Atomic and Molecular Physics
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Lecture - 17
Structure of an atom (Contd.)

So, in this class we will try to find out more quantization. So, far we have considered 3 quantization, and corresponding quantum number we have got. So, this basically principle quantum number n.

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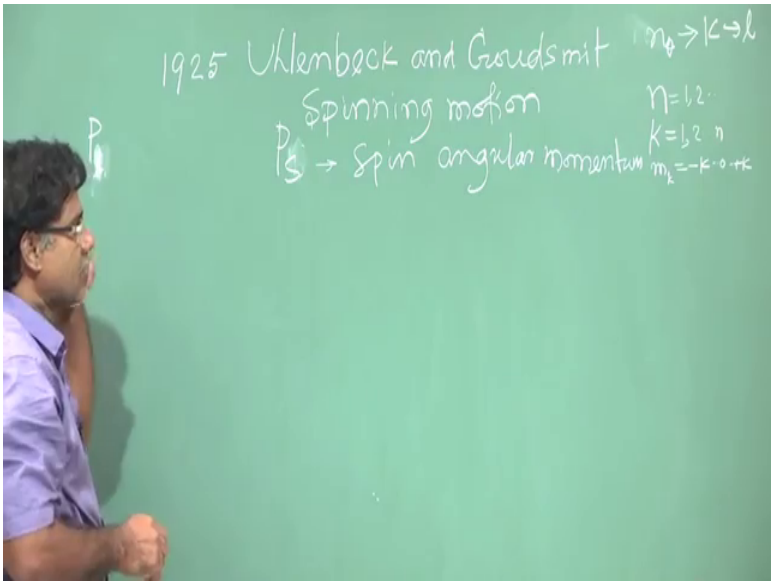

It can take value 1, 2, 3 etcetera. And then we have got azimuthal quantum number k, that can take value 1 2 up to n. So, it can take n number of k value. And then space quantization magnetic quantum number m k, it is minus k to 0 plus k so that s what we have seen. And we are able to explain normal Zeeman Effect, but we are not explain, this other fine structure of spectral lines.

So, so far, we have got for h alpha line it is splitted into 3 lines as for the as for the quantization, but experimentally it is found that 5 lines, right and for sodium d lines it has more lines d 1 d 2 anomalous Zeeman effect, it is telling that it is not splitted into not 3 lines, but it is more than 3 lines. So, there are. So, what are the source of this more lines, it is definitely there will be more splitting of the energy levels. So, more quantization we require and so, that s the motivation for searching new quantum number.

And before that you see in actually in 1925 uhlenbeck and goudsmit, not berk uhlenbeck and goudsmit. So, these 2 scientist they propose another angular momentum, that is the spinning. They consider the spinning motion of the electrons apart from the orbital motion as it is seen in case of solar system. In case of solar system that planet it rotate in a orbit right elliptical orbit so, orbital motion it has angular momentum.

Now it has also spinning motion. So, it is rotate about it is own axis, it is going as well as it is rotating (Refer Time: 04:11) it is own axis. So, that s called the spinning motion. So, it is there for solar system. So, in this case also they consider the similar spinning motion of the electron when electrons are rotating in a orbit, it also has spinning motion it rotates around it is own axis. So, spinning motion they consider spinning motion of the electron spinning motion of electrons in orbit. So, pinning motion of the planet that is that was I think it was well known, because why we see day and night. So, that is because of spinning motion. Spinning motion of the earth and we are in earth. So, due to the spinning motion of the planet earth, we see day and night within 24 hours, we see half portion is day and half portion is night, because wherever we are so, we are going just after.

So, due to spinning motion we are going to the opposite to the sun. So, sunrays cannot reach. But other part of the earth the people are there. So, they so, when we have night they have day like USA, America and this India; when in India when it is day in America it is night, because they are in opposite on the on the earth. So, this is due to the spinning motion, and season change it is winter it is summer this is because of the motion in orbit. It is coming close to the sun this summer. It is going away from the sun this it is winter. So, it is realistic consideration that the electron also should have spinning motion. So, it has a spin angular momentum like so, this one can write Ps spin angular momentum Ps, like it is similar to orbital angular momentum p k.

Now, what I will do just I will change the notation once more. So, this k so, earlier this you remember this n theta that I replaced by k. So, this I was doing because of the historical development. So, that s a change with historical development and ultimately it is going now in modern time we use this for to present the angular momentum we use l. So now, I will change this k to l k to l. So, this angular momentum I will consider now I will write l naught k, but same thing same thing. There is only difference that k value whatever. We have taken 1 2 to 1 2 3 up to n, but and k equal to 0 was not allowed. So,

total number of k value is n number. So, l value will take so, I will k replace, but l value will take starting from 0 1 2 up to n minus 1, 1 0 1 2.

