

by solving the schrodinger equation for hydrogen atom we obtained the wave functions which we called orbitals and the corresponding energies the energies corresponded to the the orbitals and we call them orbital energies when we looked at the energies of hydrogen atom which is which was essentially a single electronic species we saw one pattern of energy level the ordering of energy level when we saw the multi electronic systems we saw a different pattern of the ordering of energy levels we saw that for multi electronic systems we could arrange the orbitals according to their  $n + l$  which reflected the increasing order of their energy this is now what i am showing here is the orbitals ordered according to their increasing value of  $n + l$  which also reflects their increasing energy there are a few features that you can see here you can see that for any value of orbital angular momentum let us say we are considering s orbital for any value of orbital quantum number when you see the different orbitals of corresponding to different principal quantum number so 1 s 2 s 3 s 4 s or 2 p 3 p 4 p or 3 d 4 d 5 d or so on so forth you see that for a given orbital quantum number as we increase the principle quantum number the energy of that orbital is increasing energy of four s is greater than energy of three s is greater than energy of two s and one s is anywhere the ground state this is one observation the other observation is that if you fix a particular value of  $n$  the principal quantum number let us say three then it has got for  $n$  equals three we have got three s 3 p and 3 d you see that for a given value of principle quantum number as you increase the orbital quantum number s to p to d the energy is increasing and this trend you actually see in all other principle quantum numbers 4 s 4 p 4 d 4 f and so on so forth so there are many interesting things that is happen but that are happening in in a multi electronic system and this is what we are trying will try to understand in a multi electronic system of course we know that we have a a nucleus ah let us say that this nucleus has  $Z$  number of protons so it has got  $Z$  times  $e$  ah the charge of the nucleus now this is the nucleus and we know we have ah several electrons and they are going around the nucleus of course this is after ah discussing quantum mechanical

treatment this picture may not be the most accurate picture but this is a simple picture which will drive the point

so now what i have done is that let us say we have these three different electrons and with them on at three different orbitals right we saw if you remember the orbital energy of the energies of all the orbitals were coming out to be negative and from there we concluded that the negative value indicates that the electron is stable in the atom

so the electron is happy to be in the atom where does this electron get stability from one source of stability is the interaction

between electron with nucleus electron is negatively charged nucleus is positively charged

so the opposite charges they will attract each other and that gives an attractive interaction

energy that is true for all the electrons right you will immediately appreciate

the fact that which electron will have better interaction with the nucleus the answer is that

electron which is closer to the nucleus

so in this case electron one being closer to the nucleus will have better attractive energy interaction compared to electron number three

so this

kind of explains that why the orbital energy increases as we go away from the nucleus

as the electron stays away from the nucleus it is not only that there are other

features this is what we will discuss now you imagine that each electron is under

the attractive influence of the nucleus at the same time each electron is also facing the

electron electron repulsion energy which is coming from other electrons

so consider the electron

number two it has got negative charge electron number three also has a negative charge now this

like charges negative charge of electron two and negative charge of electron three they repel each

other

so electron number two for example not only has an attractive interaction with the nucleus

at the same time it is also being repelled by all other electrons of the atom and this is the case

for all the electrons in this atom now the other thing you would notice is that

that

so since each electron is under the influence of an attractive interaction and a

repulsive interaction that electron will be more stable where for which for whom the attractive

interaction is much stronger than the repulsive interaction coming from other

electrons and when is that going to be that is going to be for the electron number one this is because it is much closer to elec to the nucleus now electron number one by the virtue of being close to the nucleus does another thing what it does is that it screens or it shields the nucleus it shields the nucleus or we call that it screens the nucleus from interacting with the electron which are further which are ah further from the nucleus similarly electron number two which is now closer to the nucleus compared to electron number three by interacting with the nucleus it actually screens the nucleus from interacting sufficiently strongly with the electron number three so in a sense h electron screens the nucleus from interacting with the electrons which are further from the nucleus than the that particular electron is so we see that that is in in other word the electron number 1 looks at the nucleus and finds the full glory of this nucleus that means it ah looks at the all the protons or entire positive charge that is  $z$  but when you come to electron number two you see that electron number two does not actually see the full glory of the nucleus because electron number one kind of screens the elec nucleus from interacting with electron number two so electron number two will feel as if there is not  $z$  charge on the nucleus rather  $z$  minus a small number we do not know what this number is but a is is a small quantity compared to is it similarly electron number 3 will not see the full nuclear charge  $z$  rather it will see  $z$  minus  $b$  which is where  $b$  is another ah small quantity in general we can generalize that that any electron actually does not see this value of  $z$  nuclear charge rather it sees what we call as  $z$  effective which is given as  $z$  minus let us call  $\sigma$  this  $\sigma$  is known as screening constant the  $\sigma$  tells that how much this particular electron is screened from the nucleus and that particular electron sees the nucleus as not as  $z$  rather  $z$  effective which is less than  $z$  so you can see as  $n$  increases the principal control number increases  $\sigma$  increases and then the  $z$  effective becomes smaller and smaller compared to  $z$  so in a sense we can write down if we compare one s orbital two s orbital and three s orbital and compare their  $\sigma$  values will see for  $\sigma$  or the the screening constant you see this trend well for 3s screening factor screening constant is much larger compared to 2s and in turn which is again larger than 1s in other words we can also write for  $z$  effective in that sense we see 1s has greater  $z$  effective than 2s

