Introduction to Biomedical Imaging Systems
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Lecture - 41
MRI_Phys_S10-S16

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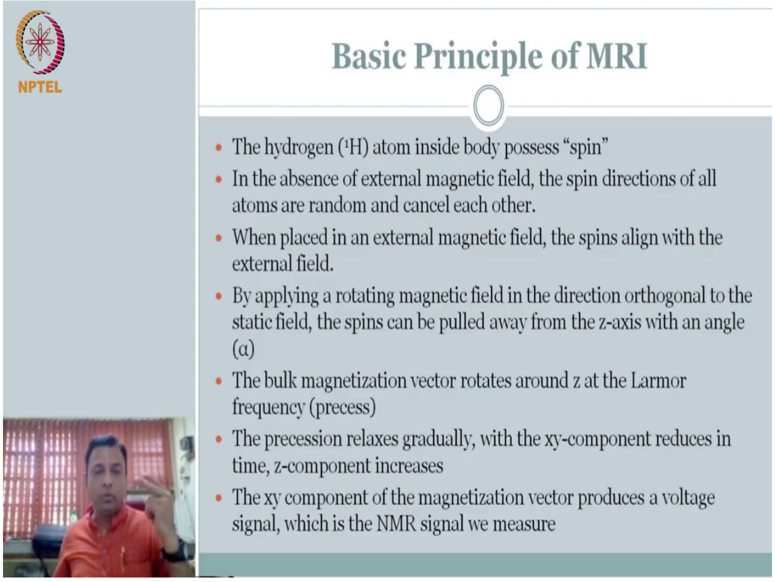

Talked about two aspects one is the nuclear has protons and the protons spin right, especially we talked about we being water bodies and we almost will be almost always will be interested in having the hydrogen atom because there is so much of H H 2 O right. So, for every atom you have two hydrogen. So, you have so many hydrogen nuclei.

And so, we talked about something that is spinning, anytime something is spinning about itself. What do you have? You have angular momentum right. So, it has protons or nothing, but it has a mass. So, when something spins there is a angular momentum to it and of course, we also added info that these are happened to be positively charged. So, when positively charged particle spins we talked about what is called as thinking like a current in a loop and therefore, there is a magnetic moment that vector that we drew yesterday.

So, clearly there has to be some relationship between the angular momentum and the magnetic moment that is generated because it is the same object because object happens to be a positively charged proton. So, when you have this spinning there should be some relationship between the angular momentum and the magnetic magnetization vector that has to be related to the material property of the object right. So, that is what we will see in the next few slides.

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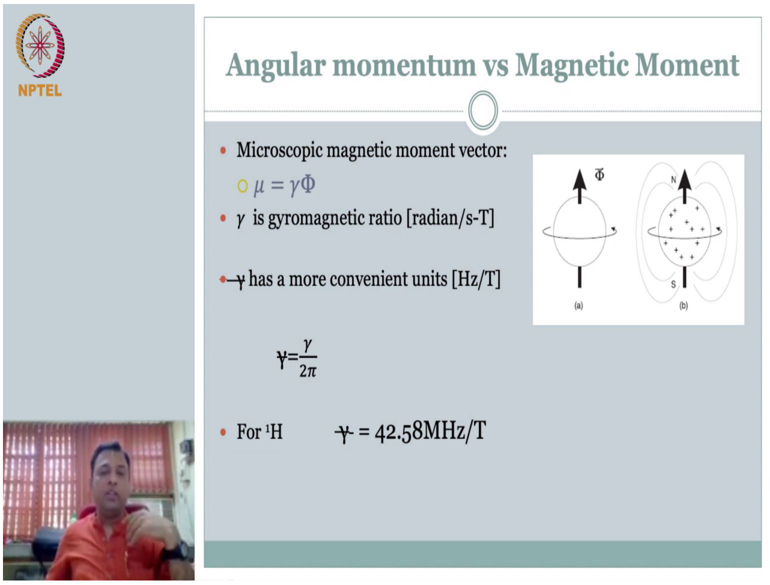

Essentially we are talking about angular momentum and then you have magnetic moment. How are these two connected right, these two are connected through the material property called as gyromagnetic ratio and as you can see the units gyromagnetic ratio is nothing but radians per second per tesla.