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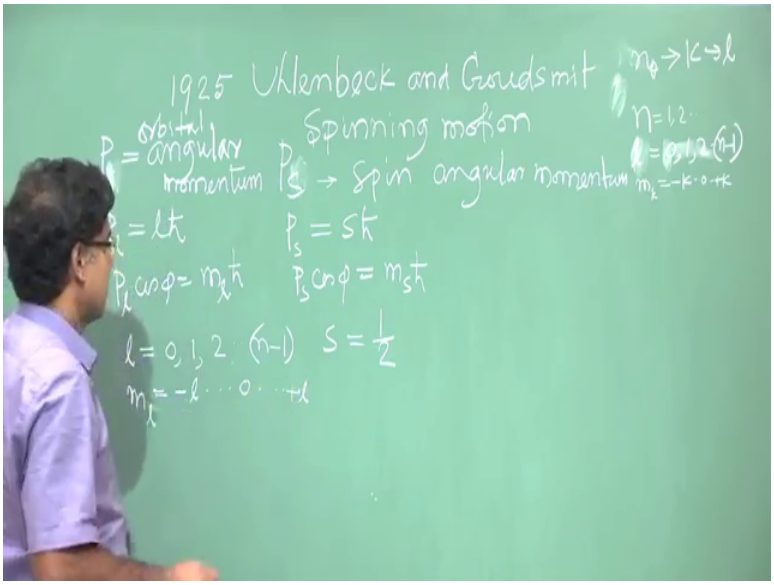

So, total number of l value is n, total number of k value is n. So, that is there, but only this value one instead of one to n it is 0 to n minus 1. So, that we have we will consider and what is the origin of that one that basically it comes from quantum mechanics so that we will see later on. So now, I will use this modern our recent notation. So now, I will write p l. So, p l is basically angular momentum, orbital angular momentum. This spin angular momentum and this is the orbital angular momentum. So, it is a p a l k p l basically this angular orbital angular momentum it is quantized. So, p l is equal to l h cross instead of k h cross now we are writing l h cross. And then this also again quantized in space. So, that was p l cos phi equal to m k, I already now I will write m l magnetic quantum number m l h cross.

Similarly, this is the, it is also angular momentum. So, similar concept here also the space quantization, and as well as this angular momentum quantization so that is also applicable here. So, in similarity it is one can it was retained that Ps this is basically s h cross, l h cross here, s h cross and then Ps cos phi. Again, this is of because cos phi we have taken it is quantized in the say same fix direction in space whether it is direction of the magnetic field or any fixed direction in the space so the similar way Ps cos phi. So, this phi this that phi may not be same. It is may be different, but concept is same angle in

space. So, this also one can write m s. So, it is m l it is m s h cross. So, l value here we have seen, l value it can take 0 1 2 is quantized quantum number; so up to n minus 1.

Similarly, s value it can take s value is basically taken only half, spin electron spin this s value is only half. For one electron it says value is half, and here m l value, m l value what we have seen this minus l to plus l. Similarly, for m s value (Refer Time: 12:22) here also it is a half. So, it can take minus half to plus, half minus s to plus s, s is half.

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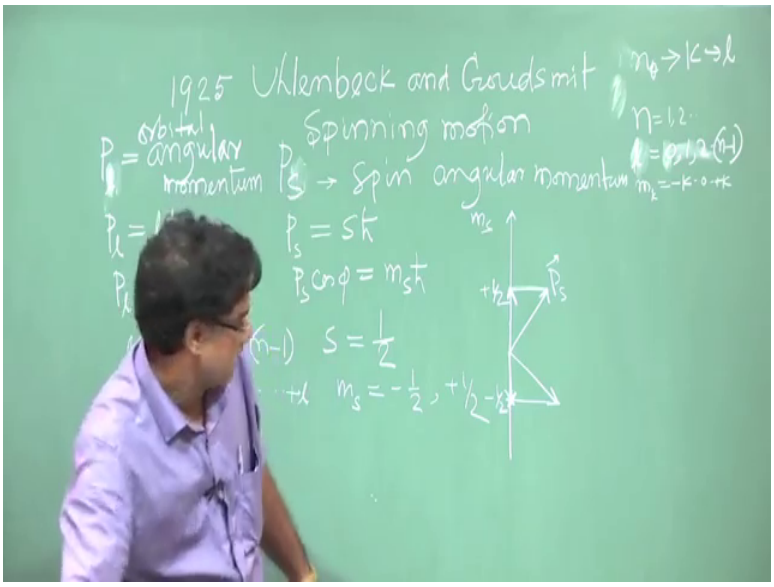

