Transcriber Name: Saji Paul
Chemistry and Physics of Surfaces and Interfaces
Prof. Thiruvancheril G Gopakumar
Department of Chemistry
Indian Institute of Technology, Kanpur

Lecture - 01
Why Surfaces and Interfaces are Important?

Hello everyone. My name is GopaKumar, I am from the department of chemistry and I am a physical chemist and my specialty is surfaces and interfaces, we look at the surfaces and interfaces using different types of microscopy and spectroscopic techniques. So, in this course chemistry and physics of surfaces and interfaces. But I would like to bring to you is a flavor of the chemical aspects and the physical aspects of surfaces and interfaces.

So, before going into the chemical and physical aspects of the course we would look at the importance and the interesting aspect about the surfaces and interface and that is what going to be the content of lecture 1.
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In which I will show you that, why are surfaces and interfaces so interesting? Or is there something important that we need to take into account about surfaces and interfaces. And you will also find out that during the course of the lecture that surfaces and interfaces are one of the most important ingredients in modern technology particularly the thin film-based technology. So, in lecture 1 we will have a look at these important aspects about the surfaces and interfaces. So, the first point is that surfaces and interfaces are present everywhere.

So, when I hold my hand onto this table or when you touch a surface when we actually interact with the air or when you move around everywhere there is actually a surface that is interacting with another surface. So, that means you cannot avoid surfaces and interfaces at any course of time while you are doing anything.
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So, if you would look at the examples like solid vacuum interfaces where an object is actually kept inside vacuum. This is actually one of the most idealistic interfaces, because the solid can actually be understood just not interacting with anything. But that is actually the most idealistic case when you come to normal life that everywhere there is actually an interface. For example, here you have a solid liquid interface;

Where water is passing through rocks which is basically a solid liquid interface or you have a solid solid interface whenever you encounter an object on another object. So, what I would like to bring to your point is actually that surfaces and interfaces are present everywhere and we cannot avoid that. So, of course the vast area of surface and interfaces will not be covered in this course. But we will be looking at the most chemical and physical aspects at a molecular level.

So that one can actually understand these surfaces and interfaces in a more quantitative way. So, why surfaces are so interesting? So, we need to first address that question before we go into the bulk of the lecture. So, first of all the main aspect that you would be just telling is that well since we are always in touch with another medium or when you do anything you are basically just coming in contact with another surface.

So, therefore interfaces are ubiquitous so it is always present. So, then of course it is obvious and clear that we need to clearly take into account about interfaces. But let us look at a few specific examples to understand this in a more quantitative or in a more interesting way or the interesting aspect about the surfaces and interfaces.
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So, this is a lotus leaf and lotus leaves or Colocasia leaves for example, are very popular for having their non-sticky property. So, that means if you drop water on the top of these leaves they will never actually stick on to the surface. So, we will look into the technical details of that why is this happening is there something interesting at this surface that makes actually the so-called lotus liquid interface kind of interesting.

Then let us take another example of a Gecko moving on a vertical wall or on the roof top which never falls. So, this is also an interesting interface that you actually create between the legs of the Gecko and the solid. So, it is a solid solid interface. So, what actually causes this Gecko not falling off the window is actually a question that one can actually just address by looking at what happens at the interface of this Gecko and solid.

Another example, plant leaves, so they are actually very beautiful looking and just at the macroscopic level of the leaf you would not be able to clearly recognize or understand what actually is going on or what is the microscopic structure of the leaf itself. So, what I am going to now address is basically to look at the microscopic picture of these three objects that we have talked about well I have already told you surfaces.