I hope you would have heard the term tesla I mean radians per second you; obviously, would have heard tesla that capital T that you see there is tesla which is nothing, but magnetic field strength right. This you would have heard probably when they talk about MRI or the scanner in this hospital is 1.5, tesla this is half a tesla, this is 3 tesla. So, you would have heard this tesla before.

So, essentially of course, if you divide it by radians per second so, you could convert it to just our hertz. So, divide it by 2 pi you get the more convenient notation of hertz per tesla. What is our interest to ask is, there are list of values given for different nuclei in the textbook you can see the table, but you will notice for hydrogen the material property what we are talking about here is the gyromagnetic ratio is 42.58 megahertz per tesla.

What this means is, if I put you in 1 mega 1 tesla scanner the hydrogen atoms in your body hydrogen nuclei in the body right has a frequency radians per second right of or converted to natural hertz is 42.58, I am hesitant to use because we will introduce the terminology of this gyration frequency in the next slide ok. But essentially this is the frequency of precision. And then what does this say; that means, if I have a known magnet if I have a known ability to measure the frequency then maybe I know how I know it is hydrogen ok. So, we will build on this material.

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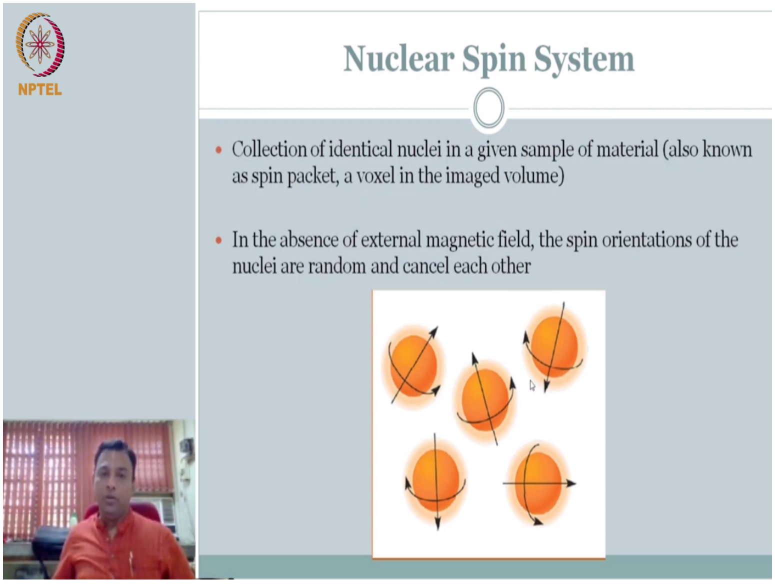

So, what we actually have is collection of identical nuclei right. You have a sample value sample volume that you take, you have several nuclei there right. We are interested in hydrogen nuclei and so all of them have different orientation that we saw yesterday right each one is in different direction so, there is no net magnetization.

But, the moment I put that volume inside a magnetic field right subjected to external magnetic field, then all of the micro spin starts to align with respect to the static magnetic field that is applied ok external magnetic field that is applied. So, in the absence of external magnetic field you do not have any net magnetization because it is all random it all cancels each other out right like this each one is spinning in in such a different orientation and therefore, the net sum of the all the vectors which is the magnetization vector is going to be 0.

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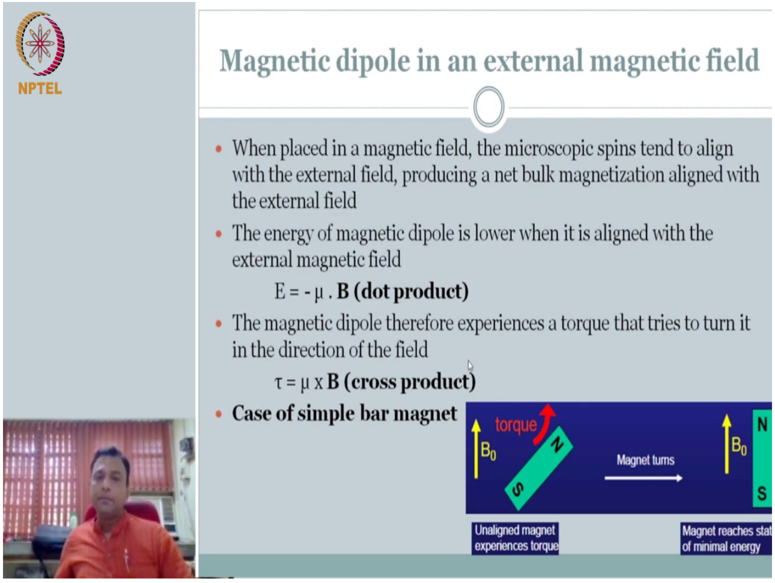