compared to 3s  
 what does that mean that one is electron when the electron is in one s orbital  
 it sees the full  
 nucleature z when it is in two s orbital it does not see the full nuclear  
 charge rather it is z  
 minus sigma and three s orbital it is z minus sigma but please remember that  
 sigma for three s  
 orbital is different from sigma of two s orbital this kind of explains that  
 why we as we go higher  
 and higher principle quantum number the energy of the orbital increases now  
 next we will discuss  
 about ah the fact that we observe that for a given principal quantum number n  
 we see that the orbital  
 energy increases as you go higher and higher in orbital quantum numbers  
 so 3p has greater  
 energy than ah 3s orbital and 3d orbital has ah energy greater than 3p orbital  
 we will try  
 to understand ah this next if you remember this is the probability ah  
 distribution  
 of electron for this was for one s orbital this is for two s orbital and this  
 is for  
 three s orbital we saw that one s orbital we have this single ah density for  
 two s  
 orbital we have we see that probability density is somewhere here and then  
 there  
 appears a node and then electrons are also ah probable ah have probability to  
 be found  
 further from the necklace and then three s had they had this feature we  
 also discussed the probability distribution plot like this this plot if if  
 you remember we have we discussed that this is the probability distribution of  
 one s orbital  
 this was the probability distribution of two s orbital there are two peaks the  
 first the small  
 peak is coming because of this electron density the the second peak here comes  
 because of the  
 electron density that that is seen in this region similarly this is for 3s  
 so this is for 3s this is  
 for 2s this is for 1s for 3s you see 3 different peaks one probability density  
 at a smaller value  
 of r the x axis is r which is the distance between the electron and nucleus  
 so at a smaller  
 value of r and then you see another density corresponding to this distribution  
 and then the  
 final density corresponds to this distribution this is this is what we saw for  
 1 s 2 s and 3s  
 what we see here if you observe let us say for 2 s orbital the electron into a  
 cervical kind  
 of penetrates into the 1s region this is the 1s orbital region in the 2s  
 orbital the electron  
 kind of penetrates into the 1s shell which is shown by this density and  
 similarly 3s electron  
 penetrates into two s shell and one s shell if i compare the probability  
 distribution for two  
 ways with 2p this is for the or 2p orbital you would see that 2p does not have

this penetrating capability

so the probability distribution in 2p is farther from the nucleus compared

as compared to the electron in the two s orbital

so in a sense if the electron is in two ways orbital it can penetrate closer and closer to the nucleus but when it is in 2p it cannot do so

when you compare 3s 3p and 3d we again see the same feature the electron which is in 3s orbital

can penetrate into 2s shell and 1s

so it can come closer and closer to the nucleus compare that with 3p p can three p does a worse job than three s it can penetrate but only to the second

shell this is the shell for the two p but in case of three d it cannot penetrate

closer to the nucleus

so in this way we see that as the orbital quantum number increases from s to p to d we see that the electron can penetrate as far as the for lower orbital angular

moment or vital quantum number when s is zero the electron can penetrate much effectively closer to the nucleus

so therefore the 2s electron the electron in 2s orbital will be much more stable than 2p and therefore the same reason applies for 3s orbital

electron which is much close can go closer to the nucleus is has less energy compared to 3p and

