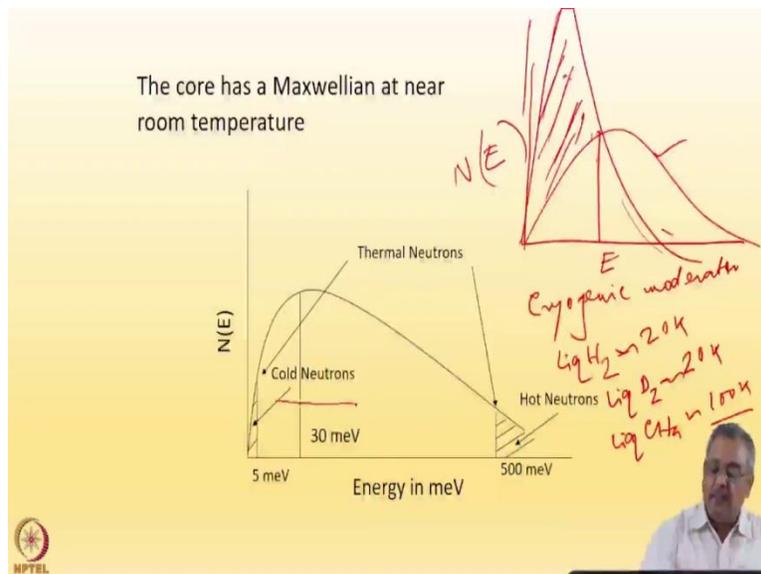


**Neutron Scattering for Condensed Matter Studies**  
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**Week 01**  
**Lecture 01C**

Keywords: Maxwellian, Cold neutrons, Neutron guides, Supermirror, Monochromator drum

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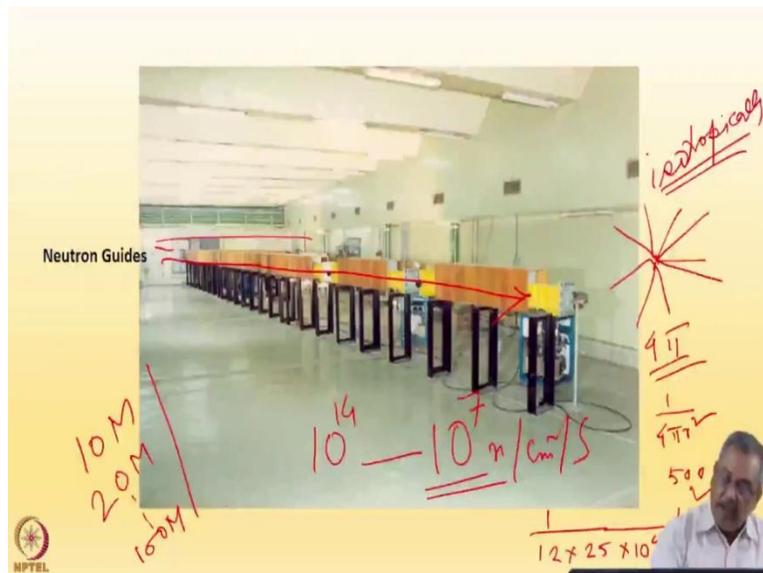


From the core or in this case, from the spallation target neutron was moderated, that has got Maxwellian at near room temperature or at lower temperatures called cold neutrons. I will quickly tell you the role of cold neutrons (thermal neutrons re-moderated to low energies) For some experiments we need neutrons with lower energies and for some we need neutrons in the thermal energy.

In some parts of the reactor or near the spallation target, we can insert a cryogenic moderator, that means a moderator at low temperature. Typical cold moderators are liquid hydrogen at 20 K, liquid deuterium at around 20 K and RAL also used liquid methane at around 100 K.

These moderators capture neutrons, re-thermalize them. That means this Maxwellian is re-thermalized into another Maxwellian and at lower temperature. In the process, you do not multiply the total number of neutrons, but in a certain region of energy, you have a gain in number of neutrons at the cost of high energy neutrons. These sources can be used for experiments where low energy neutrons are preferred. So, these are known as cold neutron sources, which gives us cold neutrons.