So, difference always difference between these 2 is one you know, difference between this one successive 2 quantum number, it is one always. So, here also it will be one, if I take minus s 2 plus s. So, m s can take value only 2 plus half and minus half. So, I have shown you the meaning of this this space quantization. Here meaning of the space quantization is similar way you know this is the direct fixed direction. This is the fixed direction, and spin direction is whatever the spin direction.

So, whatever the spin direction say this is the spin direction, cos phi s cos phi Ps cos phi. So, this is the Ps p s like p k whatever we had. So, it is space quantization say is position along this position along this. So, that is the m s value. So, m s will be only 2 possible values. One is plus half m s value. So, it is detection is detection is will be such that it can take only 2 direction so that in in these direction m s value will be plus half and minus half. So, it can it can so, these 2 orientation is possible it is minus half. Now here Ps itself is half h cross 0 half h is equal to half, so this cos phi is basically here. So,

projection if I want to get half. So, it can be in this direction. It has to be in this direction, or if I want to get minus half it has to be in this direction. So, it has 2 component. Yes, it has 2 component it is the along the space direction. Direction fixed in space or magnetic field direction or opposite to the magnetic field direction. Only these 2 states are possible for spin.

So, this is the another consideration for quantization; where one new angular momentum is introduced that is spin angular momentum, and then it is also quantized in same manner as orbital here whatever we have seen for orbital angular momentum. Now in our system 2 quantum number are available 2 angular momentum are available. Now how this angular momentum are behaving in the system. Whether they can be coupled or they are independent they do not talk each other. So, that question arises. So, we have seen this is the (Refer Time: 16:11) for spin s and this for s and similar way we have seen for angular momentum, it is right.

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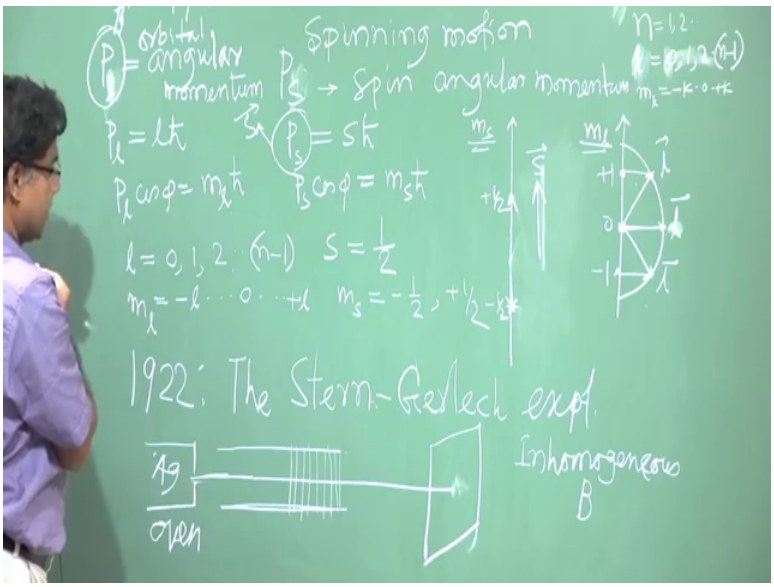

So, these 3 is possible for l equal to for l equal to 1, when l equal to 1. So, this is a l equal to 1, means m l value will be m l value will be 0 plus 1 minus 1, m l value here m s value then here m l value.

So, this we have seen, and this basically s value is you know spin is generally in the same direction is the s, and this is the l angular momentum. So now, also we will replace this p l this is whatever angular momentum we wrote. So, this will replace by just l

angular momentum is l instead of p l. We write l and instead of Ps angular momentum we write this is the s. So, we just we are changing notation. And now coming towards the present notation we are using so, s whatever you have I have written here. So, this is the spin angular momentum and this direction is this. These are the orbital angular momentum and their direction these 3 direction are possible for l equal to 1 in space so, that it is m l value will have this 3 0 plus minus 1.