3d electron has even higher energy

so if i compare the screening constant for three s

three p and three d i can write this and if i compare the z effective i will say so the larger the z effective this more stable

the electron is

so this gave us an idea about why we see the trend that we see in the orbit the energy ordering of the orbitals next we are actually we are actually

now well equipped to discuss about the electronic structure in more general terms

will now be in a position where you can take any atom by that item i know how many electrons

how many protons are there and we can discuss about how the electrons are arranged in that atom

so this is what we are going to do next we are going to start discussing about filling electrons in orbitals while discussing this our first point of discussing discussion is what is known as Pauli exclusion principle is a very important principle

that plays a fundamental role in electronic structure of atom what does Pauli exclusion

principle say it that that no two electrons no two electrons in a given atom in an atom can have the same set of quantum numbers we have actually discussed four quantum numbers the Pauli principle says Pauli exclusion principle says that no two electron in an atom can have the same set of four quantum numbers

what are these four quantum numbers n l m and m<sub>s</sub> the principal quantum number

the azimuthal quantum number, the magnetic quantum number and the spin quantum number we know what these quantum numbers represent

so looking at this let us consider one s orbital right for one s orbital  $n$  is one  $l$  is zero and since  $l$  is zero the possible value of  $m$  is again zero because there is only one orientation for s orbital and what are the values of  $m_s$  we know  $m_s$  can have either  $+\frac{1}{2}$  or it can have minus up

so in this way the one s orbital has a given value of  $n$  given value of  $l$  given value of  $m$  we cannot play with it all we have is this there are two possible values of

a spin quantum number either it can be  $+\frac{1}{2}$  or it can be minus up and therefore

Pauli exclusion principle says that you can have the outcome of or the consequence of the

Pauli exclusion principle is that an orbital can have maximum two electrons not more than two electrons why

because if I have already two electrons one of them will have  $+\frac{1}{2}$  spin the other one

will have minus half spin because they cannot have the same set and if I introduce another

electron the third electron can either take  $+\frac{1}{2}$  spin or take minus half spin and if it

takes  $+\frac{1}{2}$  spin then again it violates Pauli exclusion principle which says that two electrons

cannot have all this quantum number same

so an essential outcome of Pauli exclusion principle is

that an orbital can have up to two electrons and the second outcome is that these two electrons

in a given orbital they will have opposite spin in an orbital diagram if I write one s

so I

have one  $\uparrow$  spin electron and then I write another down spin or electron

so one orbital can

maximum contain two electrons and they have to have be of opposite spin this is the consequence

of Pauli exclusion principle this will keep in mind and look at other rules that are useful

to describe filling of electrons in orbitals the next principle that we are going to discuss

is what is called as building up principle this also goes by a German word which means which

is Aufbau which means building up or construction Aufbau principle it essentially says that the rule

that will be used to construct or to build up the electronic arrangement what does

this principle says it says that the orbitals are filled in the order of their increasing energy the energy is the determining factor that

decides which orbitals have to be filled first and which orbitals can be filled afterwards so

we already know how the orbital ordering looks like  
 so this follows this  $n + l$  pattern and this is the ordering  
 so building up principle or the aufbau principle tells that you must fill first the orbital of lower energy before  
 you start filling the orbital of higher energy will take a few examples let us start from  
 the beginning we have hydrogen which has one electron  
 so the lowest energy orbital is one s  
 so i give one electron to one s it is happy ah let us take the next one which is helium it has got  
 two electrons and i have the first orbital i see one s and i know from pauli exclusion principle  
 that it can hold two electrons  
 so i gave both the electrons to helium and i can orbital diagram i can write in this way one is upspin another is downspin the next one is lithium which has got  
 three electrons  
 so i see one s i cannot give all three electrons to one s orbital because that  
 will be a violation of pauli exclusion principle  
 so one s and it is full now i have to go to the next orbital which is the next orbital two s and ah two s how many electrons can it hold it can  
 hold two electrons  
 so i gave one to ah this two s orbital the orbital diagram looks like this  
 in  
 this way i can go on building a higher and higher z values ah let us take one more example ah  
 that is of sodium which has eleven electrons  
 so i will start from one s it can hold two electrons ah then i am left with nine electrons because two electrons are filled i have nine  
 more electrons  
 so then i go to two s orbital then i see two s orbital can take two  
 so i gave  
 it ah two  
 so i am done with four orbital four electrons i still have seven electrons to take  
 care then the next orbital in sequence is two p and if you remember two p actually has two p  $2p_x$   
 $2p_y$  to  $2p_z$   
 so there are three compartments  
 so let me keep building this orbital diagram  
 so  $2$  in  $1s^2$  into s and  $2p$  has 3 compartments this is for p x p y p z actually  
 ordering does not  
 matter  
 so they are all equivalent  
 so i have got eleven electrons four are gone  
 so i have seven  
 left  
 so i am giving all ah six  
 so two p six and then i am left with one