And interfaces are ubiquitous, you cannot avoid them but what is interesting is actually just to take these examples and to look at the microscopic level and see why this interface is so special or why the surfaces are so special?
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So, let us look first the lotus leaf. So, when you look at the scanning electron micrograph of these lotus leaves, so what you can see here are extremely tiny objects you can look at the scale of the image is about 10 micrometer and that actually tells you that what you are looking is actually in the microscopic regime. And you can see like tiny nanostructures are protruding out of the surface. Although the surface looks very smooth at the macroscopic level, when you look into the microscopic level you notice that there are basically very fine and interesting nanostructures. Now if you look at the scale of these nanostructures, they are typically in the order of a few hundreds of nanometers big. Now the point is when a water molecule wants to drop and wants to stick on to the surface.

And if there are these tiny nano objects which are present on the surface then the water is basically unable or the water droplet is actually unable to come in contact directly with the surface of the leaf. So, the nano structure or the topography, the special nano structure or the nano microscopic structure on the surface of lotus leaf actually reduces water being in touch with the surface. So, nature actually does this interesting game with surfaces in order to get achieve a certain important outcome. So, that is actually the so-called hydrophobic nature of water on the lotus plant. Of course, it is also the material that is important but here what we look at is the type of surface that actually causes the real non-sticky nature of the water onto lotus plant.

Now if you look at the Gecko feet. For example, and the Gecko feet is also been looked using microscope and this is actually scanning electron microscope where you can see tiny spatula-like objects which are actually present if you look in a extremely smaller scale. So, this you can see here is about 100 nanometer and at the 100 nanometer scale you can see there are extremely tiny features like spatulas. And the interesting thing what Gecko does is actually using these nano objects the number of contacts between the Gecko feet and the surface is basically increased.

Therefore the Gecko is basically able to stick its feet to the wall. So, this is actually an interesting engineering that nature does using surfaces in order to basically achieve a certain goal and in this case is basically that the gecko is able to stick to the wall without falling. Now if you look at the plant leaves. So, this is a particular example I have

chosen this is not very specific to a given plant.
And if you look at any plant you mostly would see that the surface of the leaf is always having these kinds of small nanostructures which are present on the surface and of course at the end what it looks like that in the microscopic level the surface is not any more smooth. It is much more rougher than what you actually just see at the macroscopic level. So, it actually is interesting now the nature does this thing in order to increase the efficiency of the photosynthetic process. You have to actually absorb a lot of carbon dioxide and water in order to do the photosynthetic process and therefore the surface is actually kept extremely rough, so that to increase the surface area and by doing this nature basically achieve a large surface area and therefore the efficiency of the process increases.

So, you see what in this particular example what we have focused is that by looking at the microscopic level and looking at the microscopic nature of each surfaces one can basically understand a lot of interesting aspects which you would not be able to address at the microscopic level.
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Now ,let us look at a certain example of at the molecular and atomic level. So, this is actually a gold crystal a Au(111) crystal. So, later in the lecture you will find out what is the meaning of this 111 and this 111 are nothing but the h k l index or the miller index we will actually just look that in greater detail later. So, what you are seeing is a crystalline gold surface and what you see here is actually the gold atoms are well connected by a hexagon.

That means the idealized crystal structure of Au(111) surface should basically look like a sixfold symmetric surface. Or if you look at the diamond structure it also appears to be extremely crystalline and in that also the diamond or the top surface atom is basically the light blue one and they are also connected and forming a perfect hexagonal lattice arrangement of the surface atoms. But now the interesting thing is that this is basically the expected atomic level arrangement of the gold crystal and also the diamond crystal. What is very interesting is that if you look at the real gold surface or the real silicon surface using microscopy what you see is something absolutely weird and different.

So, what you are seeing here is actually an STM which is scanning tunneling micrographs. We will actually just address this later how you obtain this image. So, this is a scanning tunneling micrograph and what you are seeing here these bright lines are nothing but the arrangement of atoms or it is basically an atomic lattice.

So, as expected here you would have expected to see basically a three-fold symmetric arrangement of the atoms but instead in the real microscopic structure the real microscopic image of a Au(111) crystal looks entirely different. Why is that? It is actually due to the fact that no surface is actually stable and therefore it undergoes something called a reconstruction and due to the reconstruction, this atom on the surface is actually rearranging and forming an extremely different pattern which is known as a herringbone pattern.

