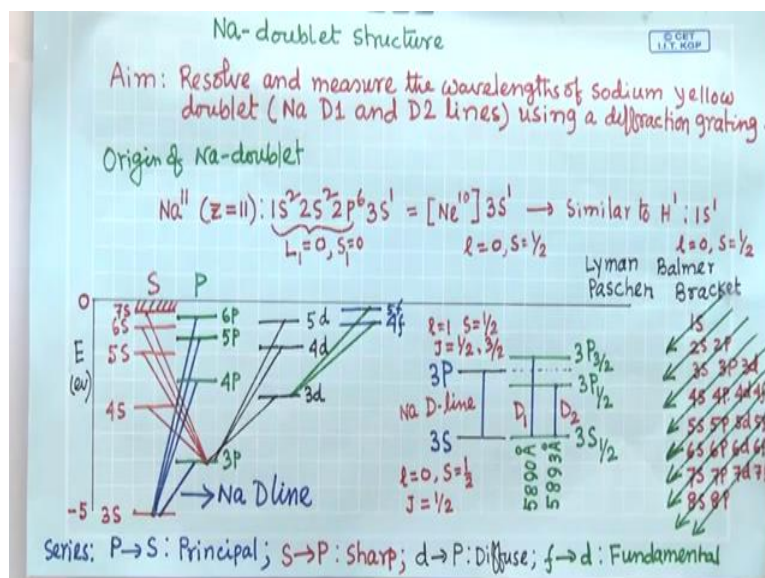


**Experimental Physics - III**  
**Prof. Amal Kumar Das**  
**Department of Physics**  
**Indian Institute of Technology, Kharagpur**

**Lecture – 42**  
**Sodium Yellow Doublet**

Today I will discuss about sodium doublet structure. Its aim of the experiment, I will demonstrate in our laboratory that that is resolve and measure the wavelengths of Sodium Yellow Doublet, sodium D 1 and D 2 lines using a diffraction grating.

(Refer Slide Time: 00:37)



What is the origin of these sodium D 1 and D 2 lines that we call this doublet structure? sodium atomic number is 11. Electronic distribution is 1 S 2 2 S 2 2 P 6 and 3 S 1 ok. That also we write that Neon 10 3 S 1. Neon you know this Lyman neon is inner gas this very stable electronic structure they will not either accept or donate electron. In these case is 3 S 1 that one electron will participate in transition from one energy level to another energy level.

It is a similar to hydrogen atom. in hydrogen atom this one s one electron is there. This electronic structure, which will participate in transition, is similar to hydrogen atom and these for sodium total angular momentum orbital angular momentum L is 0 and spin quantum number S that is half.

It is also similar to hydrogen atom or a hydrogen atom you know this  $L$  equal to 0 and  $S$  equal to half. hydrogen atom you have if you know that it shows the, it shows different series Lyman series, Balmer series, Paschen series, Brackett series bunch of transition lines spectral lines we see, that we till the tell series.

One can expect this type of series in sodium spectra also and it is objects. that series it is a call principal series, sharp series, diffuse series and fundamental series. If you arrange the energy levels of sodium. we have started from  $n$  equal to 3 because below  $n$  equal to 3 there will not be any electronic transition. Because these  $3S$  1 that is the ground state of the sodium atom.

In excited state will be the transition of the electrons at higher energy level. Where  $3P$  situated  $4S$ ,  $3d$ ,  $4P$ . here I have arranged the electron looking at this ok. Here  $1S$ ,  $2S$ ,  $2P$ , if we arrange this way above principal. Then you can arrange these the energy levels. You can see these  $3P$  energy level it is an energy is higher than the  $3S$  and lower than the  $4S$ .