so i can call i can give  
the first the last electron to the next orbital which is three s in this way i  
can i can  
go on building ah if you notice ah let us let us look at ah our periodic table  
ah you know ah the periodic table  
so this is one  
is ah sorry hydrogen atom helium atom and and so on and i will keep the um  
orbital ordering pattern  
ah here and we will try to understand how to fill the any element of in this  
periodic table  
so i  
start with this i have first ah element which is hydrogen it has got one s ah  
one electron  
so i  
fill one s orbital here and i if i come to helium i can give two electrons to  
this one s orbital so  
hydrogen and helium are gone and then when i start from lithium i have to  
start filling two s orbital  
so two s gets filled starting from lithium  
so two s is is is taken care and lithium and beryllium by  
lithium and beryllium i finished my two s orbitals capacity because it has got  
only two electrons ah  
it can take only two electrons and when i extract come from boron i would have  
to start filling two  
p orbital because four electrons are taken care and the fifth electron will  
start occupying two  
p and since two p can hold six electrons next six elements boron carbon until  
neon they will be  
filled within the two p orbitals when i start use coming to sodium which has  
11 you already  
saw that i have to start filling 3s and when i finish magnesium 3s is finished  
then starting from  
aluminum uh two argon  
so in this case i filled two p and for aluminum i am feeling three p this  
color is is not ah visible  
so let me use another ah  
so starting from boron i started filling two p  
orbitals starting from aluminum i started filling three p orbitals and  
similarly for cal ah for  
starting from potassium and calcium  
so three p is gone  
so i have four s  
so i can start from four  
rays after 4 s comes 3 d  
so potassium and calcium 4 s capacity is done and the next orbital is 3 d  
so starting from scandium which has 21 electron i will start filling 3 d and  
you know three d  
has five magnetic quantum numbers ah quantum possible quantum numbers  
so therefore five  
different orbitals and it can hold up to ten electrons each orbital can hold  
two electrons  
so starting from scandium to zinc the next 10 elements will be filled in the  
3d orbitals  
so starting from here i am filling in 3d orbital and starting from gallium the

next orbital

is four p

so you can see that as i come to the next row of the periodic table i am building

i am starting to feel higher and higher s orbitals and the p orbitals are getting to filled with from

boron aluminum gallium indium ah thallium and the d orbitals will start getting filled along this

direction from here

so this is how we also name them as s block elements p block elements d block elements these are all the outcome of electron filling pattern

so you can take your

periodic table and can write down the electronic configuration of any atom that you wish now will

take ah two more special cases ah that case is let us discuss about carbon

carbon has got six electron it has those one

i i will give ah three two electrons to one s then two more electron to two ways and then i am

left with two electron i will give that to two p if orbital diagram i will write i will write

this way to one s l two and two p has three different compartments and i have got two

electrons to give how can i give i can the way i have been doing i can perhaps do this

way or is there another possibility i think so i can do this is there another possibility yes

i can do this see there are other possibilities like instead of filling this compartment

i can fill this compartment but that is not really a unique possibility because all the

compartments are essentially equivalent

so that they are not they will not give you as new possibilities

so these are the three possibilities that i have to fill this two p electrons in ah

two two p electrons in the for the carbon atom but which of them is is the correct one

the answer to that question comes from hunds rule of maximum spin multiplicity what does it tell it tells that when

more than one orbital has same energy then electrons are filled in the separate orbitals and they carry parallel spin this is what hunds rule tells

so it says that if

there are more than one orbital which have same energy for example in this case two p x to p y to

p z there are three different orbitals and they have got all same energy so we must fill electrons

in the separate orbitals and we must give them parallel spins

so for example this configuration

what we have done is is wrong why because it is in violation of hunds rule which says

that the electrons have to be filled in separate orbitals i filled the electron in both the

electrons i gave to the same orbital that is wrong in this way in this the second case i have

done correctly because i have given electron to this ah two different orbitals and in the third case also i have done correctly because i have given them in separate orbitals but in the third case i made another mistake and that mistake is that they do not carry parallel spin they carry opposite spin so this is again violation of horn's rule so of the three possibility this one is the correct one so what the way we fill the electron is that we first fill each orbital singly and once all orbitals are set filled then we will start filling the ah second will start giving second electron to an orbital and when we give the second electron we must give it to the opposite spin because that that is dictated by paulis exclusion principle otherwise two electrons cannot have the ah same spin in the same orbital so together taking together hoons rule and police exclusion principle we can give we can write down this electronic configuration of this carbon atom what you see here has important consequences the thing is that why is this configuration accepted and these not these two this answer to that is that this configuration has a lower energy if this configuration is more stable and its stability comes from what is called as exchange interaction energy or exchange correlation energy we call that as just exchange energy what do i mean by this exchange energy you see when the two electrons are in this this way so all each of these three components are com compartments are equivalent and now if i keep them keep the two electrons parallel spin actually what i do is that i have more possibility to exchange or interchange the electron in these compact compartments and if by keeping them parallel i invoke the indistinguishability of the electron and that add gives me additional stabilization in the opposite case since the two electrons can be now distinguished one has up spin another has down spin so that indistinguishability does not come into play so that stability which is coming from in indistinguishability of the electrons is gone in the third case so this way we get most stable configuration because of this region because of the exchange energy now you can we can take this argument further i'll i'll try to fill the electron in nitrogen nitrogen resistant has seven so one is two two s two and two p three i have got two electrons here two electrons here and i will feel like this alpha spin you see in

