Nanotechnology Science and Applications
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Lecture - 21
Effect of Nanoscale on Magnetic Properties: Potential use of biomaterials

Hello, in this class we will look at the Effect of the Nanoscale on Magnetic Properties and of course, as we have done with the previous classes, we will set some background. We will look at what is the nanoscale doing with respect to magnetic properties and we will also look at some application what is that application. So, this we will look at in the context of the application process and what is the advantage we are getting from the nanoscale; first of all, what is the difference we are getting from the nanoscale and then how we can put it to some advantages use. So, that is what we will do.

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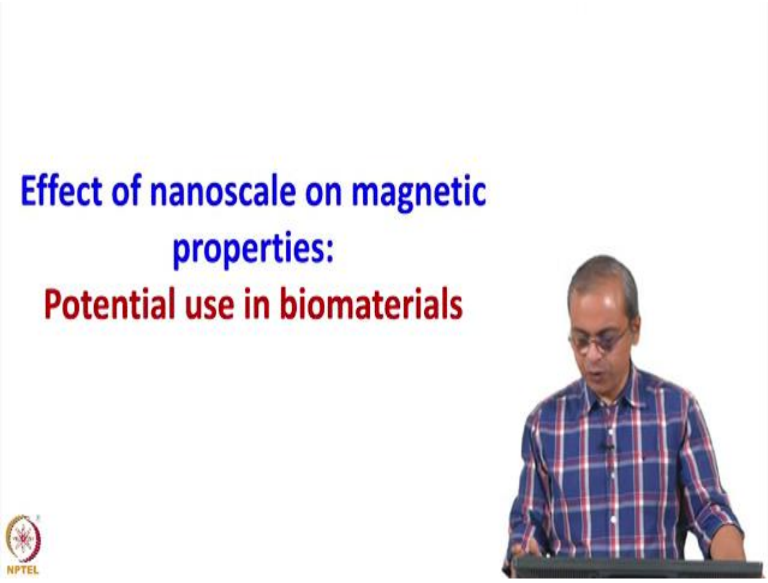

So, in our case in this particular class, we will focus on potential use in biomaterials. So, I mean there is a wide range of areas where you can apply magnetic properties and we do in fact, a technologically apply it in a wide range of areas. But, biomaterials by itself is a very vast area and also a very interesting area, after all lot of sort of medical applications are dependent on biocompatible materials being developed and biocompatible processes being developed, so that you can put something inside the human body and actually get it to do something for you, the way you want it to happen and that will help assist us in various ways.

So, biomaterials by itself is a very fascinating field and in this class, we will look at magnetic properties and maybe some relevance that it might have with respect to five applications.

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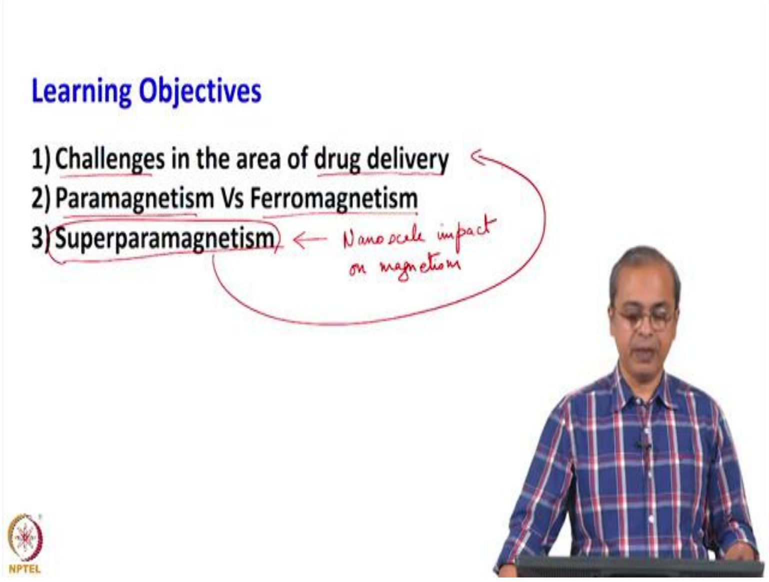

So, we will in this class we will look at some challenges in the area of drug delivery or medicine delivery. So, there are specific challenges that people try to address and we need to get a sense of what it is so that we understand in what manner we can assist it in a technological sense.

We will also briefly look at Para magnetism versus ferromagnetism. At least as a concept what they are there are much more detailed discussions on these topics elsewhere. For our purposes, we will look at some very brief comparison between the two phenomena that happen in the domain of magnetism where itself there are domains, but that is another thing.

The and in that context, we look at something which is not so commonly encountered and that is super Paramagnetism and so, this has got something to do with the nanoscale. So, this is this particular topic is the impact of the nanoscale on the magnetism phenomenon and that is what the superparamagnetism is. And potentially this can be used for this application potentially I will leave you with a reference as usual and you can look at a reference where they have actually tried to do something in this context, but the idea is that you can potentially use it for some to address some challenges in the area of drug delivery.

