CRYSTAL SYMMETRY, X-RAY DIFFRACTION, AND PHYSICAL PROPERTIES

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Lecture 40: DVD as a Diffraction Grating

From this lecture onwards I will start discussion on diffraction and just to kind of understand what is diffraction before we get into diffraction from crystals. This is something that you would have probably done in a physics course, diffraction of optical light through what is called as a diffraction grating.

Now, imagine that I have these slits and this is my incident radiation which let us say is electromagnetic radiation in the visible range. So, we can imagine as follows that I have a screen out here. I can get what is called as the direct beam, while there are going to be other beams going in different directions; these are what we call the scattered beams. Now, the scattered beam also will fall on the screen and produce some intensity.

Now, the question is whether that intensity is finite or not depends on what is called the phase difference or the path difference of the rays that are coming out from the various slits in the diffraction grating. So, if I get a finite intensity, you know I will get another spot which is what we call as a diffraction spot.

Now, under what condition whether a scattered beam will have a finite intensity or not, we can do a calculation of the path difference. So, let us say this is a scattered beam and it makes an angle of θ with respect to the direct beam. If I look at these two rays, one and two, and want to find out what is the path difference between them, let me call this as Δ_{12} to represent the path difference between ray 1 and ray 2.

So, let us do the following. I will put some parameters out here. The distance between the slits is d. Let me drop a perpendicular from ray 1 onto ray 2. Now, this angle we know is θ, therefore very clearly this angle will also be θ. And what is the path difference? The path difference means the difference between the distance travelled by the two rays before they fall on a detector or on a screen, and this difference is δ_{12}. So, clearly from this triangle out here, $\delta_{12} = dsin\theta$.

Now, what can this tell us? That depends on what is the relationship of this path difference with respect to the wavelength of the light or the wavelength of the incident radiation and how does that work. So, let us briefly look at interference of waves.

Now, one situation can be as follows. I have ray 1, this is ray 1, it has an amplitude of 1. Let us consider ray 2 which also has an amplitude of 1, and as you can see, the valleys correspond to the valleys in ray 1 and the peaks correspond to the peaks of the two rays. Such a situation we call that these two waves are in phase, and essentially the path difference is 0. If I add these two rays together, they will get amplified to an amplitude of 2. So, here what is happening is what we describe as constructive interference, and we will get a finite intensity in this case.

Now, consider another situation. Ray 1 has an amplitude of 1, and now consider ray 2. In this case, you can see that where there is a peak in one, it corresponds to a valley in the other. So, peaks correspond to valleys and valleys correspond to peaks. If I now add up ray 1 and ray 2, both have the same amplitude, but they will completely cancel out and essentially one will get complete annihilation, or what we can call destructive interference. So, out here is constructive interference and here it is destructive interference.

In fact, this destructive interference is used to create such devices as noise cancellation headphones. Now, this I would call in phase, this is out of phase, and in fact it is 180° out of phase. You can also say that I have shifted ray 2 with respect to ray 1 by essentially creating a path difference of $\lambda/2$. When I shift the wave by a distance of $\lambda/2$, and remember λ is the wavelength, you can clearly see that the peaks correspond to the valleys and the valleys correspond to the peaks.

So, now coming to this, we want to find out what kind of a path difference should be there so that the rays are coming in phase. That is possible when δ_{12} is an integral multiple of λ. So, if the path difference is an integral multiple of λ, which is constructive interference, I will get a finite intensity. Hence, I can now write that constructive interference occurs when $n\lambda = d sin\theta$.

If $\delta_{12} = (2n + 1)\frac{\lambda}{2}$, then this creates destructive interference. There can be situations where the path difference is in between constructive and destructive interference, for example 90° or 45° out of phase, leading to partial constructive and partial destructive interference.

Hence, we can now write that this becomes the condition for diffraction: $n\lambda = d sin\theta$.