case of nitrogen when there are three electrons i have i will have maximum exchange energy this is this will be a very stable configuration why because each of the compartment has single electron

so now we have got three electrons to exchange with and they are all indistinguishable so therefore exchange energy is more favorable similarly if i have a situation where i have a d orbital d orbital has five ah compartments if i have a situation where there are five electrons in d orbital

so this is p three configuration if there are five electrons in d orbitals which is called let us call d five configuration this will also be very stable because of this exchange energy similarly if i have a for vital which has seven one two three four five six seven f seven this is also very stable configuration

so we see when you have p three or d five or f seven these are called half filled shells the half filled shells provide very stable configuration similarly the fulfilled shells also give good stability

so full field and half filled shells are very important for for stability we will cons we will now ah take up two more ah

examples ah the first example is chromium we have got twenty four electrons in chromium ah

so for chromium i can write down as one s two two s two two p six three s two three p a six if you see chromium this appears here in this place before chromium you see that argon has 1 h2 2s2 3h2 and 3p6 if this config if you check this configuration one s two two s two three s two p six raise to three p six i have got eighteen electrons here and this is the configuration of argon

so instead of writing all these things i can write simply argon and then follow what is coming

so after three p i will have to fill the i have to fill the four s electrons and then comes three d electrons

so i have four s two and by four s two i am done with twenty electrons and i am left with four electrons

i gave four electron so this i can equivalently write ah in simple way as four raised to three d four these these represent core electrons and these are called valence electrons the

valence electrons are useful for doing chemical reaction that they have the reactivity

the core electrons are more or less inert

so this is the configuration that i am

getting but look at this situation if i draw the orbital diagram  
so this is 4s and this is  
3d i have four electrons  
so i am filling them up i see that this is just one less than d5 situation  
but i know that d5 situation is very stable this is exactly what happens  
chromium finds  
in more stable configuration which is this what it does is that it transfers  
one  
electron from four s to three d by that what it gains is that lot of exchange  
energy and  
that therefore this configuration is more stable and this configuration is  
less stable so  
when chromium we see we see chromium in this configuration ah we can take  
another example  
ah in addition to chromium there is another element ah copper which has got 29  
electron i can  
again write the core and valence configuration 18 electrons are taken care  
so i have got now ah  
11 elect electrons to fill i give 2 electrons to 4 s and next is 3 d and i am  
left with 9  
electrons  
so i gave them if i draw the orbitals 1 2 3 4 5 i have 6 7 8 9.  
now  
what we see here is that only one orbital is half filled the remaining are  
fulfilled  
so we know that both half filled and fulfilled shells are stable  
so in this  
case there is a change in the configuration copper adapts as conf change in  
the electronic  
configuration and goes to 4 s<sup>1</sup> 3d<sup>10</sup>.  
and in this case the all the 3d orbitals  
are doubly occupied and this is the stable configuration of copper ah another  
example where  
this ah factor plays out is gadolinium which has 64 electron and i i would  
suggest that you please  
do this ah yourself you see that you start with a xenon which has already 54  
electrons and you  
will be left with ah 10 electrons you first write down the config electr you  
will first fill  
the electrons according to the orbital energy and then you should try to  
figure out if there is a  
possibility of another stable configuration the way we saw in chromium and in  
copper and find out  
write the correct configuration of gadolinium atom in this series of lectures  
we have travelled a long way we discussed the discovery of various of atomic  
particles the discovery of electron proton neutron we saw how nucleus was  
discovered  
on the basis of those discoveries we went through different models of atom ah  
starting from  
dalton's atomic model which was very rudimentary in nature slight improvement  
was given by plum  
pudding model of jesus thompson we saw about we talked about rather force  
model and finally we  
came to boards model bohr's model was was quite good for hydrogen atom or