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DHRUVA Reactor Hall

The photograph shows DHRUVA neutron guides. I will briefly tell you about neutron guides. Basically, the reactor is on the other side, there is a wall here. I showed you the reactor hall. Let me just show the photograph. This is the reactor hall and this is how the neutron guides are taking neutrons out from the reactor hall. The neutrons are coming from the reactor hall and then traveling through the guide like this.

These are neutron transporting devices. But they are static devices. There are no moving parts in them. They work using the principle of total external reflection of neutrons. This is necessary because it is difficult to place all the experimental facilities in the reactor hall. So, you need more space. That is possible with neutron guides, Neutrons are neutral. They are coming out isotropically from the reactor core. There is no directionality. They go in all possible directions. So, every point of the reactor core behaves like a  $4\pi$  source.

If it is a  $4\pi$  source, you can see that the fall of intensities will be  $1/4\pi r^2$ . That means, if I go 5 m or 500 cm, then the flux falls by  $1/4\pi r^2$ .

i.e.,  $\frac{1}{12*25*10^4}$

12\*25 is 300.

$$\frac{1}{3} * 10^{-7}$$

, Flux falls by a factor of  $10^{-7}$ . This is too small value. If you start with  $10^{14}$  neutrons, and if I just allowed to go by 5 m, which is typically the distance it has to travel to reach the outside of the reactor block, I get neutrons only which is number is to about typically  $10^7$  neutrons/cm<sup>2</sup>/s.

Neutron intensity falls very fast because, they are coming out isotropically. Now, how to take them say. 10, 20, 30 or even 100's of meters away? How do I carry them? I cannot carry all the neutrons, but I can carry some neutrons and how can I do that I will just quickly tell you.

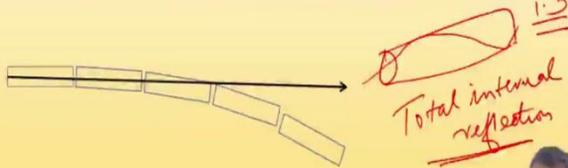
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If we try to take neutrons far, the intensity falls as  $1/4\pi r^2$   $n < 1$



Neutron Guides are optical fibres for neutrons

They were glass coated with Ni or preferably Ni<sup>58</sup>. Now-a-days we use supermirrors 1.5  
1.3

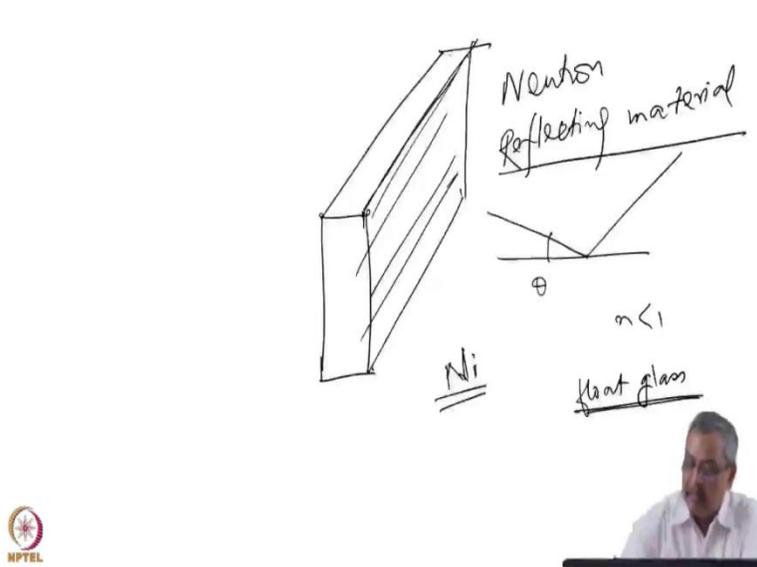


It avoids direct line of vision to the reactor core. Reduces Fast n. and  $\gamma$  background



If we can assemble neutron reflecting elements like this, consider how light travels in an optical fiber. You know that optical fiber is a cylindrical thing and once the light enters, it can follow the optical fiber whether you bend it or keep it straight, through total internal reflection. In the case of neutrons, a similar thing is done, but for neutron, the refractive index,  $n$  is slightly less than 1. For light, the refractive index is typically more than 1. So, you have total internal reflection. While, in the case of neutron, because  $n$  is less than 1, you have total external reflection.