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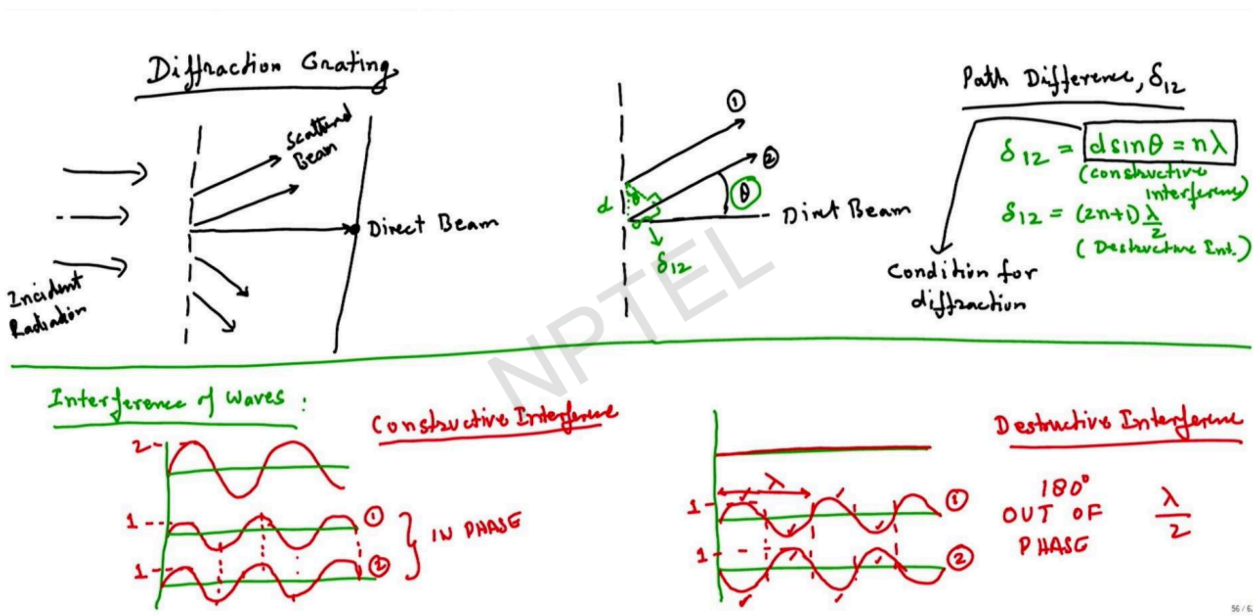

Now, what we will do is conduct a small experiment on diffraction. If we look at a DVD, it has tracks, and the tracks have certain spacing. These tracks are nothing but grooves on the DVD surface, and these grooves act as a diffraction grating. A DVD or even a CD can be used as a diffraction grating.

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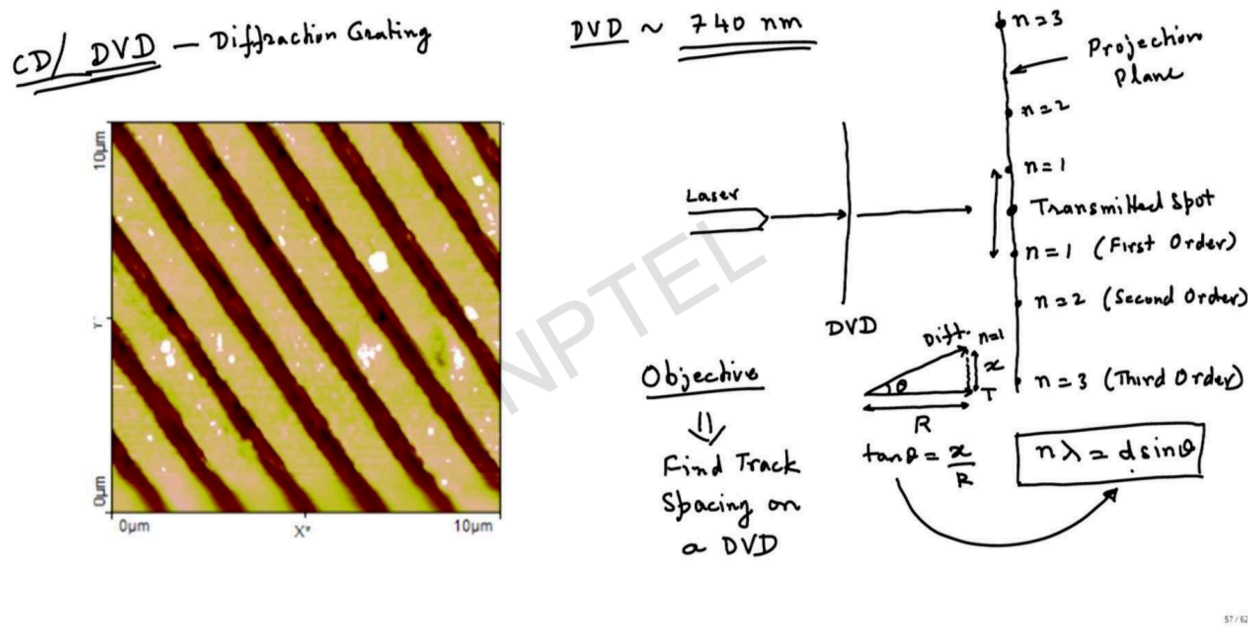

If I look at a DVD surface under a microscope, we can see these tracks that are very close to each other. For example, in the case of a DVD, the track spacing is of the order of 740 nm. Now, I take a DVD, remove the backing, separate the two layers, and take the transparent part on which the writing is done. When I shine a laser onto it, this creates a diffraction pattern. This is the transmitted beam or the direct beam, and then I will have several diffraction spots.