other single electronic species but it was off the mark for multi-electronic systems then we had to uh take shelter to a different theory which is which was quantum theory the quantum theory ah was in the picture because of several developments for example there were photoelectric effects and black body radiations which could not be explained by the world theory the classical theory and during those course of scientific discoveries we learnt that light is both a wave and a particle followed by the hypothesis of de bruy who suggested that matter also behaves like a wave uh then there was heisenberg's uncertainty principle he said that for microscopic objects you cannot simultaneously determine that position and momentum with these new principles with these new fundamental rules the quantum mechanical model ah was formulated and we did that for an uh for an atom and in in a in principle we can extend the quantum mechanical model to any larger molecular system we solve the quantum mechanical model in terms of the schrodinger equation and the solution of the schrodinger equation gave us the orbitals and the and their energies we also saw that the orbitals have differ had different shape ah different orientation and they could be described by what we call quantum numbers the principle azimuthal magnetic and spin quantum numbers and we also discussed about how electron electron correlation affects energy ordering of this orbitals at the end ah starting from dalton's pure crude atomic theory we came to a situation where we could discuss the electronic structure of a multi electronic atom we could take any atom from the periodic table and discuss how the electrons are arranged in in that particular item next what we will do is we will go through the previous year je question papers and i have done that for you i have gone through the last few years je question papers and selected ah questions that were from these the topics that we discussed we will go through a few questions and we will see how to solve them the first question is ah is is given here the question says that the there is this hydrogen like species lithium two plus which is in a spherically symmetric state s one and this state has one radial node by upon observing light this ion lithium two plus ion undergoes a transition to a state s two so it was in s one and it goes to s two state the state s two has one radial node s one had one radial node and s two also has one radial node and the energy of state two is

equal to the ground state energy of the hydrogen atom this is the information that we have the question asked what is the state  $s_1$  what do we know about the state  $s_1$  we know that it is a symmetric state by symmetric what do we mean we we know that only  $s$  orbital is symmetric sorry it is a spherically symmetric  $s$  orbital is spherically symmetric so  $s$  one state must be one  $s$  orbital and then it says that it has got one radial node among  $s$  orbital we can have one  $s_2$   $s_3$   $s_4$   $s_5$  we do not know which one but it also says that it has got only one radial node we know one  $s$  orbital has no radial nodes two  $s$  has got one radial node three  $s$  has got two radial nodes and so on so forth so from these two information we know that this state one study state  $s_1$  is two  $s$  orbital all right this we answer the next question tells that the energy of the state  $s_1$  in units of the hydrogen atom ground state energy so we have what we know about the energy of the ah lithium 2 plus we know that its energy is minus 13.6 this comes from the bohr's atomic model  $Z^2$  square divided by  $n^2$  square and the energy is in the units of electron fold so we know this is the energy of this ah lithium two plus what it says that state  $s_1$  has the same it wants us to find out the energy of state  $s_1$  with respect to the energy ground state hydrogen atom energy so let us find out the energy of state  $s_1$  so minus thirteen point six  $Z$  is three because it is lithium so three square is nine  $n$  is two because we have discovered we have already found out that it is in two  $s$  orbital so this is nine by four electron volt and what it asks it us in the units of the hydrogen atom ground state energy what is hydrogen atoms ground state energy we can find that from this equation itself for hydrogen atom  $Z$  is one and ground state  $n$  is one so this term does not give any contribution so we have only hydrogen atoms ground state energy is minus thirteen point six electron volt so in the units of hydrogen atoms ground state energy this is 9 by 4 and which is 2.25 this is the answer the third question tells that the orbital angular momentum quantum number of the state  $s_2$  is what so it wants us to find out  $s_2$  state what is what is its

identity and find out this orbital angular momentum quantum number  
 the  $s^2$  what  
 do i know about  $s^2$   $s^2$  has one radial node that's one piece of  
 information the other is  
 its energy is equal to the ground state energy if i want to find out the  
 energy of  $s^2$   
 let us let me write down this energy is again  $Z^2$  by  $n^2$   
 in the units of electron volt  $Z$  is 3 for for lithium  $2^2$  plus  
 so this is  
 this quantity is 9 and this energy for  $s^2$  is equivalent to the energy of  
 hydrogen atom  
 ground state and when is what is that that is 13.  
 6 when will this quantity be equivalent to 13.  
 6  
 it will be when  $Z^2$  divided by  $n^2$  is 1 or in other words  $n$  is  
 equivalent to  $Z$   
 so this way we got to know that principle quantum number of  $s^2$  state is  
 equivalent  
 to the atomic number of lithium which is  $n$  is three  
 so now we know it is  $n$  is three so  
 if it is three then it can be three  $s$  or three  $p$  or three  $d$  what more do we  
 know the question tells  
 it says that it has got one radial node  
 so we can find out how many radial nodes we have in case of  
 three  $s$  three  $p$  and three  $d$  we know that three  $s$  has got two radial node three  
 $p$  has got one radial  
 node three  $d$  has no radial nodes  
 so the answer final answer is that the state  $s^2$  is three  
 $p$  and since it is three  $p$  its orbital angular momentum quantum number is one  
 which is this  
 answer will ah take off the next question it says uh the next question tells  
 that the maximum  
 number of electrons that can have principal quantum number  $n$  equals three and  
 spin quantum  
 number  $m_s$  equals half  
 so  $n$  is 3 if  $n$  is 3 what are the orbitals possible  $3s$   $3p$   $3d$  in  $3p$  i  
 have  $3p_x$   $3p_y$   $3p_z$  and  $3d$  i have five different orbitals three  $d_{x^2 - y^2}$   $d_{z^2}$   $d_{xy}$   $d_{yz}$   $d_{zx}$   
 square minus  $y$   
 square and  $z$  square i am not writing them down and it also says that find out  
 the electrons that  
 have spin quantum number minus half i know each orbital for example three  $s$   
 orbital can have two  
 electrons and one of them will have plus half spin the other one will have  
 minus substring similarly  
 for three  $p_x$  three  $p_y$  three  $p_z$  and each of the five three  $d$  orbitals will  
 have one electron  
 with  $m_s$  plus half the other electron with  $m_s$  minus  $r$   
 so that means i will have one electron  
 from each orbital that will have  $m_s$  minus  $r$  so i the answer to this question  
 is essentially  
 counting the number of orbitals one two three four five six seven eight nine  
 so one plus three  
 plus five  
 so there are nine orbitals for three  $n$  equals three and each orbital can

