Neutron Scattering for Condensed Matter Studies
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Week 9: Lecture 24B

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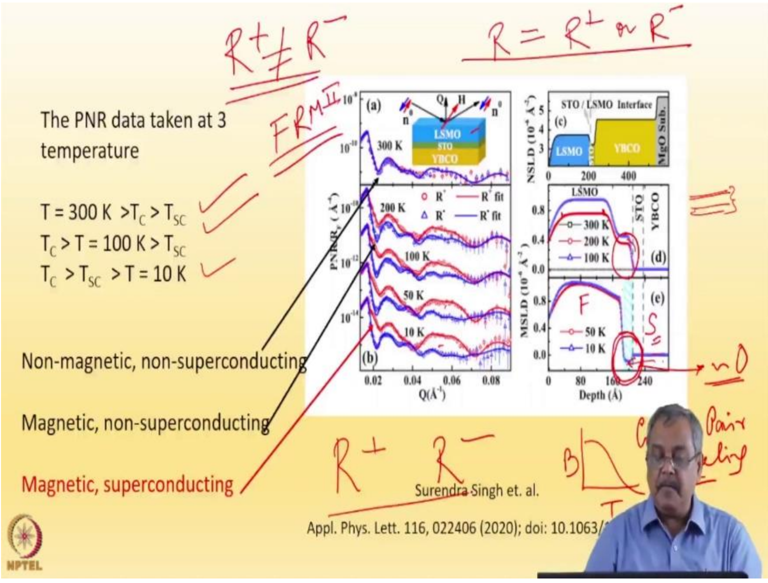

Here, I show you the results. The polarization reflectometry data was taken at three temperatures. One is at 300 K where neither LSMO is ferromagnetic nor YBCO is superconducting. Then data was taken at 100 K where LSMO is ferromagnetic but the superconductor (YBCO) is still in normal state. And then we also have data at 10 K, where the magnetic material (LSMO) is ferromagnetic and the superconductor has become superconducting as it has undergone superconducting transition at around 65 K. So it is a combination of a superconductor, an insulator, and a magnetic material.

First, let us discuss the room temperature data. You can see that there is no difference between R^+ (red) and R^-(blue), $R^+ \approx R^-$. This indicates that sample is non-magnetic at 300 K. However, the 100 K data show the signature of separation between R^+ (red) and R^-(blue). When this happens, that means the sample has got a magnetic moment density. You already know that for a magnetic sample, different polarization of neutrons sees different potential resulting in different critical angles and intensity profile. So, what do you find when we fit it?

Here I will get the magnetic moment density profile of the sample and more specifically that of the LSMO layer, as this is the only magnetic layer in our trilayer sample. At 300 K, MSLD profile shows no magnetization while at 200 K we have got a profile which tells us that LSMO is magnetic where magnetic moment density reduces towards the interface. At 10 K, the ferromagnetic LSMO is at a tunnelling Junction separated from a superconducting YBCO (by an insulator).

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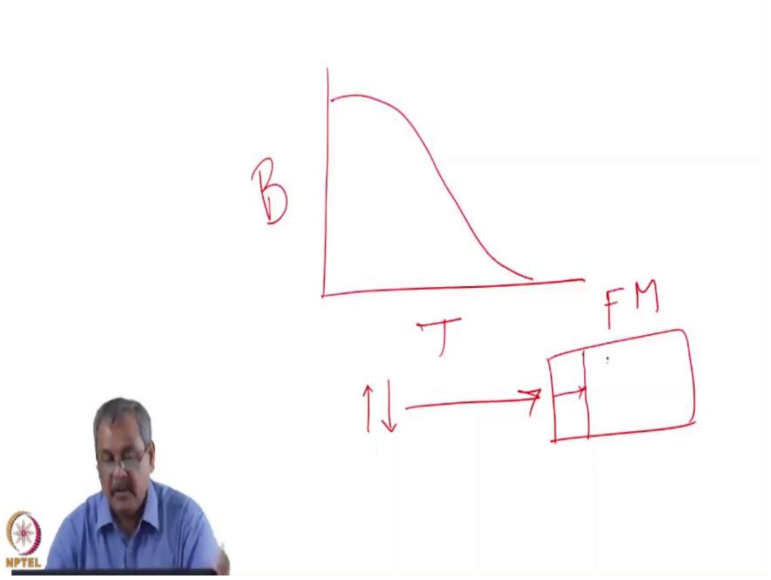

We are aware that for a standard ferromagnetic sample magnetization increases as we go down in temperature and that is precisely what we found from the analysis of PNR data here. Sample is non-magnetic at 300 K and magnetic at 200 K whereas magnetic density increased as we went down to 100 K.