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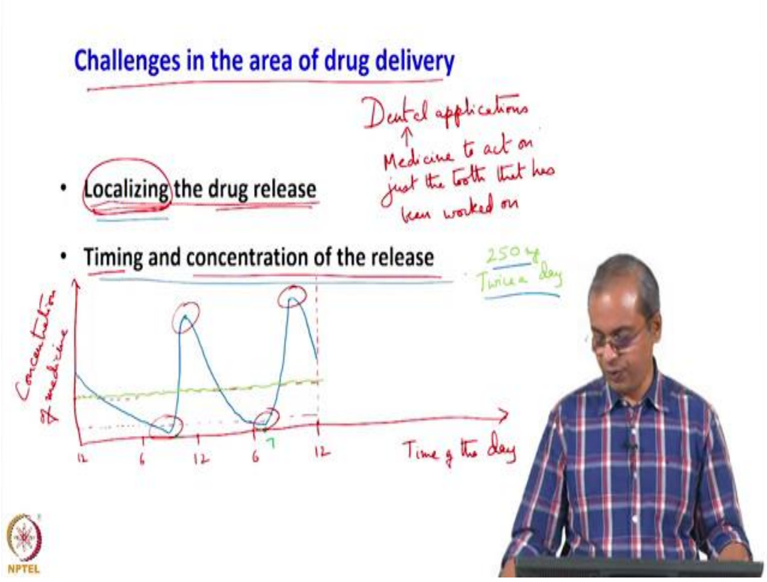

So, with these learning objectives let us start with the first point that we are trying to look at which is the challenges in the area of drug delivery. So, the first thing that the first issue that or one major issue that is encountered in this area of drug delivery or medicine delivery in the human body is the issue of localizing the drug release. So, localizing the drug release, this is actually a very important issue.

So, if so, for example, if you mean if you are aware of people who undergoes say, for example, they have to undergo say chemotherapy for say they to address some cancer-related issue in their body. So, the chemicals that are pumped into the body as part of chemotherapy, are expected to target the cancer cells. So, that is the those are the chemicals that are being pushed into the body and they are going to spread through the body try and locate cancer cells and destroy them.

Now, the issue that often happens, in this case, is that the drugs that go into the body actually do not target only the cancer cells, they end up also damaging lot of other cells. This is also true for any medicine that you take almost any medicine that you take is not has an intended use. So, some particular use is there. So, it is supposed to go and do some particular activity in your body.

But, quite often when we talk in terms of side effects of the drug it has got to do with the fact that medicine is not simply doing that one task that you are hoping it will do, it also because it is in the body because it is in contact with a lot of the other cells in the body the lot of other tissues in the body and organ organs in the body it has an impact on all of those cells all of those tissues all of those organs at some level. Maybe some of them have negligible impact some of them have more significant impact. So, that variation may be there.

But generally, you are faced with this issue that once the medicine is put into the body it is actually acting all over the body even though you may actually have a problem only at one part of your body right. So, it could be anything, it could even be a painkiller. you have sprained your leg; you are sprained your ankle and you are having some pain and it is in basically your right leg is a sprint. So, you take a painkiller. Now, that painkiller is not going to act only on your right leg. It has an impact all over your body to whatever extent that it does impact body. So, it is all over the body, but your requirement is only on your right foot. So, that is where you need it right.

So, therefore, there is a lot of interest in trying to localize the medicine. It is very nice to see if you can find a way to localize that medicine, so that it acts only in that location and many times for example, in dental applications. So, one classic example would be that, in dental applications. So, somebody has a procedure done on one tooth of their mouth. Now, it is sufficient and useful if the medicine acts only on that tooth. So, it they do not even want it acting on all the rest of the teeth. So, the medicine should act only on that tooth.

So, I should act on just on the tooth that has been worked on and maybe the neighbouring one or two teeth because there may be some pain on either side etcetera. So, to that degree we want to localize things. We want to localize things so that now it is not even something that is going to impact your entire mouth it only acts at place. Usually in externally applied medicine that is often possible because you are putting an ointment on some small scratch that you have, some antiseptic ointment so, you end up applying it only in that location. You do not apply it all over your body because you have a scratch only at one location. But the internal medicine is the other way round you are applying it more or less over your entire body even though it is only impacting one location. So, localizing the drug release is very important.

And, the second thing which is also very important is the timing and concentration of the release. So, many times when you go to the doctor to get some medication for some necessity what they will say is you take this particular medicine twice a day; once at lunch at once at dinner. So, something like that they will say. So, why do they say that? Why do not they just say take both the tablets take double the concentration in the morning and be done?

So, the reason they say that is if you make a plot of time of the day and concentration. So, the concentration of medicine in the body. So, if you make a plot like that this is whatever midnight 12, this is 6 AM, this is 12 in the afternoon, this is 6 PM and this is back to midnight so, something like this. So, if you do that you take the medicine once in the morning at about whatever 10 o'clock and then once again in the evening at about say 7 o'clock. these are the two instances at which you take the medicine.