have

only one electron with  $m_s$  equals minus half

so the maximum number of electrons that

can have these two quantum numbers are nine the next question is along the similar

line it says that in an atom the total number of electrons having quantum number  $n$

equals four

so it says  $4n$  is 4 it also says  $ml$  the mod of  $ml$  is 1 we what we called  $m$  during

our discussion is called as  $ml$  because we have  $ml$  and  $m_s$  is the magnetic quantum number that

we know and  $m_s$  is the spin quantum number

so  $m_s$  is minus half a mod of  $ml$  is plus 1 when  $n$

is 4 i can have  $l$  as 0 or 1 or 2 or 3 when  $l$  is 0 the values of  $m$  or  $ml$  is only 1 that is 0 when  $l$

is 1 values of  $ml$  is minus 1 or 0 or plus 1 which i know that minus 1 2 plus 1 when  $n$  is  $n$  is sorry

when  $l$  is 2 i can have  $m$  value minus 2 or minus 1 0 plus 1 plus 2 and similarly minus 3 minus 2

minus 1 0 1 2 3 when  $l$  is 3.

now the second part of the question says the mod of  $ml$  should be 1 when is that possible

so that means  $ml$  can be either be minus 1 or plus 1.

so let us find out

the orbitals that satisfy this

so how many did we find we found six different orbitals

so this

corresponds to  $p_x$  these three are  $p_x$   $p_y$   $p_z$  and we know each of  $p_x$  or  $p_y$  can hold maximum

up to two electrons

so the next ah requirement is that the electron should have minus half spin and

i we know from the discussion of the last question each orbital will have one electron with plus

subspin and one electron with minus subspin so corr if we want the electron with minus half

spin

so we will find one electron in each of these circled orbital which satisfy this

so how

many are there two plus two plus two which is six ah we will look at uh the next question it

says that not considering the electronic spin all right the degeneracy of the second excited

state which is  $n$  equals three of hydrogen atom is nine do we know that if you remember for

hydrogen atom the orbital energy depended only on the value of principle quantum number

$n$

so the lowest energy or the ground state was 1 is the next state was 2s and 2p

combined this is 2s 2p they had the same energy because they had the same

principle

quantum number the third energy level  $3s$   $3p$   $3d$  this is the ground state this is the first

excited state this is the second excited state second excited state has  $n$  equals three that you

can see here how many orbitals were there one two three four plus five so there were nine

so this question we understood this part of the question the question actually

asks if this is the case what is the degeneracy of the second excited state of

$H^-$  ion now  $H$  this is for  $H$  which has one electron  $H^-$  has got two electrons

right and this is a multi electronic species if for multi electronic species we know that

the ordering depends on  $n + l$

so we will write down that  $1s$  then  $2s$  then comes two  $p$  then comes three  $s$  and

so on

so forth what is the ground state in  $H^-$  this is the ground state this is the first excited state and this is the second excited state and the second excited state is essentially

two  $p$  and how many orbitals are there in in this case the degeneracy is three the

final answer is three the degeneracy of the second excited state for  $H^-$  is three the

next question is from uh photoelectric effect it says that the work function of some metals it is listed below

so lithium sodium potassium and others their work function if you remember work

function indicates that the minimum amount of energy that you must supply to the metal before