That you can see from here that  $3P$  it is a higher it is a lower than the  $4S$ , but higher than the  $3S$  because this way if you move; we are moving towards the lower energy to higher energy level; lower energy to higher energy level. I have arranged this is  $3S$ ,  $4S$ ,  $5S$ ,  $6S$ ,  $7S$ . next  $3P$ ,  $4P$ ,  $5P$ ,  $6P$ ,  $3d$ ,  $4d$ ,  $5d$ ,  $4f$ ,  $5f$ ,  $6f$  etcetera ok. these going to the continuum energy. That is the energy is 0 and these below is the negative.

Generally, this  $3S$  this energy level it is the energy is around minus five electron volt. If you follow the transition rule  $\Delta l$  equal to plus minus 1. you will see that this type of transition is possible from  $P$  to  $S$   $3S$ ; from  $P$  to  $3S$ ,  $3P$  to  $3S$ ,  $4P$  to  $3S$ ,  $5P$  to  $3S$ .

These will give one series.  $P$  to  $S$  depending this name  $P$ . that is why it's called principal, then  $S$  to  $P$ ;  $S$  to  $P$ . this series  $S$  to  $P$  sharp,  $d$  to  $P$ ;  $d$  to  $P$   $3P$ . this  $d$  to  $P$ , diffuse  $f$  to  $d$  this fundamental ok. this type of transition will see in the sodium atom and we will see this type of series. Now if you, if you see this this spectral line between  $3P$  to  $3S$ . this we generally tell sodium D line because these spectral line is very deep yellow colour and in many experiment we use this spectral line, its wavelength is 5893 angstrom.

Now, here it is one spectral line, but actually, it is not one it is that two lines are there is ok. From where these two lines are coming? That I have shown here, this is the sodium d

line between 3 P to 3 S. Now, if you consider spin orbit coupling and then J energy level will depend on J total angular momentum. If you see these for 3 S the l equal to 0, S equal to half, J will be half.

For 3 P l equal to 1 S equal to half, J will be half and 3 by 2 ok. This line 3 P line is into the spin orbit coupling it will be splitted into two 3 P half and 3 P 3 by 2 ok. 3 P 3 by 2 it is an energy is higher than the original 3 P and 3 P half it's an energy is lower than the original 3 P ok.

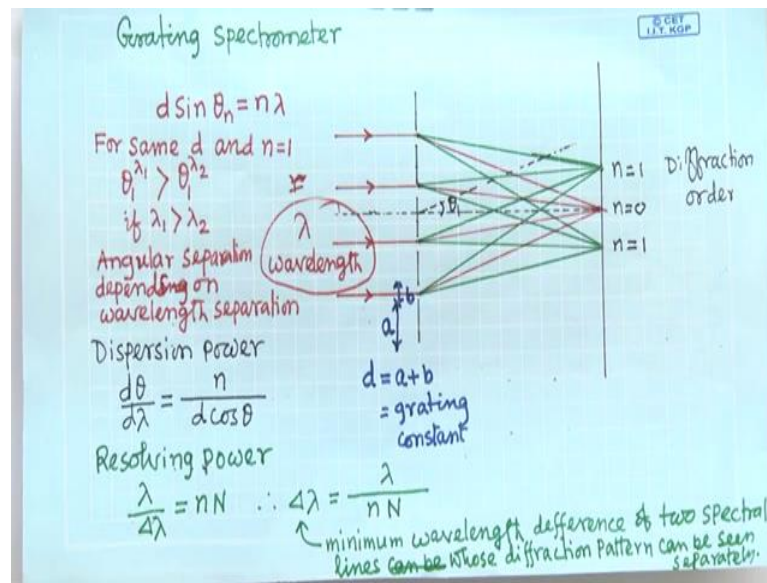
Now, J this transition  $\Delta J$  equal to 0 plus minus 1, there is the transition rule. There will be transition between J equal to 0 as well as  $\Delta l$  equal to 1 plus minus 1. following this transition rule here there are these two possible transition, we will get. One is one is this spectral line energy difference is higher; energy difference is higher, wavelength will be lower.