So, this is 7 and this is 10. So, it will be somewhere here. So, we do this. We take the medicine the person is supposed to take medicine like this. So, what happens is at this point just shortly after the person takes the medicine, the concentration of the medicine goes up. So, that is the level of the concentration of the medicine right after the person has taken that medicine. So, it reaches this value and then it starts decreasing in the body; slowly we know due to various reasons it is getting consumed by the body and it drops down, drops to a very low value.

As it starts dropping to a low value you pump to take the next dose of the medicine. So, the next dose of the medicine again pushes the concentration of the medicine up. So, it is pushes the medicine up as quickly as possible and then it reaches a peak value and then again begins to drop. So, we are already now at close to this is the midnight point. So, that is midnight. So, you will see the medicine beginning to drop. So, that is there. So, that would be somewhere here. So, at midnight continues to drop and you come to very low concentration again and then again you pump the medicine in, it begins to climb up.

So, you see a behavior that looks like this right. So, the concentration of the medicine goes up and comes down, goes up and comes down every time you push the medicine into your system it shoots up and comes down. So, this is a very important part of the way the medic the medicines operate in our body and the reason why they give a specific dosage and the reason why doctors tell you that at this particular time we should take this medicine and at this interval you should take the medicine so that it goes up comes down, goes up comes down that is the way it does.

And in fact, some of the medicines, in fact, try to distribute this load across the times time frame. So, just, for example, say there is a certain minimum concentration of this medicine that has to be there in the person's body for it to very effectively function. So, that minimum value is somewhere here. So, and very effectively it will work at some concentration here. very effectively it works at that concentration.

So, you want to keep the medicine above that concentration most of the time some minimum value is there; there is some very effective concentration you want to keep it at the concentration at most of the time. So, these spikes which are well above the concentration value and these lows which are going below the concentration value are not very useful. So, you would actually prefer to have medicine being released in the body which is almost at this level.

So, this way because when you put a very high concentration of medicine into a person that is going to have some negative impact. It will it is going to do some damage whatever damage it is going to do to the rest of your body by putting higher concentration you are increasing the damage. So, always with medicine you want to use just the right amount of medicine to get the job done, you do not want to put more medicine into the person that is the basic idea. But, the typical way in which we take tablet us as prescribed by the doctor creates this spike up and down, spike up and down of concentration. Generally, this is what is going to happen in terms of how the medicine acts in the body, but you would like to maintain some steady value throughout right.

So, that is the; so that is the preferred option; preferred option is to keep it stable adjust very adjust the right level that is necessary or at least many cases that would be the preferred option; maybe there are some specific cases where the spike is also useful for the overall recovery process, but generally you want to keep it at that level that you want it to be effective. So, therefore, in fact, people do various things. If you look at some of the tablets they come with coatings; with coatings so that coating will dissolve even though you would consume the tablet in one go the coating dissolves slowly and to the extent that it dissolves slowly in the body, it is spreading out the release of the medicine.

So, therefore, many tablets these days they will say use supposing you are instructed to take 250 milligrams twice a day, that was what of some medicine you are asked to take twice a day. For some medicines they will we have this tendency that if you go to the shop and you do not find 250 milligrams you get a 500 milligrams tablet we tend to think that it is to get the 500 milligrams tablet and then break it into two halves and then take the take one half in the morning one half in the afternoon, whatever some something like that we may do.

For certain types of medication, this is actually not correct because they would have done some coatings, they have done something to that tablet that they have created so that it dissolves gradually in your body and releases the medicine gradually into your body right. If you cut it in half you are actually negating the whole coating process you are basically getting to the interior of the tablet without enabling the coatings to do this time-release. So, then the purpose of the tablet is defeated. So, those tablets have to be taken only in that manner. You cannot take to a 500-milligram tablet and break it into two; you should get only a 250-milligram tablet and use it.

So, those kinds of things are there which sometimes the general public may be unaware of, but this is something that is very important that for that medicine. I guess the nearest commonplace example would be like a chocolate Eclair that we have if you, I mean if you take it as a whole then clearly you reach the chocolate in the middle only after you have gone in fairly deep into the chocolate. On the other hand, if you cut it into two the chocolate comes instantaneously right. So, that is the difference. That is exactly the same concept the coating ensures that you take some time to reach the concentrations that are required.

So, anyway so, this timing and concentration of release is very important, localizing of the drug releases is also very important. So, these are both major challenges in the area of drug delivery and many of the scientists who work in the area of biomaterials have a significant focus in this area of drug delivery.