So now, this existence of spin was discovered. Experimentally it was found, but it was found I think this experiment was done before this before 1925, the experiment was done in 19 experiment was done in 1922 is very famous experiment the stern Gerlach experiment. Now which experiment does stern Gerlach experiment, that was done in 1922 by stern and Gerlach. This Gerlach g e r or g a r, I think g e r stern Gerlach experiment very famous experiment that experiment confirm the existence of the spin angular motion, spin angular momentum or existence of spin of electrons. So, let me describe this experiment briefly. This is very nice experiment, and easy experiment what was that experiment?

I think here it is a just simply I can, but in 1922 the experiment was done not to find out the spin angular momentum or existence of spin. It was done to check the space quantization. You know to check the existence of m l space quantization. So, in this experiment, the silver atom was taken. So, there was a oven so, here silver material was taken, silver material was taken. And it is heated it is oven basically, oven it was heated, and then from here this silver atom as a vapor silver atom was coming out. So, it was collimated, it was passing through a small hole. So, silver beam of silver atom was coming beam of silver atom was coming. And then here this one skin was put is basically metal skin was put, and silver will deposit on this skin, because this skin is metal skin it is cold. So, this silver beam whose kinetic energy, because of the temperature is kinetic with kinetic energy it will move. And it will reach to the metal skin, and silver atom material will be deposit around this fine there is no problem.

Now, they applied magnetic field here. But that field was not uniform filled. Means, filled this beam is going; the field is not in the form. It was in (Refer Time: 22:43) in homogeneous magnetic field. It is not uniform or homogeneous magnetic field. Homogeneous magnetic field means, we see this it is intensity of field in any direction at a particular direction say, intensity of field is same intensity of field is at everywhere it is

same. So, this then it will be uniform magnetic field or homogeneous magnetic field. They consider the inhomogeneous magnetic field B. Reason is that if you put and this atom was neutral you know silver atom neutral atom the there is no charge such atom is moving.

So, if I apply magnetic field if I apply magnetic field. So, if the atom is not having magnetic moment, then you will get any effect of magnetic field. But already we have seen that atom have magnetic moment, because of the orbital motion of the electrons and then get. So, we got mu l we got mu l corresponding this for this that we have seen mu l. So, here also I will write it yes. So, we will get mu l. So, where to write I think I will write.

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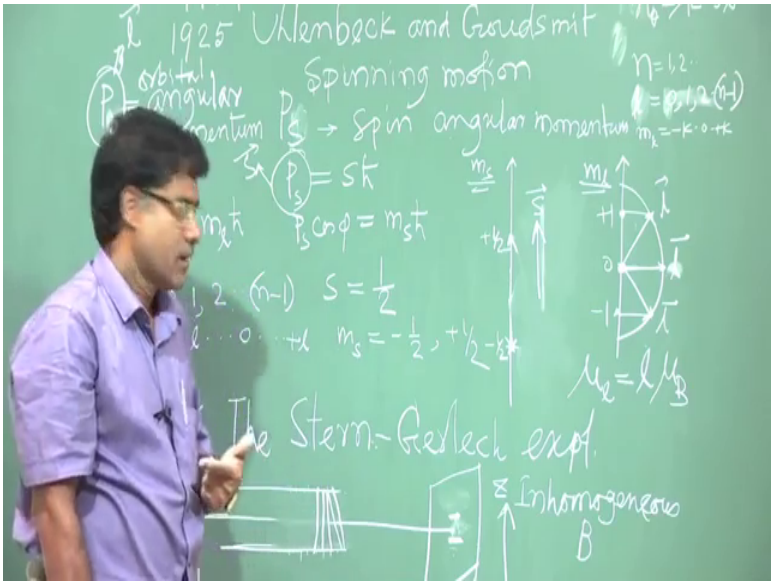

So, we have seen this mu l is l mu b, it is quantized in terms of in terms of maybe. So, that we have seen, and that s that s what we are able to explain the normal Zeeman Effect. And now that so, silver atom should have also magnetic moment mu l. And because of applying magnetic field there will be force on it.

Now, that force; if you apply uniform magnetic field, if you apply 2 cases will happen if you apply uniform magnetic field. So, basically you will get torque, not force so that moment will rotate due to torque and if we apply inhomogeneous magnetic field. So, we get force. So, the system will feel force. This system will feel force. So, that is the reason that inhomogeneous magnetic field was taken so that this moment if silver atom had

moment it will it will feel the force not torque. So, in homogeneous field how it was applied; so basically you know in magnet we use pole piece or permanent magnet one can take. So, it depends on the face of the pole if both pole are flat. So, it depends on the area of the pole, if 2 poles is just flat and parallel. So, one will one will behave as a North Pole another will behave as a South Pole.