But, we are interested in a case where we want to use it as a signal right and so if everything is cancel to 0 then we actually do not really know much about. So, somehow the whole scheme in magnetic resonance imaging is how do we manipulate, how do we generate this magnetic moment vectors. Of course, by virtue of having hydrogen and its own spin there is some microscopic magnetization vector that is there.

But, how do we manipulate so, that we get some signal out of this right how do we get some measurable quantity because random distribution it is 0 otherwise. So, how do we engineer it to our advantage that is the whole idea. So, how do we do that this again think about it.

So, we talked about analogy between the spin and the bar magnet the spinning proton and the bar magnet. And then what we noticed is if you take the bar magnet and put it on the table we may have 10 pieces of bar magnets you put them in the table and you throw that so, such that it was all falling in different directions initially.

But, then you will notice that quickly it will all align to the earth's magnetic field that is when you subject this to external magnetic field which is earth's magnetic field it will all nicely align itself. Of course you have to give some finite time right you throw it and then it quickly it will all reorient. So, what happens similarly what happens if you have a spin and you have a micro microscopic magnetic moment vectors.

What happens to this when this is subjected to external field you would expect similar thing right. So, let us just complete what we know of case of simple bar magnet you have you throw it in any direction right the B naught here in this case is your earth's magnetic field. So, the magnet bar magnet will turn to align itself. So, it is experiencing a torque and that torques experience torques makes it aligned into the North pole direction.

So, this has to be your resting state which will be your low energy state and naturally initially when you started with it was in the high energy state right. So, unaligned magnet experiences torque, magnet reaches state of minimal energy. So, this is the case of simple bar magnet.

So, now if I ask you this question as to what do you expect your spinning charge right your spinning charge which has magnetic moment if you put it to a external magnetic field. Of course, here B naught in this diagram is earth's magnetic field, but let us say the spin I am putting it in a I have another magnetic field and I place this spin what is going to happen.

Well your first guess is it is just because there is an analogy turn you would expect that the spinning nuclei will also align itself to the direction of the external magnetic field and that is partially correct I mean you know it has to behave very similarly, but notice there is a big difference between the analogy of the case of bar magnet and at the spinning nuclei that we use for an analogy.

In case of bar magnet the bar magnet does not have any angular momentum right whereas, in this case of spinning magnet not only do you have spinning nucleus not only do you have moment magnetic moment vector very similar to the effect of bar magnet, but the magnetic field, but then it is having an angular momentum.

So, what happens when you have an angular momentum is when it is trying to come align itself to the magnetic field, but it is spinning; that means, it is having angular momentum I think there is one important concept that you would have heard. In fact, we use the term loosely in the previous slide gyromagnetic ratio.

So, I am sure you would have heard gyroscope what how it works it is all brush up your 3rd semester, 4th semester or even 1st year if depending on the college and stream that you took your undergrad. You would had a subjects called Engineering Mechanics where essentially it has to do with you know not only force and the resultant motion.

But, also in one of the later chapter they would have covered this precision log you know precision and you have the top example like we will be cover some of it, but I think you should brush your material in that Engineering Mechanics chapter before you will be able to really get a good view of connection between the basic mechanics that is not taught at 1st or 2nd semester level to how it is applied in a neat field called as magnetic resonance imaging ok. That is what something beyond the scope of this course, but I would urge you to go have the joy of connecting the two concepts.

So, essentially what we are saying here is if you subject that magnetic moment vector to external field B this case then there is a dot product which is the minimum direction until there is a cross product. So, essentially the cross is your torque right. So, magnetic dipole therefore, experiences a torque that tries to turn it in the direction of the field right.