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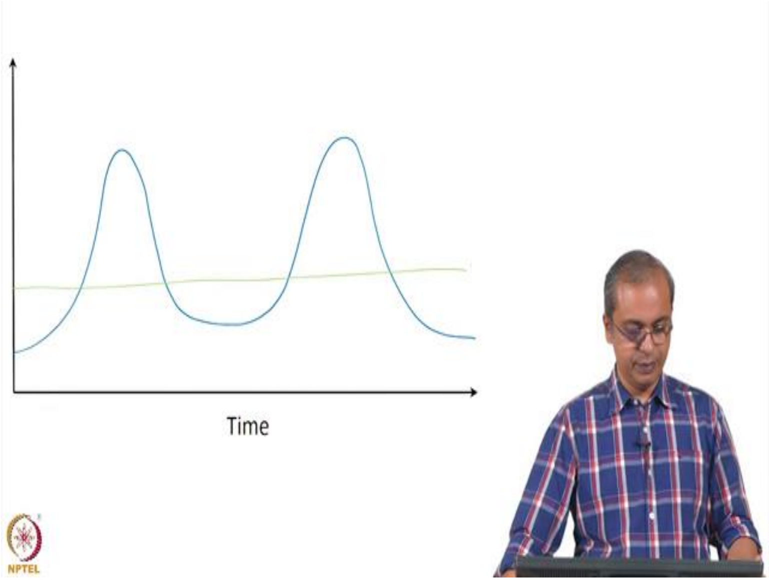

So, this is what I meant, concentration versus time. This is what you have seen. So, you can see concentrations that normally go like that and our preference is a concentration that looks more along some flat value right, concentration versus time. So, this is what we would prefer to do with respect to medical applications in our body.

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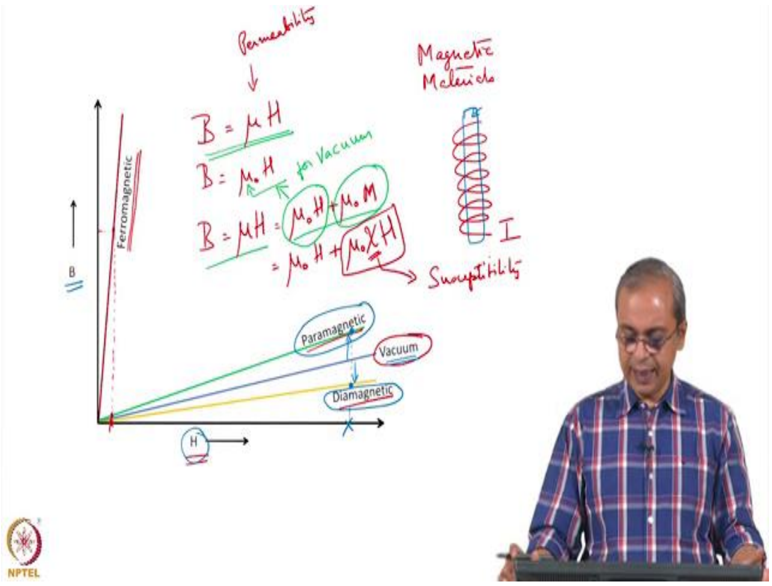

So, now let us see briefly what we have in terms of a magnetic materials. Basically, materials display magnetism. So, it is an experimentally some materials displayed very strongly. It is an experimentally observed phenomenon where some materials tend to attract other materials even in the absence of an electric field for example. And those magnets and generally if you take once that concept was understood and then it was explored some more across all materials the materials could get classified into all of these kinds there were diamagnetic materials, paramagnetic materials and ferromagnetic materials.

So, these are sort of three major kinds of materials that people could sort of three in different categories into which materials could get segregated. So, that is all got to do with how those materials compared with what vacuum does in the presence of a magnetic field. So, that is the way so, you can use a coil you can take a coil and you can send current through it. And based on the number of coils per unit length and the current that you send you to generate an applied magnetic field or a magnetic field strength and that is this value H, the magnetic field strength is generated.

And if you place some other material inside this then due to this field that you are creating because of the current going through that coil you can induce a magnetic field in this material. So, that is the magnetic field induction magnetic induction as it is called and that is this B. So, B is magnetic induction, H is the applied field strength that we have. Now, if we did not have so, what is generally seen is if you apply a value of H, then and if you have nothing there then there is a certain response that you see which is the response of the vacuum and that is the response of the vacuum in the I mean that is what you will see as a field in that region in the absence of any material.

And then based on what material you can see what material you put there you will find some materials very gently assisting the magnetic field or adding to that magnetic field strength that you have adding to this H and then some other materials which in a very mild manner oppose that magnetic field. So, the induction for those materials which are opposing the magnetic field is less than what the vacuum is holding at that location and the induction with the materials that are slightly assisting the magnetic field is higher than that of what the vacuum level is at that same field magnetic field strength that you apply.

So, these materials are referred to the where the induction is higher it is referred to as a paramagnetic material and with respect to vacuum and where it is lower than vacuum it is referred to as a diamagnetic material. Generally speaking, both paramagnetic and diamagnetic materials are giving you that response only when there is an applied field and so, that means, when you switch off the field you have applied this level of field whatever is this level of field, you apply this field and then these are the responses you are getting right. So, you are getting a response here and you are getting a response here.