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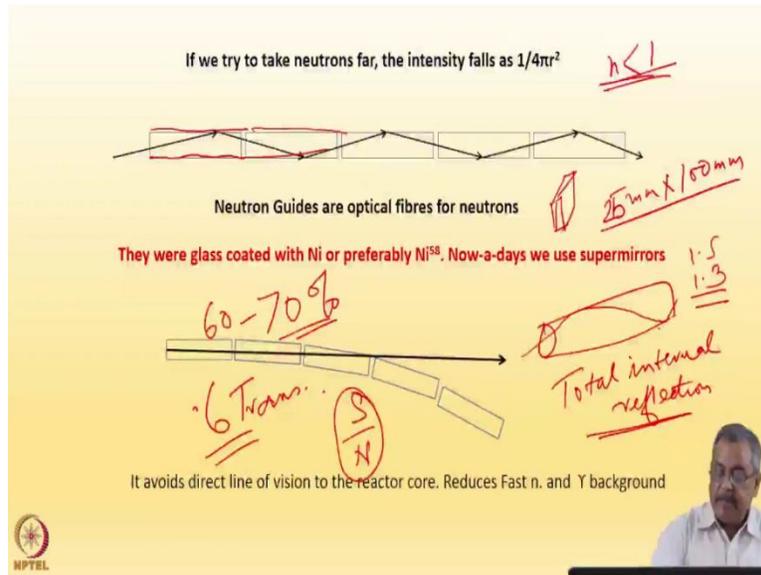


I will show you, how typically a neutron guide looks like. It is a rectangular assembly, but these walls are made of some good neutron reflecting material.

Reflection means optical reflection. It follows Snell's law. Neutron impinges on the surface and then reflect but because  $n$  is less than 1, up to a certain angle neutron gets total externally reflected. Example for a typical neutron guide material is nickel.

There are very flat glass pieces known as float glass. Float glass is coated with a good material for neutron reflection. Nickel is good because nickel has got a reasonably large critical angle and also it is a good metal to handle.

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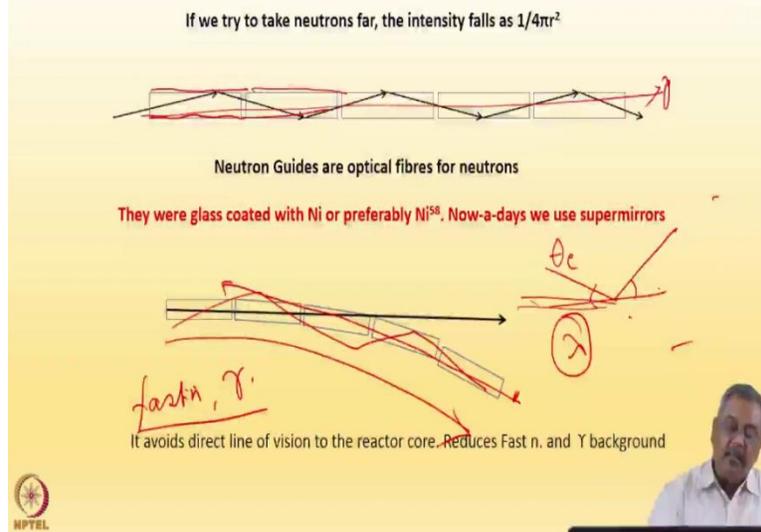
The neutron guides, that I showed you here in DHRUVA. These are the plan view of the guides. These are the nickel coated pieces. In case of DHRUVA, the dimension of this guide is  $25\text{ mm} \times 100\text{ mm}$ .