It is a 5890 angstrom of this D 1 spectral line and this other one energy is lower wavelength will be higher. this 5893 it is not 3 it should be 6, I think I have done mistake. It should be it; should be 65896 angstrom. This wavelength of these D 2 line ok. Now, separation of these two line is 6 angstrom and average of this two line is 5896.

Generally this when we get the resolve this sodium D 1 and D 2 lines are just we see one line, generally we take wavelength is 5893 average of these two ok. From here, you can see the origin of the sodium doublet structure and the origin is spin orbit coupling. If you experimentally if we can see these two line. There is the demonstration of the spin orbit coupling; demonstration of the spin orbit coupling and another challenge is this difference wavelength is if you see 5890 and 5896.

It is a more or less you see in 6000 whether 600 whether 6 angstrom we can resolve or not. It is a challenging work to resolve these very close this wavelength 6 angstrom wavelength different difference in wavelength how we can resolve for that you have to takes special care. That also very good demonstration in laboratory how we can resolve these two lines and see. we will use the, we will use the grating spectrometer for resolving these sodium D 1 and D 2 line grating spectrometer.

(Refer Slide Time: 11:58)



You know this for grating spectrometer, that getting that diffraction of light through grating. That will get diffraction their pins the principal maxima of interference. Condition for principal maxima that is  $d \sin \theta = n \lambda$  ok.  $d \sin \theta = n \lambda$ . Now, here you can see; here you can see  $n$  is the of course is the order; is the order of diffraction order and  $d$  is the grating element or grating constant. I will I will I will tell in details.

But from this relation just mathematically you can see for the particular grating; that means, for same  $d$  and for a particular order say it is  $n$  equal to 1 or 2 or 3 whatever for  $n$  equal to 1. Here you can see that  $\sin \theta$  that  $\theta$  will depend on the  $\lambda$ .  $n$  equal to 1,  $\theta_1$  ok. If  $\theta_1$  for  $\lambda_1$  wavelength will be greater than  $\theta_1$   $\lambda_2$  wavelength, for  $\lambda_2$  wavelength ok.

This if  $\lambda_1$  is greater than  $\lambda_2$  from this mathematics you can tell the angular what is this  $\theta$ ? This  $\theta$  is the diffraction angle. It will be diffracted in different angle and for that, we will get different order.

For first order if angle is  $\theta_1$  diffraction angle is  $\theta_1$  for second order  $\theta_2$  etcetera ok. if I think for first order, then we are seeing this angular separation of in first order for  $\lambda_1$  and  $\lambda_2$  that will be different ok.

And in that case  $\theta_1$  will be for  $\lambda_1$  will be higher, it will be higher than the  $\theta_1$  for  $\lambda_2$  so; that means, if wavelength difference is here then that will see; that will see in the diffraction pattern ok. There will be angular separation of the of the diffraction pattern say in first order depending on the wavelength.

That means for two different colour you will get two different principal maxima their angular separation will be different; angular separation angle will be higher if wavelength is higher; if wavelength is higher angle will be higher if wavelength is higher.

$\theta_1$   $\lambda_1$  is greater than  $\theta_1$   $\lambda_2$  if  $\lambda_1$  is greater than  $\lambda_2$  ok. angular separation depends on the wavelength separation ok. That is dispersive power of the grating and these dispersive power you know  $d\theta$  from here itself we can find out  $d\theta$  by  $d\lambda$  for separation of  $d\lambda$  what will be the separation of angular separation ok.