Now, if you switch off the field if you have a suddenly turn off the current I, so, there is some current I that is flowing here. So, that current I if you turn off then abruptly this applied field that you are putting on the sample drops to 0 and for both paramagnetic and diamagnetic materials their response also drops to 0. So, their response also immediately drops to 0. So, in that sense to the extent that they are not having of their own, any magnetic behavior and they have the behavior only when there is an imposed field on them to that degree they are considered as non-magnetic materials. They are basically non-magnetic in that sense.

Ferromagnetic materials are quite different in the sense that first of all when you apply a field on them their response is very strong they have a very strong response to that field and strong assistive response it adds to the response of the field that you are applying and therefore, that is, therefore, you can see here very high induction for the same strength. So, for same so, if I apply this field you see very small response from the two materials here, the diamagnetic and paramagnetic material, but extremely strong response from the ferromagnetic material so, very high in high level of induction and.

So, and importantly if with respect to ferromagnetic materials if you switch off the field if you abruptly drop the field to 0, you switch off the current the induction or the induced magnetic field that is there in the system does not actually drop to 0 instantaneously. So, we will we look at that briefly, but basically, this B and H are related by this equation

$$B=\mu H$$

where μ is the permeability. And if it were vacuum then you would have

$$B=\mu_0 H$$

where μ_0 is the permeability of the vacuum.

So, this is the general way in which we write this and we can also write this $B=\mu H$ as

$$B = \mu_0 H + \mu_0 M \text{ or } \mu H + \mu_0 \chi M$$

where chi is the susceptibility; susceptibility is essential. So, this second term that you have here the second term that you have so, the reason we are writing it like this. So, we first have B=μH this is the response of that material. So, you are applied H, you got some B and that proportionality is mu. If no material was there and you only had vacuum then you would get $B=\mu_0H$. So, that permeability of vacuum is this value here for vacuum.

So, when we now write this as B=μH this first equation which is what I have written here in the form of two terms what we are basically saying is that any way you would have got this from vacuum this is what is here. So, any way you would have got this μ_0H response from vacuum. This is the additional response due to the presence of that sample. So, this is the additional response due to the I am sorry this is not M, this is H. This is the additional response due to the presence of the vacuum and that is the same term that we are putting here as a function of H.

So, this chi here is referred to as susceptibility and it sort of represents how easy it is to magnetize that material. So, a higher value of chi means it is more susceptible to magnetism lower value would be less susceptible to magnetism. So, this is a general idea here.

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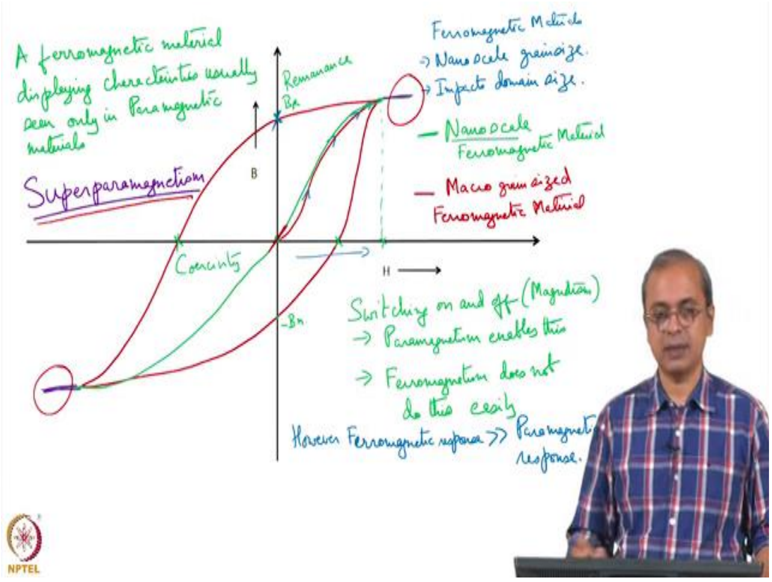

So, now if you actually look at a ferromagnetic material, then you see this behavior when you apply a magnetic field you start with this value H and you start applying the magnetic field you will see a behavior that looks like that. So, what this means is that when you switch off the magnetic field. So, this should be fairly level here sorry. So, when you switch off the magnetic field, if you have raised the magnetic field to this value here and then you switch off the magnetic field what we find is that the induced the magnetic induction that has happened does not drop to 0, it actually comes to this value.

So, this is called remanence. So, this is what is remaining in that material. So, this is Br and this is -Br in the opposite direction and you have to now apply a field in the opposite direction of sufficient strength to actually remove this to make this material again having 0 magnetism that is this value. So, this is called coercivity. So, similarly, you have it here right. So, coercivity you will have and so, accordingly you would apply the field in the opposite direction to get it to go drop to 0 or a positive direction to get it back to 0 if you have remanence in the opposite kind.