I will show you the photograph of the guides and the experimental setup that have been put up in the guides in my later talks. Low energy neutrons are taken out by using neutron guides from the reactor halls and the experimental setups can be set up in a neutron guide hall.

There are several advantages of using neutron guides. One is that instead of  $1/4\pi r^2$  loss, as it is traveling through total external reflection, you can have typically 60 to 70 % transmission of the neutrons. So, you will have some loss of intensity, but the fact is that as we have gone outside the reactor hall, the number of background neutron counts fall drastically by a factor of  $10^4$  or  $10^5$ .

So, the 0.6 transmission with a drop in the background of  $10^4$  gives you an excellent signal to noise ratio for experiments, and you can do much cleaner experiments in the neutron guide hall, and I will describe such experiments in my later talks when I discuss typical experiments using neutrons of lower energy or cold neutrons.

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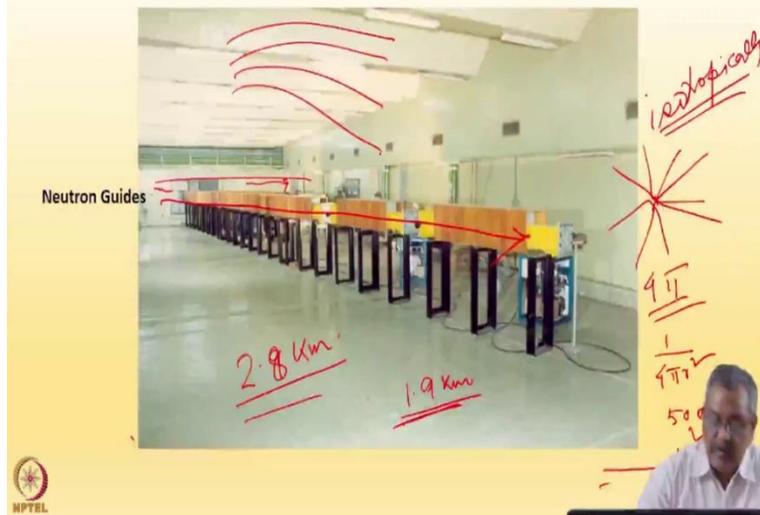
Why cold neutrons are preferably transmitted using neutron guides, because, the critical angle of reflection depends on the wavelength of the neutrons. Longer the wavelength, lesser is the energy and larger is the critical angle and they are preferably transmitted in the neutron guide.

Also, another interesting thing is that, instead of making the neutron guide straight, we can make the neutron guide slightly bend. When you do this, you can see that now this neutron beam which is coming out at this point, but you do not look at the reactor core directly. You are avoiding looking at the reactor core directly.

Basically, along with desired neutrons which are low energy neutrons, you also have fast neutrons and gamma rays coming out from the reactor core and they will also travel in this direction.

But we do not want them. The fast neutron means high energy neutrons. For our experiments in guide, we need low energy neutrons. Because of a certain solid angle, you are looking at the reactor core directly and gamma rays are harmful. When you make slight curvature, the neutron which is following the neutron guide, by total external reflection can also follow the curvature of the guide and come out here, but fast neutron and gamma rays cannot follow the curvature of the neutron because fast neutrons will have a very low critical angle, and they do not transmit and gamma rays do not get reflected by the guides. So, they cannot follow. I can get rid of the gamma ray and fast neutron backgrounds by bending the neutron guide.