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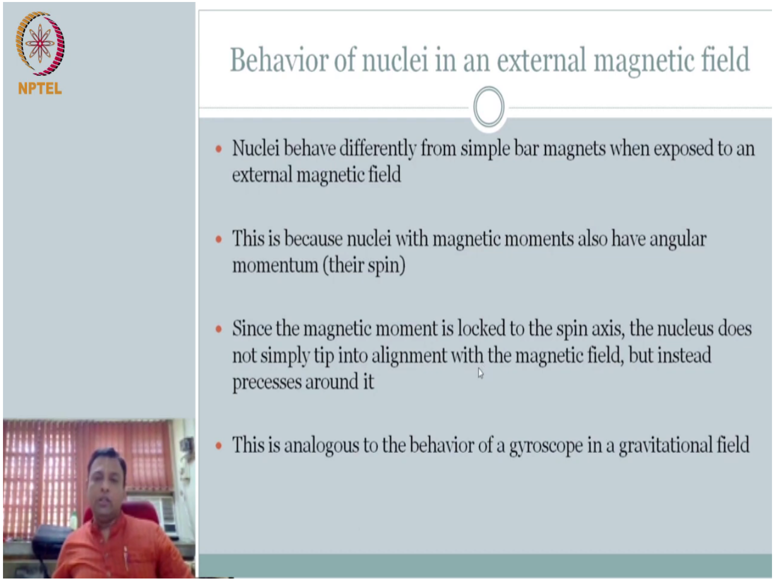

So, the interesting aspect is unlike bar magnet this does not directly come and align nicely in your magnetic external magnetic field direction that is applied because it has angular momentum. So, what happens is it behaves slightly different and because of the angular momentum what happens is it does not actually align it is spining around the axis.

So, it does not come and align itself right it is not doing this and aligning. It will if this is the axis right this is the spin it will spin with whichever direction it was this is the magnetic field external magnetic field direction you would expect the bar magnet to come like this.

Whereas because this is spinning it is not going to come like that it will try it will go it will go it will go around it will spin, but it will go around spinning gives its magnetic moment, but the angular momentum makes it precess around what is called as precess around the external magnetic field direction.

So, since the magnetic moment is locked to spin axis, nucleus does not simply tip into the alignment of the magnetic field, but it precesses around it ok. So, this is very analogous to the gyroscope in gravitational field.

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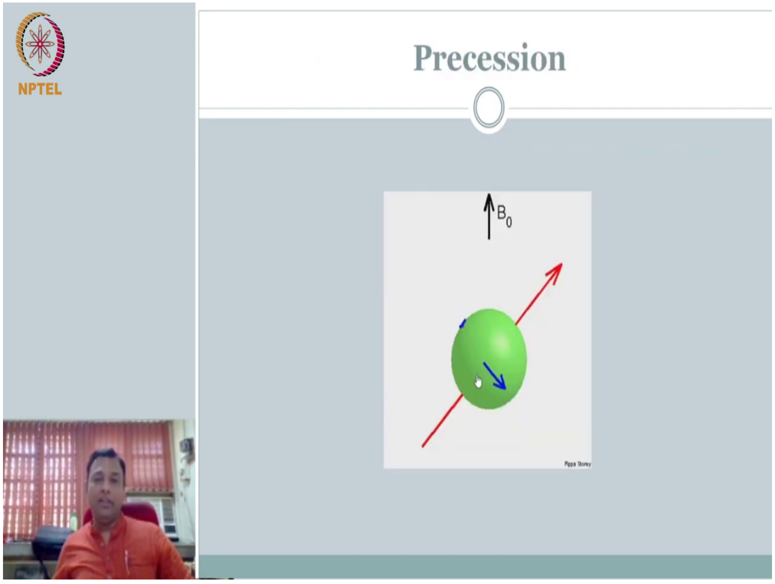

So, here is an example I mean it is very nicely done animation compared to the hand that I showed. I try to use this because in in a class it will be very helpful I will one wake several of you from sleep, but the other thing is some of the concepts actually can come out very nicely when you participate ok.

So, I will try my best to do it pretend that you are all listening to me and try to do it, but anyway there is a animation if you want to take a look at it later ok. So, this is called as a precession. So, you would have heard this before.