So, now this means if you are using this for some application every time you if you are using some magnetic material for an application where you need it to switch on its magnetism, do something for you and then when you switch off your current you want it to drop to 0, if you want to do that this ferromagnetic material is not convenient. So, with the ferromagnetic material, you cannot just switch off the current and expect it to drop to 0, its performance to drop to 0. You have to actually put opposite current and that we would carefully put that opposite current so that you just about cancel out that magnetic field and get it to drop to 0 right. So, that is something that you have to control. So, same way you know.

So, so this becomes from the perspective of utility it is a little bit inconvenient at the same. So, on the other hand if you use a paramagnetic material you switch on the magnetic field, you have magnetism, you switch off the magnetic field it drops to 0. So, that aspect of switching on and switching off is very convenient with Paramagnetism. So, if you are talking of switching on and switching off for with respect to magnetism this is convenient Para magnetism enables this; ferromagnetism does not do this. So, ferromagnetism does not do this easily; Paramagnetism is what does this easily.

But, on the other hand, the ferromagnetic response is much greater than the paramagnetic response right. So, ferromagnetic response is much greater than paramagnetic response which is what we saw here. You can see that we are getting only a very small response from the paramagnetic material, but you are getting a massive response from the ferromagnetic material. So, in one sense the ferromagnetic material is very convenient to us.

So, if you are trying to switch on something and switch off something you want to switch to be a very clear switch. So, and to do that with respect to a paramagnetic material you have to go to very high applied field strength before you can get the paramagnetic material to also show a significant amount of magnetism, a significant amount of current you have to put to get that level of magnetism. And then when you switch off it will go to 0 with ferromagnetic material tiny amount of current in the applied circuit will enable the ferromagnetic material to in the coil that is around the ferromagnetic material will get that ferromagnetic material to give an excellent response. Only thing is when you switch off it will not drop to 0.

So, if you say your job is done you want to switch it off it will not switch off. You have to now put the negative current and also of the correct value so that you have managed that coercivity correctly and then brought it to 0. So, this is the challenges relative challenges of two of the two of them, therefore, it would be nice if you could make a material that shows paramagnetic behavior in terms of switching on and switching off, but has the kind of strength that are ferromagnetic material will give you right. So, that combination is a very nice combination to have.

So, what people have done is to actually look at the nanomaterials based on. So, if you take magnetic materials ferromagnetic materials and you create that in the nanoscale so, you make extremely small so, nanoscale grain size. So, if you start going to nanoscale grain size, what is happening? So, now, the grains are all going to get oriented in different directions. So, if you go to very small grain size in the 10s of nanometers or of that nature 10 few tens of nanometers, then it is not just the grain size that you are impacting you are also impacting the domain size.

So, this is very important. The magnetic domain is the region over which the magnetic moments are cooperatively aligning with respect to each other. So, that is where they are adding to each other strength and that is what gives you this overall magnetic response in a ferromagnetic material. So, the so, that is why they start aligning as you apply the field and then you see the strong response from the material to the applied field and since they are cooperatively assisting each other they hold the they hold even after you have switched off the field after you have switched off the applied field they are actually assisting each other.

So, the moments are assisting each other and they are preventing random orientation. So, if you take a ferromagnetic material you will see 0 magnetism from that material if the magnetic moments are randomly oriented right. So, if they are randomly oriented you will see 0 magnetism and if you get them to orient with respect to each other the magnetic moment story and with respect to each other you see strong magnetism. So, this is how the ferromagnetic material behaves.

So, when you apply the current in the coil; in the coil that we were looking at if you apply this current and you keep on increasing this current I, then what you are doing is you are getting the domain the moments in the domain to align and then once they align they are actually assisting each other regardless of the presence of the current. So, that is why when you start applying this current when you start increasing this H the B starts increasing this way and it reaches this point.

So, now, when you switch off the current the moments are already now assisting each other. So, they continue to remain. So, some assistance they were getting from the current goes away so, they drop a little bit, but they still maintain this value and that value of B they are maintaining is because they are assisting each other, the moments are assisting each other right. So, that is the manner in which this is happening.

Now, if you go to the if you will start decreasing the grain size and you go to the nanoscale, then you are impacting the domain size and the ability of the moments to assist each other decreases and in fact, if you go into the nanoscale it decreases dramatically to the point of being almost non-existent. So, there is virtually no exists to support that the domains are giving the moments are given to each other you have disrupted this structure in a dramatic way and therefore, they are not able to assist each other.

So, when you switch off the applied magnetic field they simply collapse, the moments are no longer able to assist each other they collapse. And so, therefore, suddenly you find that the ferromagnetic material is behaving in a manner where if the applied current is high they are aligning with each other very well giving you a response corresponding to a ferromagnetic material if you switch it off it drops to 0.

