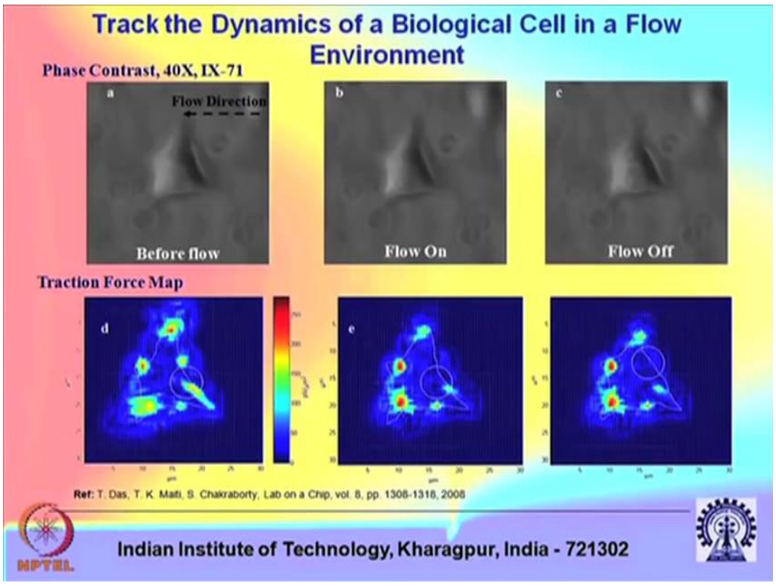

Next example is to track the dynamics of a biological cell. Now biological cell is a very interesting object in general. And there are several motivations of studying biological cells in a small confinement. In human bodies there are hierarchical structures of blood vessels: you have large arteries large veins, small arteries small veins, arterioles, venules and micro capillaries. The micro capillaries are of the order of micrometer dimensions, and cells are also of the order of micrometer dimension. Like, typical length scale of cell in a human body may be around 10 micron.

So, when these cells are moving through human bodies; let us think of a challenging problem of like how to understand cancer progression. So, one of the little stages of cancer progression comes when a cancer cell from its origin moves to a distant location within the human body cutting across are removed, not cutting across moving across the blood vessels. So, when it moves across the blood vessels it has to also move through micro capillaries. And there is a tremendous resistance that comes from fluid dynamics considerations for moving against moving of cells through micro capillaries. Despite that cancer cells are able to survive under that stressful condition, where normal cells are not able to survive.

So, can fluid dynamics give an answer to this question; that why cancer cells can survive effectively in a micro fluidic confinement, where the normal cells are not able to do. So, there are several possible answers. And some of the answers, I am not going in to the answer; this is not a research presentation. So, I am not going in to the answer to this question or possible answer to this question. I am just giving you some clues where fluid dynamics find this relevance in this application.

So, the cell membrane if you look in to the cell, the cell membrane in its composition is somewhat fluidic in nature. So, the fluidity of the cell membrane has something to do with the malleability of the cell. And the manner in which a cell membrane can control its fluidity based on that it depends on whether a cell can adopt or adjust its shape effectively to withstand a stressful condition. And a cancer cell possibly does it in a much more better way than a normal cell.

So, that is how a cancer cell survives in a stressful condition. And it is a very important and interesting area of research, because if one understands the proper fluid dynamic mechanism that goes in a run around the cancer cell which controls the adaptation of cancer cell then possibly newer and newer drugs can be discovered that can inhibit the survival capacity of cancer cells in a stressful environment.

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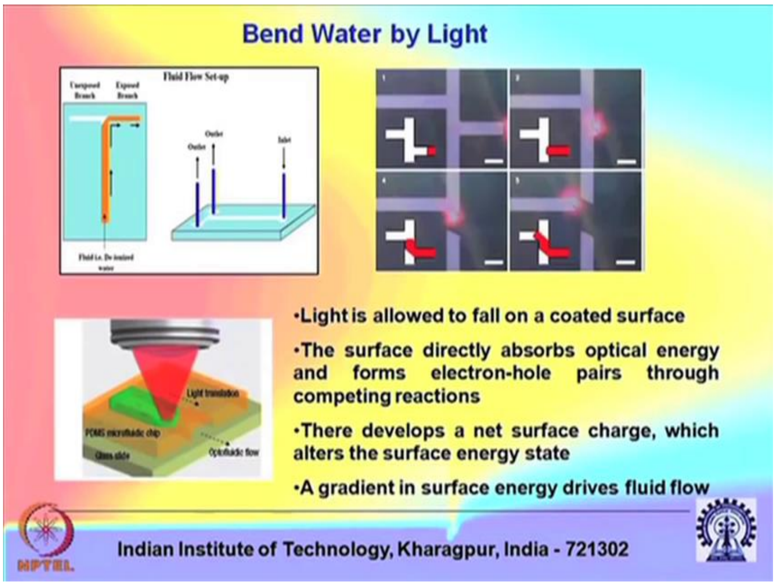

Coming from a biological example; I will give you another example which just illustrates that fluid dynamics can be multi physics. So, multi physics means that you just do not require only fluid physics, only flow physics. The flow physics maybe we need to be combined with electricity, electro hydrodynamics, magneto hydrodynamics that is electrical sciences or electromagnetic theory or sometimes optics. So, this is called as multi physics, where physics from multiple disciplines need to be converts together to solve a fluid dynamics problem.

Let us look in to this slide where we intend to show that you can bend water or move water by using light. So, what is the strategy? Briefly the strategies as follows: you coat the surface of a channel with a metal oxide semiconductor say- titanium dioxide or zinc oxide and you shine ultraviolet light on that. When you shine ultraviolet light on that, because of the typical energy gap you have its compatible energies that is provided by the ultraviolet radiation, and immediately electron hole reactions will start. So, based on that the surface will either acquire a positive charge or a negative charge depending on whether it will have excess holes or excess electrons.

I am not going to the exact details what happens in this specific case, but the net effect is that the surface energy gets altered. Because the surface energy gets altered a surface which was earlier disliking water may start liking water. That is from so called hydrophobic it becomes hydrophilic and water we move in to that direction. So, you do not require a physical pump to drive water. You just require a source of light to drive water. And you can even bend water by light.