Now, at 10 K you can see that the major (part of magnetic) profile (in LSMO layer) remains nearly the same. Insulating STO and superconducting YBCO parts have almost zero magnetic moment density. Now, closely watch the part of LSMO layer having interface with the insulating STO. Here, we can see that with the superconducting state appearing in YBCO, then the interfacial LSMO magnetic moment density is close to 0 or marginally negative. Now, this is something typical of Cooper pair tunnelling. If the Cooper pairs enter a ferromagnet, then they will tend to cancel the magnetism in the ferromagnet because that is the nature of superconductors. Here, the penetration depth (of the Cooper pairs) will dictate up to what distance it will be able to cancel out the magnetic moment density and that is what we found in this experiment.

Now, you can see that at 100 K and 200 K we have this interface magnetic moment intact, which is lower than that of the bulk, but it is not negligible. However, when YBCO is in superconducting state this interface moment has gone to almost 0, and this is a signature of Cooper pair tunnelling. This is a very interesting observation. So far as tunnelling of Cooper pair is concerned which I have been able to understand it by using polarized neutron reflectometry on this sample. This experiment was done at FRM II (Germany).

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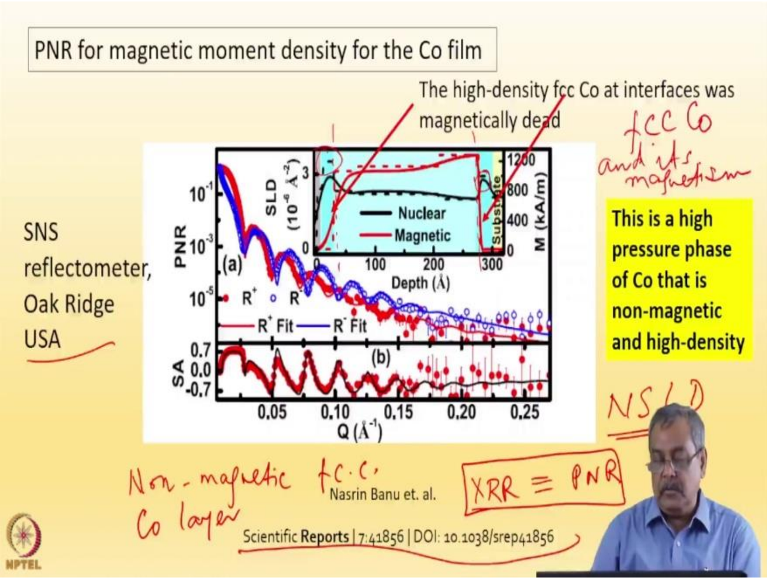

I have shown you two examples, one non-magnetic Co layers (at interfaces) that I could catch (detect) using polarized neutron reflectometry, and here in case of a superconductor-insulator-ferromagnet tunnel structure, I could also catch (detect) the tunnelling of Cooper pairs from the superconductor into the ferromagnet in terms of reduced magnetic moment density at the interfaces. With these two examples, I hope I have been able to justify that polarized neutral refractometry is an ideal tool to understand interface magnetic moments in interesting samples.

Here, one was non-magnetic interface layers in a Co film and the other one was a ferromagnet LSMO (layer), where we have observed Cooper pair tunnelling. These two studies were done with R^+ and R^- measurements without any polarization analysis.

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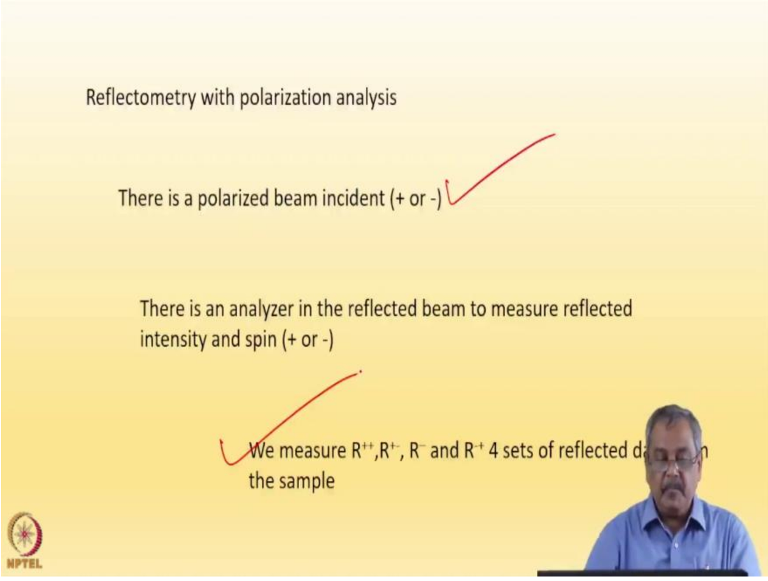