So, instead of showing you the behavior that you see in the red curve you now start seeing behavior that looks like what is being shown in this green curve you will see a behavior that looks like this. So, this value up here is the saturation magnetization. So, this is saturation magnetization and so that saturation magnetization it is showing you in a manner similar to that of a ferromagnetic material. So, it is a very strong response very high level of saturation magnetization, but when you switch off the. So, this is now ferromagnetic nanoscale ferromagnetic material, the red is the macro scale for a magnetic material macro grain-sized. So, it is macro grain-sized material.

So, what we see is the saturation magnetization is high, but when you switch off the field it drops to 0, the magnetization drops to 0. So, you are the moment you switch off the field it drops to 0, specifically there is no hysteresis more specifically there is no hysteresis and therefore if you are using it for some application where you want to use it as a switch this is an excellent material to have. This is an excellent material where by applying the magnetic field you get a very strong response.

So, it is like it is on in some sense and in on in a very distinct manner because of the very strong response. And when you switch off the current it drops immediately to 0 more or less instantaneously to 0 and the response is 0 it is a well-defined 0 and therefore, you can say that you have switched something off.

So, therefore, this now gives you this on-off behavior very nicely this kind of material, but it has the behavior of a paramagnetic material because in a paramagnetic material that is this so far this was only visible to a in a paramagnetic material. So, what we are now seeing by going to the nanoscale is we are seeing a ferromagnetic material displaying characteristics usually seen only in paramagnetic materials.

So, you are seeing this behavior which is normally seen only in a paramagnetic material being shown by a ferromagnetic material and this is referred to as super Paramagnetism. This idea that a ferromagnetic material shows you behavior that is similar to a paramagnetic material is referred to as super Paramagnetism. It has got exclusively I mean very significantly to do with the fact that you have taken a ferromagnetic material and change the grain size of the crystal sizes down to nanoscale thereby disrupting the ability of the domains to assist each other and thereby creating the situation that when you switch off the applied field the induction drops to 0.

And this is called super Para magnetism because of this on-off behavior where you switch on you get the response, we switch off you drop to 0. So, we, but we do not call it Paramagnetism, instead we call it super Para magnetism because the saturation the value of saturation magnetization is very high the saturation of. So, from the perspective of saturation magnetization that is the highest value that you are getting here; so, this value that you get here and this value that you get here this, from the perspective of saturation magnetization this material is behaving like a ferromagnet. From the perspective of dropping to 0 when you drop the applied field to 0 from that perspective it is behaving like a paramagnet and so, this combination we call as a super paramagnet magnetism is a phenomenon.

And, so, this super Paramagnetism is a phenomenon that is seen in the nanoscale domain. It is a very nice example of something of a phenomenon that is not normally seen in the micro-scale and is seen in the nanoscale we discussed right at the beginning that when we talk of nanomaterials it is not simply sufficient that something be in the nanoscale because if it is in the nanoscale. And, it simply shows you the same property that the material is showing you in the macro scale, then you have not actually accomplished anything special right it is exactly the same. And, so, you can use it you need not use it. It is irrelevant.

But, on the other hand, if you come to the nanoscale and by just because you came to the nanoscale you are seeing a property dramatically different or significantly different in some way than the property shown by the same material in the macro scale then you have got something interesting. It means now that material can actually do something for you which it was previously unable to do for you right. So, now this is the same situation here we have now got ferromagnetic material which was which did certain things nice, it has strong response relative to paramagnetic material, but it had the problem that it could not be switched off when you switched off the applied field. Now, you have a situation where it still shows you this high magnetic response, but it can be switched off.

So, therefore, it can be used in some biomedical applications where you want there are some kind of porosity or something that you want to close and you want to close it by putting some magnetic material there which is superparamagnetic; you apply a field it closes, you remove the field it opens and it does so immediately. You could have used a paramagnetic material also in to enable you to do that, but you would have had to apply a very strong field for it to show you that response, here you can do it with a much milder field. So, this is a nice part of it.

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So, it is in this context that I will draw your attention to a reference here. This is a very nice reference in the field of biomaterials and using some new phenomenon in the nanoscale for biomaterial material applications. It is actually in the Journal of Controlled Release. So, you can see how important this idea of controlled release of a drug is that they have an entire journal associated with controlled-release just that concept of controlled release, there is a journal associated with it. There are so many people working on it.

And there is this article on something called a nano-Ferro sponge where they have used some kind of spongy material in which they have incorporated this nanoscaled magnetic materials. Nano scaled magnetic material has been incorporated into it and that enables them to do controlled release. So, you can take a look at this paper. They talk of in fact, essentially this idea that we have spoken about in general terms in this class is used in great detail in this is in this work.

You can see how they prepare samples, how they create this nanoscale magnetic material and having created this nanoscale magnetic material how they incorporate it inside that tissue. So, all of that is there I mean or what is they look at processes they are doing it without actual actually using it in any in a body they are doing it in a simulated condition. So, what all they do in terms of simulating it, what is the medicine that they simulate the release of, how do they incorporate this nanomaterial in the walls of that the spongy structure to enable some control and they look at various things.