Or if you look at the Si(111) surface as expected you would have seen basically a hexagon, but instead what you are seeing is a much larger hexagon. But the arrangement of the atoms are looking entirely different than in the expectation. It is also due to the fact that the atoms on the surface actually undergo a rearrangement due to something called as reconstruction and the surface is actually then giving rise to something like an entirely different microscopic structure than what is expected.
So, what you see here is actually again at the microscopic level you see that there is a huge difference in the way the atoms are arranged on the surface. So, you would ask a question at this point, whether it is important to know the surface if I want to basically do something with the surface. Yes, it is important that one needs to know clearly the microscopic structure of the surface in order to basically use the surface. Because this was actually the expectation and the real outcome is somehow very different.

So, that is also the reason why in our course we will also be looking at these particular surfaces or even more surfaces using microscopy in order to clearly undefrstand the microscopic nature of the surface.
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So, the next most important aspect of thin film I would like to bring to your attention is its application in thin film technology. For example, in most of the modern devices that we use for example in diodes thin film transistors, solar cells or whatsoever we would be using basically a technology that is based on thin films. That would means if you would like to construct a light emitting diode. We would need to basically use the thin film technology and we need to basically understand the underlying basic principle of interfaces.

To understand that I have here a basic construction of a light emitting diodes and as you see here, they are constructed by many different layers. It has already 1, 2, 3, 4, 5, 6 layers of materials are put together in which the most important is basically the layer number 3 which is the emitting layer and where of course the light is emitted when you apply a load or when you apply an electrical field. But in a simple light emitting diode but you would require is only two electrodes and an emitting layer. But in modern light emitting diodes or more efficient light emitting diodes what you need are these additional layers like 2, 4 which are nothing but the electron transport layer or the whole transport layer. Well, what are these? These are actually the layers that bring electrons and holes to the emitting layer. So that the recombination is more efficient and therefore you get basically a higher efficiency in the light emission from the light emitting diode.

So, you can basically see that if I need to construct this kind of a light emitting diode, I need to basically understand what is going on all these interfaces. So, I am basically constructing already six or more interfaces already in this very simple device.

That means if I need to clearly understand or make this device work better, I need to clearly understand what is going on at these interfaces and what sort of chemical changes or what sort of electronic property changes or what sort of microscopic property changes are happening at this interface is a most important ingredient in constructing such devices. Therefore, for us the interfaces are the most important;

As you see we already have seven interfaces here and we need to basically understand all these interfaces at the microscopic level at this chemical level and also at the electronic level in a highly detailed way. And you see that for a simple light emitting diode or a simple electronic device we are already coming across many many such interfaces. And that is the importance of understanding the interfaces in general and when it comes to the technology.

I would also like to bring to your attention that there are already exciting news when it comes to the chemist because there are already examples of organic light emitting based tv you already have it in the market the flat tv and the curved tv which are basically using the organic light emitting diodes in which the emitting layer is basically nothing, but an organic molecule. So, this would be an organic molecule.

So, this is good news for chemists so we are basically now also going on with modern technology where we would be using basically also organically. Well at the end of the day what I would like to demonstrate here in this slide is that what we are basically just trying to do is actually using the thin film technology in constructing our modern devices, therefore it becomes a must in understanding the interface chemical microscopic and electronic properties.
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Now I would like to show a few more examples of application of thin film in technology