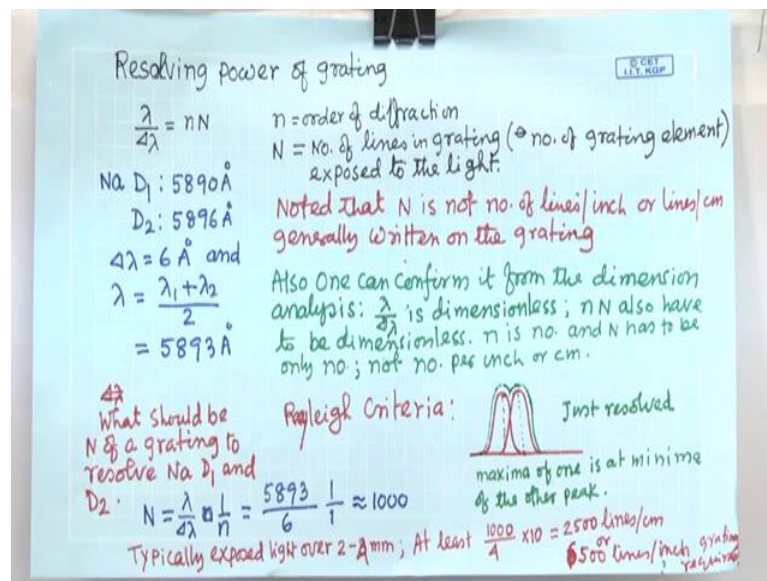
That  $d\theta$  by  $d\lambda$  equal to  $n$  by  $d \cos \theta$ . Therefore; obviously, from here you can see if for higher order of the diffraction pattern you will see the higher dispersive power means for same wavelength separation angular separation will be higher. For same wavelength separation angular separation will be higher in higher order and also it will depend on, if  $d$  is higher  $d$  value is higher, then dispersive power will be lower and vice versa.

Also another term we use that is resolving power of the grating. definition of the resolving power is  $\lambda$  by  $\Delta\lambda$  equal to  $n$  capital,  $n$  is the number of order. Resolving power will increase when it will increase for higher order when  $n$  is higher alit will depend on; it will depend on the  $n$ . Now, what is that  $n$  that I will tell you what is that  $n$  that I will tell is a number of lines of the grating it is related with the  $d$  value grating element and number of lines in the grating?

From here, you can see that  $\Delta\lambda$  equal to  $\lambda$  by small  $n$  and capital  $N$ . what is  $\Delta\lambda$ ?  $\Delta\lambda$  is in resolving power here these  $\Delta\lambda$  is the minimum wavelength separation which can be resolved means which can be seen separately. That separation that wavelength difference minimum wavelength difference that will depend on these three factors.

One is lambda if wavelength is smaller for smaller wavelength line. del lambda will be smaller ok; that means, resolving power will be higher ok; that means, smaller angular smaller wavelength separation you can be resolve. In addition, this for higher order also del lambda will be smaller dissolving power will be higher ok. for higher order you will see the higher resolving power also if n capital N is higher than this del lambda will be smaller del lambda is smaller means these lambda by del, lambda will be higher means resolving power will be higher ok.

(Refer Slide Time: 19:42)



What is this capital N? that is important and most of the time generally we do mistake to understand these that capital N. resolving power of grating lambda by del lambda equal to n capital N, n is order of diffraction and N is number of lines in grating means number of grating element, number of lines in grating means number of grating element exposed to the light exposed to the light.

Noted that N is not number of lines per inch or per centimetre is generally written on the grating. In comprehensively the as a specification what is the number of lines per inch or number of lines per centimetre? That is written on the grating. these capital N is not that that many numbers per centimetre ok. Whatever here we are using, that is not this lines per inch or lines per centimetre.

Most of the time generally we do that mistake we generally this n we just write this what is the number of lines per centimetre we write, it is this n is number of lines in grating

exposed to the light. In addition, whatever I told you also you could confirm it from the dimension analysis.  $\lambda / d$  see it is a dimensionless.  $n$  capital  $N$  this one also have to be dimensionless  $n$  small  $n$  is the number is the number because is the number of order, is a number.  $n$  has to be number only ok.

$n$  capital  $N$  has to be number only it is not it cannot be number of per inch or per centimetre. Then these hand side the dimension will be per centimetre ok. It cannot be per centimetre or per inch. it has to be simply number. What is that number? Number of lines in grating exposed to the light. The here most of the time we do mistake we take this  $n$  value generally number of lines in grating per centimetre. that is not correct ok.