you can take out its electron from it from the metal

so this essentially indicates

the binding energy of that metal minus energy of the electron to that matter the

question as the number of metals find out the number of metals which will show photoelectric

effect when light of 300 nanometer wavelength falls on the metal

so i am supplying energy where

corresponding to  $\lambda = 300$  nanometer and i know that this energy

so there is

there was this conservation of energy from the photoelectric effect discussion this is the

energy of the radiation this is this corresponds to the binding energy or the work function  $\phi$  and

the remaining part of the energy will be used for the kinetic energy of the electron

so unless the

energy of the radiation is more greater than  $\phi$  there will be no photoelectric effect

so if

the question essentially asks us if  $\lambda$  is 300 nanometer what is  $e \cdot h \cdot \nu$  if

you calculate  
 e in terms of  $\lambda$  from its this expression ah you will get the energy as 4.  
 13 electron volt  
 and you see if the energy supplied is 4.  
 13 volt lithium requires only 2.  
 4 electron volt energy so  
 if i supply this energy lithium will have be happy to give me that electron  
 similarly sodium is all  
 right potassium is fine magnesium is fine when i look at copper it has got 4.  
 8 electron volt and  
 i i have got only 4.  
 13 electron volt from this radiation  
 so the from the photon  
 so this  
 cannot remove photoelectron 4.  
 3 greater than 4.  
 13 it cannot 4.  
 7 again cannot 6.  
 3 is way  
 high cannot 4.  
 75 it cannot the question is find out the number of metals which will show  
 so i  
 can see one two three four only four number of metals that can show that will  
 show photoelect  
 photoelectric effect when i supply this radiation ah let us look at the next  
 question ah this  
 concerns the de bruy hypothesis it tells that the atomic masses of helium and  
 neon are given 420 amu  
 the value of the de broy wavelength of helium gas which is at minus 73 degree  
 celsius is m times  
 that of the debris wavelength of neon gas at 727 degree celsius what is the  
 value of m neon  
 gas is kept at temperature  
 so let us find out the temperature of neon gas 727  
 degree celsius which is ah 1000 kelvin temperature of helium gas is minus ah  
 73  
 degree celsius which is 200 kelvin all right and it says find out the masses  
 are given it  
 find out the de bruy wavelength what do we know about the deprived length as  
 we know that libro  
 suggested that for a particle with mass m moving its speed v has the de broy  
 wavelength of  $\lambda$   
 which is given by  $h/mv$  or  $h$  by momentum p the question says that these two  
 gases are kept  
 at different temperature  
 so let us see  
 so that if i say ah the question tells how many times helium  
 has  
 so it wants us to determine  $\lambda$   $h e$  divided by  $\lambda$  any this is what we  
 wanted to get if i  
 use this equation  $h$  is a constant  
 so i can write  $\lambda$   $h e$  divided by  $\lambda$  neon is the momentum  
 of neon ah divided by the linear momentum of helium  
 so this we have to determine and what do

we know about the ah what does the question tell us give us to know about the momentum  
 see this tells us about the temperature we know both helium and neon are monoatomic  
 inert gases  
 so they are kinetic energy  
 so if this is the temperature the kinetic energy of monoatomic gases is given by  $\frac{3}{2} kT$  and  $20$  is the temperature all right  
 and we know that kinetic energy  $E$  is  $\frac{p^2}{2m}$  of momentum divided by two  $m$   
 so therefore momentum is  $\sqrt{2m \text{ kinetic energy}}$  square root all right so the momentum of any divided  
 momentum of ah helium which is what we are trying to get is therefore  $\sqrt{2 \text{ mass of neon kinetic energy}}$   
 of neon and what is that which is  $\frac{3}{2} kT$  this is boltzmann constant and  $T$  is  $1000$   
 kelvin for ah neon i am not writing the down the units because both will have same units  
 they will anyway cancel  
 so two mass of helium multiplied by three by two  $k$  and boltzmann constant and the temperature is  $2000$  they are all multiplied and this is under square  
 root and mass of neon is  $20 \mu$  mass of hydrogen a helium is  $4$   
 so this is  $20$  divided by  $4 \times 2 \times 2$  and three by two and  $k$  three by two cancel  
 so i have ah ah twenty divided by four from uh mass and then thousand divided by ah two hundred which is five and this is five into  $5 \times 25$   
 square root of that is  $5$ .

so the final answer  $m$  that we need is is  $5$ .

these are the few questions that i could find from last few years of joint and trans ah j questions that that are related to the subjects that we discussed during the course of this lecture i collected ah some material from the books that are listed here if you have any questions or queries or comments you can always write me at the email address that is being shown here i hope you enjoyed the course as much as i did delivering it thank you very much you