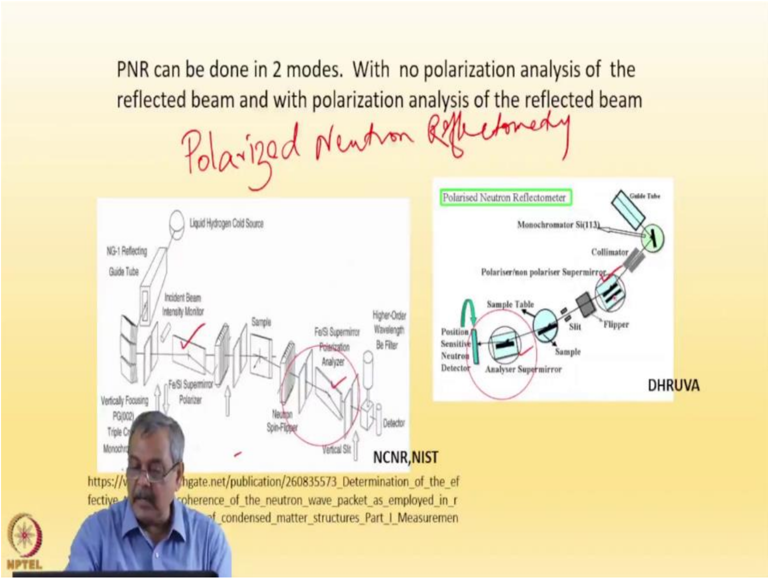

From here, I jump into the next part, which is (neutron) reflectometry with polarization analysis.

There is an incident polarized beam which is + or -, and there is an analyser in the reflected beam as I showed you in the two experimental setups. Let me just quickly show you experimental setups; you have analysers here, so with this we can do a polarization analysis of the reflected beam. You can measure R^{++}, R^{+-}, R^{-+}, and R^{-+} so that we have four sets of reflectivity data now.

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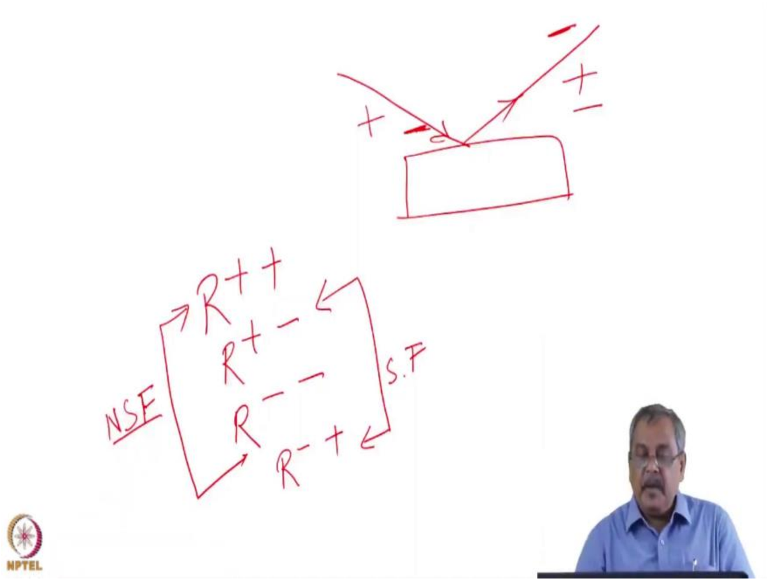

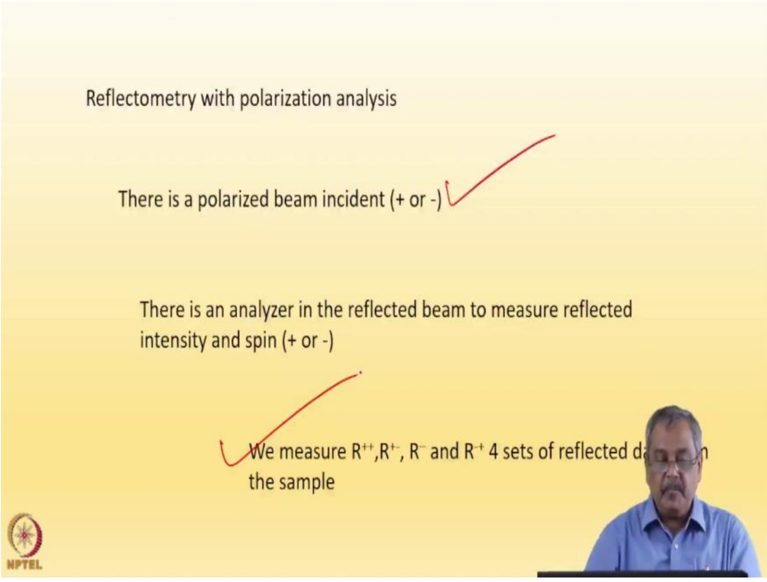

Now, I am doing analysis of the reflected beam, so if plus goes to plus than we have R^{++}, if plus goes to minus then we have R^{+-}, similarly, for down polarized beam we have R^{-+}, and R^{--}. So, we have two spin flip (R^{+-}, R^{-+}), and two non spin flip (R^{++}, R^{--}) (data sets). We have got four sets of data, two of them are non-spin flips, two of them are spin flips, and from here I will be able to determine the magnetic structure in the sample.

I will stop here before I go on to the next model.