That way I emphasize this point. Now, what is this resolving power? That  $\Delta\lambda$  this is the minimum wavelength the separation whether we can resolve or not. that Rayleigh criteria is that if the diffraction  $P$  or  $\lambda_1$ , it holds at the minima of the diffraction peak of same order of course of the of  $\lambda_2$ . If then this  $\lambda_1$  and  $\lambda_2$  1 can; one can dissolves means one can just see them separately ok.

The thin dotted line I have drawn. resultant spectral for these two wavelength you will see, you will not see if then very well separated you will see just you can you can; just you can resolve them you can you will see like this sub slight deep between these two. To far well separation. This wavelength separation that  $\Delta\lambda$  it should be higher than the; it should be higher than the actually these wavelength separation which you can just resolve ok.

For measurement, actually, you need; you need higher resolution to see them quite well separation. now, in our case what should be the, here you can see this for a particular order resolving power will depend on this  $n$  capital  $N$ . what should be  $N$  of a grating to resolves sodium  $D_1$  and  $D_2$ ? Ok. Here just I tried to calculate capital  $N$  equal to  $\lambda / \Delta\lambda$  by  $n$  order number by  $n$  1 by  $n$ .

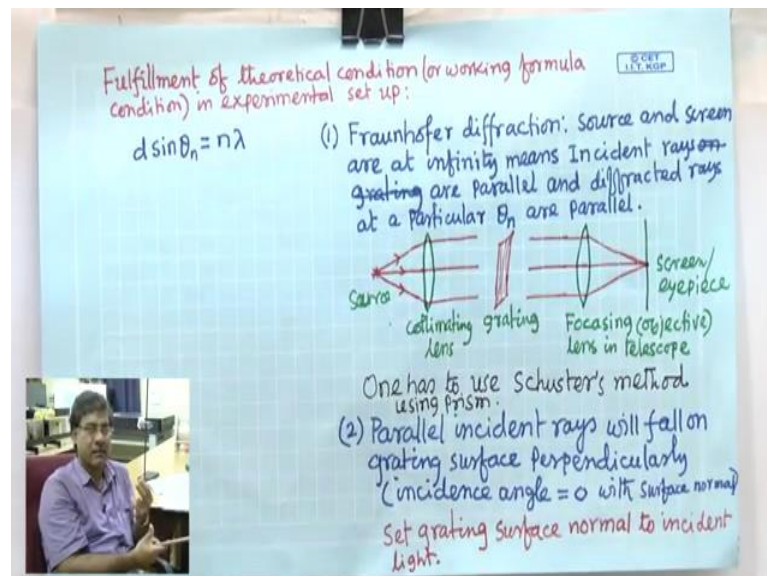
This  $\lambda$  is average wavelength 5893 of  $\lambda_1$  and  $\lambda_2$  and separation is 6 angstrom ok. Now, for first order if you want to resolve them in first order. Approximately it is the 1000 lines; 1000 line should be should be exposed, 1000 lines of the grating should be exposed ok. Typically, in our laboratory this exposed light exposed over the over the 2 to 4 milli meters of the grating.

in that case the grating you have to take to resolve these sodium D 1 and D 2, it should be if you just 1000 for say if you for it is exposed on 4 milli meter. Divided by 4 for 10 milli meter being for 1 centimetre into 10 that will be 2500 lines per centimetre ok. One should take at least a grating, which have which have these specification 2500 lines per centimetre or 6500 lines per inch.

If you take less than that it, you cannot resolve you cannot. these we have taken just to resolve. That we cannot resolve in laboratory whatever the setup will use. We have to take quite higher than this value. That is why we take generally 600 6000 lines per centimetre or 12000 lines percent were even higher ok. this just roughly or the estimation that which type of grating we should use on resolving the sodium 1 and sodium 2 to d lines ok.