They look at how it how the responses in terms of when you switch on – switch off, how much drug is coming out, how much drug is not coming out that kind of activity. They also look at so and also try to model it try to tell what is happening here, how is that magnetic field impacting this release process so, there is some modelling associated with that and they also speak about fatigue.

So, in all these cases in all applications, we want to know how long we can persist with this process. So, does it mean that for one or two cycles it will work well, but after you switch on and switch off like three or four times it will stop working or can you continue to switch on and switch off hundreds of times and we will continue to have this opening-closing kind of behavior. So, all of that is looked at in this paper. So, it is a very nice paper for a very specific and detailed example they, of course, show you all the micrographs and everything.

So, you can go ahead and look at this if you are interested to see how this magnetic phenomenon the nanoscale is being used for a biometric materials application.

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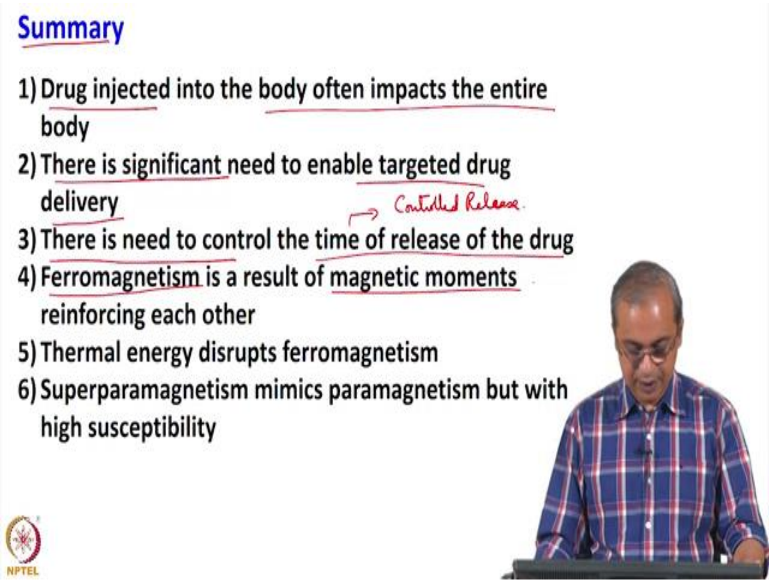

So, in summary we began by saying looking at this idea that a drug injected into the body often impacts the entire body and often that is not a desirable condition it is not desirable for it for us to have a medicine impact all of the rest of our body because that is exactly what is referred to as a side effect and mostly the side effects are undesirable. So, this is what we do not want. So, we want medicine to act only at that particular place.

So, there is a significant need to enable targeted drug release. So, there is a significant need to have a targeted drug release. And also, in the same context so, that is targeted with respect to location there is also a need to control the time of the release of the drug and this is this idea of controlled release.

And in fact, there are various ways in which they do this controlled release. They actually sometimes, you can use heat to enable you to do this, you can use electricity to enable you to do this, you can use magnetic properties to enable you to do this, you can control pH the acidity or alkalinity basicity of that region to help you control this. So, and each of them has positives and negatives in terms of how well it can do it and how well I mean the limitations that you may have, but there is a need for this to control the release of the drug.

And in this context, we have also looked independently at this idea of ferromagnetism and if that it is a result of magnetic moments reinforcing each other and therefore, there is some level of permanent magnetism in the material. And, that is why we call it a magnetic material as opposed to paramagnetic and diamagnetic materials and that generally this there is thermal energy which disrupts this ferromagnetism. So, this is one aspect that we have to keep in mind the thermal energy is trying to disrupt ferromagnetism.

But the domains are able to reinforce each other significantly in the macro scale that the thermal energy is unable to disrupt them in the micro-scale at room temperature. So, if you raise the temperature at high enough temperature you will have enough thermal energy that it will disrupt this magnetic orientation, I mean reinforcements and they will become random. So, that always happens. So, magnetic materials may often lose their magnetism if you go to high enough temperature.

If you go to nanoscale material then the domains have been made very small and then you have created the situation that they are unable to reinforce then each other on a sort of on a permanent basis, at that point the thermal energy even at room temperature is adequate to disrupt them. So, that is the reason why they are going back to 0, that the thermal energy at room temperature is adequate to disrupt the magnetic moments from reinforcing each other and so, a ferromagnetic material begins to show you paramagnetic behavior.

So, super this is referred to as super Paramagnetism and it is the idea that a ferromagnetic material is mimicking Para magnetism or showing you aspects associated with Paramagnetism, but it has high susceptibility. So, in other words the saturation magnetization that you get is very high and therefore, it shows you from the perspective of saturation it is showing you behavior like ferromagnetic material, but from the perspective of 0 response and they in the presence of 0 applied field it is showing you paramagnetic behavior.

This concept this combination is referred to as superparamagnetism a very unique to the nanoscale can be used for various applications and I have given you a reference where they have used it for biomedical applications. So, that is our discussion for today. We will look at some other concepts in our subsequent classes.

Thank you.