particularly in electronics. So, this is one foremost example that is actually a field effect transistor. And field effect transistor is in fact the most important and the fundamental building block of all electronic devices, you name a computer you name a phone or display whatever electronic device you take you will always come across a field effect transistor. Now in this type of a field effect transistor this is particularly an n-type metal oxide semiconductor field effect transistor or generally known as a MOSFET transistor. In which you have basically an n type material here and a p type material here which is making an interface. And now as you already see this is an interface this is another interface which makes this typical p n junctions.
That is actually the fundamental units of this particular device and now each of this n type semiconductor material is actually again making an interface with metal which is nothing but the drain and the source of this device. Then the p type material is actually making an interface with an oxide material and again the oxide is making another interface with the gate electrode and then finally even the p type material is actually making another interface with the body ground.
So, now you already see that in this very simple device and the most important device indeed you have about 1, 2, 3, 4, 5, 6, 7 interfaces are already included in this very simple device. So, that means when you want to basically just get this kind of devices operational or functional in an efficient way it is quite important for us to understand these interfaces, and without understanding the interfaces you cannot construct them in an efficient way.

So, therefore from the technological point of view studying interfaces or making interfaces are quite crucial in the development of modern technology and that also gives a great perspective for us to study actually the interfaces. Let me also show you one more interesting example which is actually the fundamental principle that goes under the hard drive disk or any sort of this kind of disk, where you store basically information.

This is basically uses the principle of giant magnitude resistance and for the discovery of the giant magneto resistance, Albert Fert and Peter Grunberg has won the Nobel prize in 2007 in physics and what it actually use is again an interface of a few different materials. So, here you have a ferromagnetic material making an interface with a non-magnetic material and again with the ferromagnetic material.

Now you create this nice interface of the materials and now imagine that the both the ferromagnetic materials are actually having the same orientation of their magnetization both are up orientation. Now when the electrons with the spin specific electrons are passing through this material you can see if the spin of the electron is matching with the magnetization of the material.

So, like here in this case both up then the electron is basically able to transfer or transport through the material without any resistance. But the moment the spin of the incoming electron or transporting electron is basically opposite to that of the magnetization of the material the ferromagnetic material, then you see there is a large scattering that happens at all these interfaces and then effectively the transport is very weak in that case.

Well, by looking at or orienting the spin in the right way we can basically use this combination of ferromagnetic non-magnetic and ferromagnetic material. That means this particular interface or the combination of this interface in selectively transporting a type of spin that means you can basically get the so-called current with the specificity in the spin. So, that is actually nothing but the spin selected current for example.

So, that is the fundamental principle that you use in all this hard disk and that is actually nothing but known as the giant magneto resistance. And here also you can see a different combination you can use if you have like the opposite magnetization for one material and the other has the opposite orientation then you see basically the spin transport is facilitated at one interface but at the other interface it is actually kind of scattering.

Again, the same here in one interface it is facilitated but on the other interfaces it is basically not working. So, you see by again this kind of a device is again working using the principle of creating interfaces, thin film technology. So, ideally all these kind of magnetic hard disk devices are also using nothing but the thin film technology.
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Well, I would also like to bring one more example which is nothing, but a solar cell and a solar cell is nothing but the opposite of the light emitting diode what you have seen here what you basically do is you shine the device photon is basically just going through the material and you have basically something like a light absorber and the light absorber basically would absorb the light and then you can basically split the hole and the electron. And then you can use that hole and electron to operate some electronic device.

So, this is nothing but the opposite of an LED. But you also see here that this device is again created by several interfaces that you put together. You have a contact layer and then you have an anti-reflection coating layer, you have a transparent electrode and you have junctions that connect basically the light absorber then again contact.

And so, you already see there are six or more interfaces here that basically connect everything together and this is again the fundamental principle of electronic devices. So, this is basically what I would like to show you that the electronic devices are all using nothing but the thin film technology.
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So, just to put it in summary, what I would like to bring here is that surface and interfaces as you have seen it is very crucial in current days technology, which is a thin film-based technology and in that the microscopic structure of the surface basically controls the growth of thin films. Because if the thin film need to be prepared you always need a surface and depending on the microscopic structure of this surface you would basically be able to control the growth of thin films. Then the chemical interactions so that is also something we are going to address a little later which is actually coming to do with the chemisorption and physisorption options and things like that. So, the chemical interactions at the interface also controls the electronic property for example, so you would actually just see later that depending on the interfaces that you form you can highly tune the electronic properties.