Next we need to we need to; we need experimental arrangement. for that we need grating spectrometer. In experimental physics-I, I have shown you the prism spectrometer. In case of prism if we use the grating. Then we (Refer Time: 28:14) grating spectrum.  $d \sin \theta = n \lambda$ . That is for getting spectrum that is the formula or I could I can show here this one I do not use that one, I need yes.

(Refer Slide Time: 28:34)



Using the grating spectrometer, you have to do that  $d \sin \theta = n \lambda$ . that is the formula we will use for our experiment. These the working formula one can say or this is the formula based on this is the grating spectrometer will work.



It is very much necessary to understand to know the condition to know the condition of this equation in which condition generally when we derive something we apply some condition ok. these formula that is why I have written fulfilment of theoretical condition or working formula condition whatever the in which condition this working formula was derived ok.

That should fulfilled in experimental setup. This is the condition for the Fraunhofer diffraction. Now, what is Fraunhofer diffraction? Where source and screen will be at infinite distance will be at infinity means incident rays are parallel and diffraction rays at a particular  $\theta$  are parallel. In laboratory to get this parallel rays, we use lens we use lens. that source has to be at the focal point of this lens then other side we will get the parallel rays

That is why we use collimator in spectrometer there is a collimator lens. Now we have grating now from getting that different sets of parallel rays will get for different diffraction angle. To see the image. Parallel rays they will be at infinity. Screen should be at infinity, but in laboratory within a small distance if you want to see again we use the lens, it is a focusing lens in telescope we use telescope there is a lens is called objective lens also.

That parallel rays diffracted rays at parallel rays at different diffraction angle for a particular angle a set of parallel rays that will be converge to a point where that image will fall ok. this screen will be at finite distance. for that we have to use a focusing lens means, we will use the telescope and in that telescope there is a eyepiece that eyepiece is nothing, but in our case that is the screen ok.

This formula is for this Fraunhofer diffraction. this condition we have to we have to get in the experiment. how will make sure how will be make sure that the collimator lens and the focusing lens in telescope they are at the; they are at the position where source will be at focal point and screen or eyepiece will be at focal point. there is a process to get it. That is called one has to use Schuster's method using prism.

Before starting experiment, we have to get this condition for that this Schuster's method is compulsory. if you do not do this Schuster's method properly. This you will not get go for parallel rays ok. there will be error in the experiment because we will do calculation

based on this formula. For this formula, condition is to be to give the parallel rays. One has to do the Schuster's method that I explained in experimental physics two.

Here also I will tell you second is second condition is this formula is derived based on that the parallel rays incident rays incident parallel rays will fall on the; will fall on the grating surface perpendicularly ok; that means, incident angle is equal to 0 with surface normal. Not this theta. For this theta, it has to be 90 degree ok. So; that means, you have to put grating on the prism table in such a way that its unruled surface has to be perpendicular to the or normal or to the incident line ok.

In spectrometer, this condition has to be fulfilled for this experiment for this spectrometer grating spectrometer. After getting that condition then we have to do; we have to experiment means we will use sodium source and then we will use grating then we will see the diffraction of pattern. You will see the first order, second order, third order spectrum diffraction pattern.

There whether this sodium D 1 and D 2 are resolved or not that we have to see and we have to measure the angular separation there theta n we have to measure, d will be supplied ok. this for first order second order ok. You can find out the lambda.

We will find out lambda 1 for sodium D 1 line and lambda 2 or sodium D 2 line and then that is what the experiment whether we can resolve this very close to wavelength and after resolving how to measure the wavelength that is the standard. We have seen this other experiment how to measure the wavelength ok.

In this case challenging is to resolve the sodium D 1 and D 2 and then you should enjoy the physics behind it of this; of this D 1 and D 2 sodium D line. This physics behind it is this spin orbit coupling ok. I think it is I will demonstrate the experiments in our entire laboratory.

Thank you.