The spots closest to the transmitted spot correspond to $n = 1$, called the first order. Spots further away correspond to $n = 2$, $n = 3$, and so on. Eventually, there will be a value of n for which this equation cannot be satisfied because $sin\theta$ cannot exceed 1.

The objective of this experiment is to get at least the first order spot and measure the distance from the transmitted beam. If we measure the distance between the two first order spots on either side and divide it by 2, we get the distance between the transmitted beam and one first order spot.

Let us call this distance x, and let the distance between the DVD and the projection plane be R. Then $tan\theta = \frac{x}{R}$. Once we know θ, we can substitute it into the diffraction equation $n\lambda = dsin\theta$ for $n = 1$.

In the experiment, R was measured to be 130 mm. The distance between the pair of first order spots was measured to be 285 mm, so $x = 142.5$ mm. Therefore,

$tan\theta = \frac{142.5}{130}$,

which gives $\theta = 47.6^{\circ}$.

The diffraction condition gives $d = \frac{\lambda}{sin\theta}$.

Using a green laser with wavelength $\lambda = 532$ nm, $d = \frac{532}{sin47.6^{\circ}}$, which gives approximately 720 nm.

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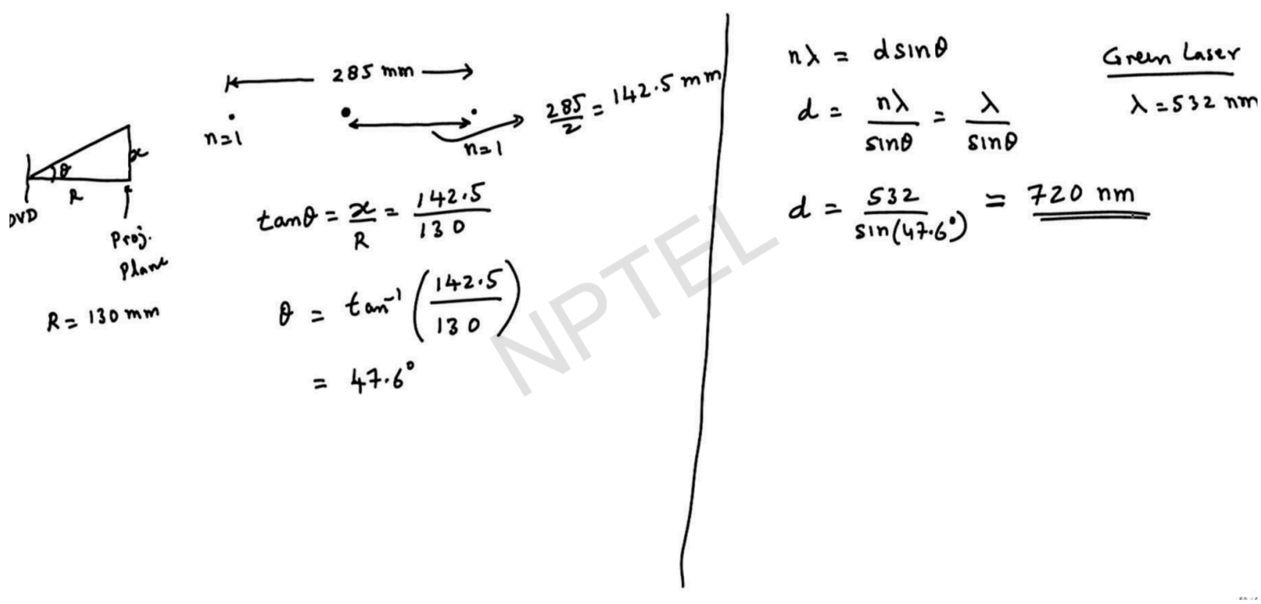

This is quite close to the expected value of about 740 nm for a DVD. Given the crude nature of the experiment and measurement limitations, this is a reasonably good result.

This experiment demonstrates that diffraction is a very powerful tool for making measurements, and in the case of crystals, lattice parameters can be measured with very high accuracy using X-ray diffraction.

Thank you.