So, field goes from North Pole to South Pole. So, it will so, from it from sem area of the North Pole, so here also same area of the South Pole. So, this force magnetic force of magnetic lines of force it will. So, it will be uniformly distributed. Now if this pole is flat and other pole is just is not flat is sharp. So, in that case what will happen? So these lines of force from this face from this pole so it will enter from p from North Pole and it have to enter to the South Pole. So now, South Pole has same has small face area right. So, all lines of force will enter into this, this through this, this smaller e of the South Pole. So, basically all lines of force will condense along this.

So now we can see when you are moving from North Pole to South Pole, you will see this field intensity increasing field intensity in. So, to produce inhomogeneous magnetic field; so 2 pole is taken of different face area pole area. So, that way it is inhomogeneous magnetic field is generated. So, that s that way it was taken. So, field here now say from south and North Pole and depending on the area of the pole. So, say field was say field was like this field was like. So, it was it was becoming intensity becoming more when it is going towards this direction. So, this direction you can take as a z direction. So, along the z direction field is intensity is increasing. So, field is inhomogeneous along the z direction. So, along this inhomogeneous direction, this silver atom it has magnetic moment.

So, it will feel force. So, it will move towards that towards the direction of the force. So, what here what after applying inhomogeneous magnetic field if this silver atom have this magnetic moment? So, we will get the shift of this. So, we will expect this deposition of the silver of. And since if it is space quantized, space quantization, if space quantization is exists, then we should see depending on this m l value we should see different discrete deposition of silver on the spin. So, that one should observe, but experimentally what was observed. Experimentally observed that all the time, we are getting 2 spot. One is up from this centre, one is up and another is down.

So, whatever we are expecting that due to space quantization, we should get splitting of the spot here on spin the splitting of the spot on the spin it is there. So, they were happy this stern Gerlach was happy that some space quantization exists. So, that s why we are getting, but whatever the splitting quantitatively it was not matching with the theory. It was not matching with this this space quantization. So, that is the problem that then this experiment whatever splitting we are getting it is not because of the space quantization. So, something else something else, and then later on in 1925 uhlenbeck and this goudsmit they propose they posculate that there is a spin. And spin angular momentum there is a spin angular momentum it has corresponding magnetic moment also so that was considered to explain the fine structure. And but before that this experiment, it was done to see the space quantization.

So, but the experiment result is telling no, no whatever splitting we are getting that is it is not telling of the space quantization. So, what it is telling?

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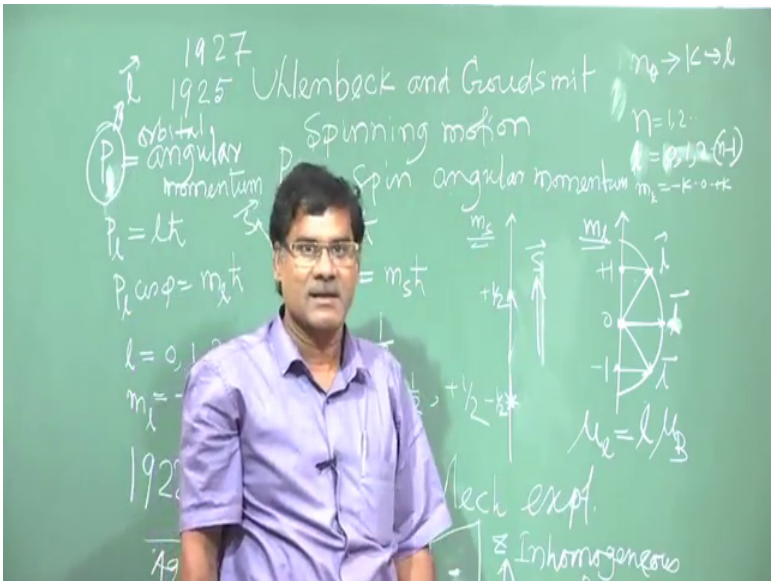

So, that was not known in 1927. I forgot the name some 2 scientist. They predicted that. They explained that these 2 are one is getting; that is, because of because of spin. And this 2 spot we are getting for m s equal to plus half and minus half, so this 2 splitting. So, plus half it is going it is up, and minus half it is going down. So, this is coming from the spinning from the spin magnetic moment; that we will see spin magnetic moment. So, that was the stern Gerlach experiment they got Nobel Prize actually stern Gerlach they

got Nobel Prize, because of this simple experiment which is basically the direct proof of the existence of the spin and spin magnetic moment.

So, I think I will stop here. I will continue in next class.

Thank you.