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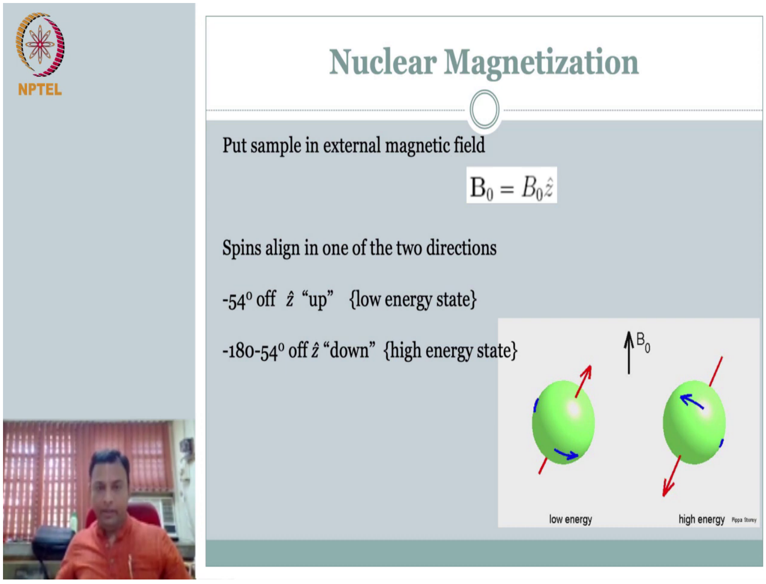

So, what happens is in the case of nuclear magnetization when you put the we would have some direction. So, when you put the external magnetic field let us called it as B naught cap the bold represents that it is a vector. So, it has a magnitude B naught and the direction z ok.

So, the spins align in either of the two directions. So, you have spins align in one of the two directions and as you would have guessed there will always be preference for low energy state that is in this case low energy is considered to be the up direction. So, what we are interested is not just one nuclei I mean you are not subjecting one nuclei alone to external magnetic field you have a volume right. So, there are going to be many of these that are there and so we talked about everything being random initially and therefore, the net magnetization is 0.

But, now you understand the concept which you have many of them and you supply B naught then all of them are going to try to either align in the plus or up direction or in the down direction. Of course, nature has its preference and therefore, there is a small preference towards the up therefore, there is more number of spins in the up direction than in the down direction. And therefore, what happens the net magnetization is always in the up direction there is a net non zero magnetization that is along the direction of the external magnetic field that is the key.

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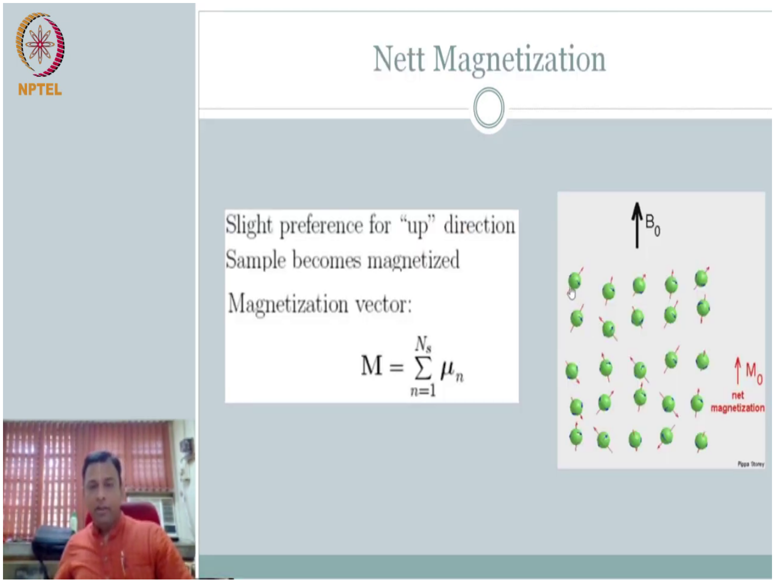

When you have multiple of these right each one you take a volume and you have several nuclei that are spinning you are subjecting all of that to B naught. What happens is in the end you have a net magnetization in the up direction. So, net magnetization vector capital M is a collection of all the micro spins that are there.