Then another interesting aspect which is actually the charge transfer at interfaces. So, what is a charge transfer? So, now let us assume that you are creating an interface using a metal, so this is a metal and semiconductor. So, for a semiconductor I have basically a band gap which is like therefore I have the valence band and the conduction band and here I have the valence band and the conduction band. And this is basically my fermi energy and here in the semiconductor region I have an energy gap. So, now you see that when you create such an interface it is clear that this interface is very ideal. You can see that there is no change in the band structure of the semiconductor when it touch actually the metal. But this is a very unideal case so this is only a very ideal case where the interface electronic property remains as you would expect in the ideal case.

But in a real case what happens is that you have the metal and the semiconductor band start to bend near the interface. So, it is quite interesting that this change in the band structure which is typically known as band bending, is actually something to do with how the charge transfer occurs at the interfacial region. That means when an interface is formed between two different materials.

Let us say like metal one and semiconductor and then you can actually have a charge transfer the electron transfer from the metal to the semiconductor or you can have a charge transfer from the semiconductor to the metal. So, depending on the charge transfer you would basically be seeing two different types of band bending either a downward bending or you would also be able to see something called an upward band bending.

And this would look like this and this different type of band bending will have a strong influence on the electronic property of the surface and the interface. So, therefore it is quite important for us to kind of understand how the electronic property of the interface is actually controlled by the charge transfer, the chemical interactions and also the microscopic structure. So, therefore understanding the physics and chemistry of surfaces and interfaces are very crucial in developing the new technology which is basically based on thin film technology.
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Now I would also like to just show you a few daily day examples that you also come across where you are using interfaces for example surface coating. So, you are ofcourse using something called paint every day in your life which is basically to protect your surfaces or for example plating and this is also been used regularly for protecting surfaces and also liked to protect surface against corrosions and things like that. So, therefore this kind of surface coating is also nothing but a formation of a kind of interface on different surfaces.

So, the physical and chemical properties of these interfaces is basically just defined by the texture and the composition. So, what is the texture or what is the composition of the material that you put onto the surface is actually defining the physical and chemical properties of this kind of interfaces that you use in paint, plating etc.

So, here I just took two examples from the market, this is actually two different type of paints that you are using in your daily life when you want to protect surfaces like walls or like metallic surfaces or wood and so on. And you basically come with this kind of advertisement called teflon surface protector weather code and so on. So, what you do ideally in all these things are nothing but just creating interfaces using different types of materials that will actually just help us in protecting the surfaces.

Then,for example ,mirror is actually a best example of having an interface. The silver coating which you use to observe your image is basically a typical mirror or you also can use actually like the thin film coating to have like a two way mirror where you can actually observe the image on this side and also on the other side. So, this is nothing but just using different type of materials and also like this modern sunglasses windows and lenses that are also now currently available in market where they use actually anti reflect coating.

So, this is an example of like a sunglass and a window shield which is actually sunglass and a window shield which is created using anti reflex coating and the outcome is very obvious here. So, like as soon as you use the anti reflex coating you can see there is no reflection in this sunglass and also you can see here there is absolutely no reflection of the light of the opposite approaching cars and therefore like your visibility is very nice in the night.

So, this is the type of different interfaces that you would come across in your daily life. And which is also kind of commercially available. Well, as I told you surfaces and interfaces are ubiquitous and, in this lecture, what I could conclude or I could show you is that different possible aspects of surfaces and interfaces and actually their presence in nature and their presence in technology and also their presence in daily life and so on.

With this I would like to conclude the first lecture and I will now come to the second lecture and in that I will just give you a little bit of the historic perspective of the surfaces and interfaces and the development of surface science itself, thank you very much.