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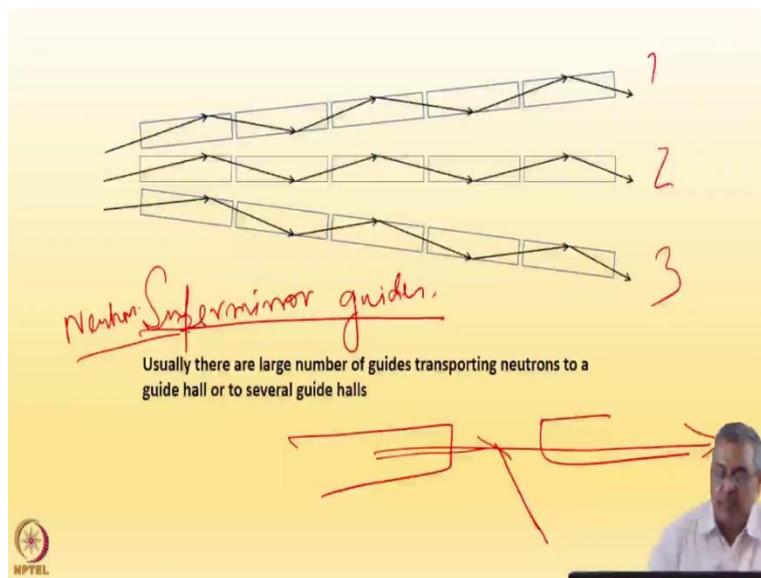
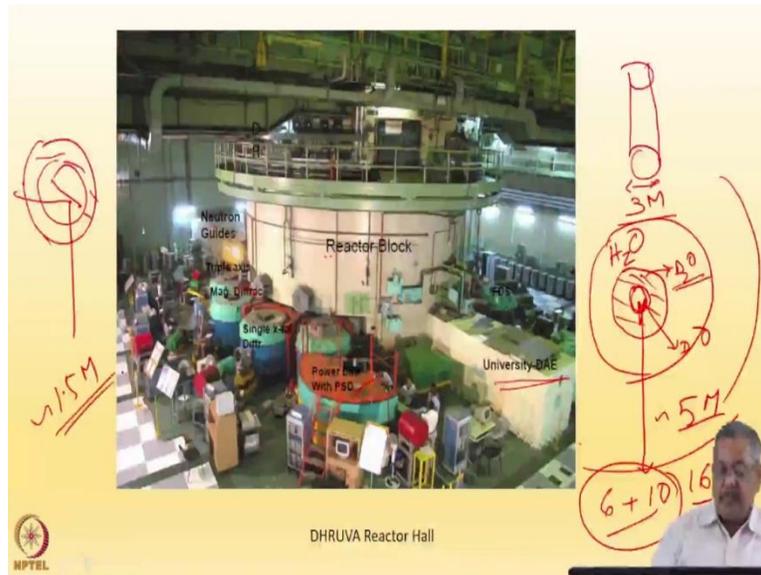


I have showed you a photograph of guides. There are two guides. this one and this other guide at the top. One has a radius of curvature of 2.9 km.

This curvature is very small and the other one has a radius of curvature of 1.9 km. i.e., 2900 m and 1900 m are the radius of curvature of the two guides so that we can avoid fast neutrons and gamma rays.

We will come to it again when the time comes to discuss experiments using cold neutrons, but this is one advantage of using neutron guides and going outside the reactor hall to do experiments at lower background environment.

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Another aspect is that, when we want to put more number of instruments. You can see the reactor hall. Let me just go back to the reactor halls once again. Look at this photograph, you can see the reactor hall for setting up experiments. We need to shield the outgoing beam and these are known as monochromator drums, which shields the neutron beam. They are called monochromator drum because each of them has a monochromator at the center of the drum. We have a monochromator which monochromates the incoming neutron beam by means of Bragg reflection and shields the other unwanted radiations. It does not allow them to come out but then, these monochromator drums are large. They are around 1.5 m in diameter, which does not allow too many setups to be

made inside the reactor hall and for that, the answer is that we can use neutron guides and we can use more number of neutron guides in a beam path where we can put more number of instruments here.

And also, you can have a break in the guides where we can put again a monochromator and take the beams out and the rest of the neutron beam can travel so we can put more number of instruments at a low background environment in a neutron guide and today, apart from simple nickel guides, there are super mirror guides. We are also planning to install super mirror guides.

Super mirrors are above mirrors that is why they are called Super mirrors. They are called neutron super mirrors and I will discuss neutron super mirrors in a later lecture. Today, I will stop here after familiarizing you with the neutron sources.