

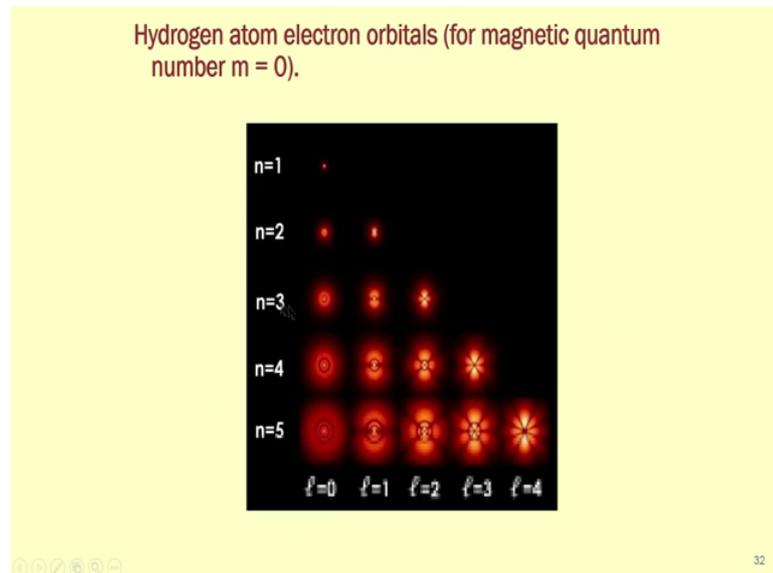
**Inductively Coupled Plasma Atomic Emission Spectrometry (ICP-AES) for
Pollution Monitoring**

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**Lecture – 06
Course introduction and atomic structure – VI**

So, this is how the l electrons are imaginable for us, and these are all dumbbell shaped etcetera.

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Now we will discuss about the m electrons.

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Magnetic Quantum number (m)

Some spectral lines split if the source is kept in a magnetic field. This is known as 'Zeeman Effect'. The orbital angular momentum vector undergoes a precessional movement and describes a cone about an axis in the direction of the field the magnitude of which is given by $ml(h/2\pi)$. There are $2l+1$ magnetic quantum numbers ascribed to each 'l' orbital.

Thus for s electron, $l=0$ and $m=0$ (1 orbital)
p electron, $l=1$ and $m=-1,0,+1$ (3 orbitals)
d electron, $l=2$ and $m=-2,-1,0,+1,+2$ (5 orbitals)
f electron, $l=3$ and $m=-3,-2,-1,0,+1,+2,+3$ (7 orbitals)

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So, the Magnetic Quantum number is defined as m. So, every, like this is the third identity of the electron; that means, in a magnetic field, if I take an electron and subjected to a magnetic field.

The movement of the electron, the magnetic properties also alter. So, this altered magnetic effect is visible to us as a spectrographic proof. So, if there is 1 line, spectrographic line, spectroscopic line, corresponding to an electron and if the same spectrograph, a spectroscope is taken in a magnetic field, that say 1 single line will look 2 single lines.

So, if without magnetic field there is only 1 a spectral line, and in presence of magnetic field there will be 2 spectral lines. So, it means that the electron apart from its orbital angular momentum, it also has some effect or some, it is associated with some magnetic field also, and this magnetic field is evidenced by the splitting of the spectral line, this is known as Zeeman Effect ok.

So, the Zeeman Effect is basically the orbital angular momentum vector, that undergoes a precessional movement, and describes a cone around its axis, this is how we can try to imagine. The electron is there like this, and it will be rotating, you can imagine a pocket, you know a small pocket in which you carry you food. If you go to a grocery store, he will give you a paper packet made of cone, I think most of you are familiar with that. And it is also like you know ice cream, cone ice cream.

So, the electron will be going around the cone, describing the cone, and if the magnetic field is not there, it will be like a single line, but the moment you put magnetic field it will come alive, and then start moving, describing a path that is described by a cone. So, the orbital angular momentum vector undergoes a precessional movement, precessional, precision it is called, and it describes a cone about an axis in the direction of the field at which we apply the magnetic field.

Now, you can imagine that, I have an electron, and if I apply, I can apply, the magnetic field above and below the electron or horizontal both sides of the electron. Now all the 4 sides we cannot apply, because it, for that we had to design a box, in which the electron needs to be put, but it is a different arrangement, that is not convenient, but we can imagine the electron, that the magnetic field, has applied from the top and bottom or from the sides.

So, the precessional movement is always any movement for example, orbital angular momentum or repetition, repetitive moment in a circular or elliptical path, is always given by the, described by the, again magnetic momentum. And that magnetic momentum for any electron is described by this equation, m into l into h upon 2π , $m l h$ by 2π . So, for each electron, there will be, for each l electron there will be so many. So, there are all in all, $2l + 1$ magnetic quantum number. Quantum numbers ascribed to each l orbital, for every l orbital there will be so many $2l + 1$. So, if for s electron there l is equal to 0, and m also has to be, if l is zero, $2l$ is 0, plus 1 is 1 orbital.

So, the magnetic quantum number m is defined as 0, but there will be 1 orbital corresponding to m is equal to 0. Similarly for p electron, l is equal to 1, and m would have $2l + 1$. So, for l is equal to 1, 2 into 1 plus 1 that is 3 orbitals. So, the 3 orbitals are designated as minus 1, 0, and plus 1, total 3 orbitals. Similarly for d electron, l is equal to 2, and m should be 2 into 2 is 4 plus 1 is 5 so, total 5 orbitals, and the value of that would be 2, minus 2, minus 1, 0, plus 1, and plus 2.

So, for m is equal to l is equal to 1, there will be minus 1, 0, and plus 1. Similarly for f electrons, l is equal to 3, and it is minus 3, minus 2, 1, 0, and plus 1, plus 2, plus 3 orbitals, total there will be about 7 orbitals. Now the fourth identity of the electron in any element is spin of the electron.

So, so far we have described what is known as principle quantum number that represents the distance, orbital angular momentum associated with the movement of the electron around the shell is l , and then when the same electron is placed in the magnetic field, that is magnetic quantum number, and when all the three quantum numbers are same for an electron, the spin language, spin only is the, only spin of the electron is the only one that differentiates between 2 electrons.

So, what is the concept? The concept is, an electron just like our planet earth, it not only goes around the nucleus, but it also goes around itself. So, the spin of the electron can be in l , clockwise direction or anti clockwise direction, both. So, it can, if you by convention clockwise and anti clockwise direction movements are defined as plus half and minus half.

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Spin Quantum Number (s)

An electron also rotates on its own axis. Hence it has its own angular momentum amounting to:

$$\frac{h \sqrt{s(s+1)}}{2\pi}$$

where $s = 1/2$ or $-1/2$ depending upon whether it is precessing along the applied magnetic field or opposing it. For each value of ' m ' orbital there are two electrons opposing in spin.

No two electrons within any atom can have same 4 Quantum numbers. This is known as '[Pauli exclusion Principle](#)'. Each electron differs from every other electron in a given atom in its total energy.

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Because it is 50 50, we cannot really differentiate, which is clockwise and which is anti clockwise, especially given the small size of the electron and our inability to see an electron processing around itself.

So, theoretically, yes, the spin quantum number is defined as plus half or minus half, but it's angular momentum, due to this spin amounts to an equation defined like this, that is h into square root of s into s plus 1 divided by 2π . And this expression is derived from quantum mechanical considerations.

We need not worry about, how this expression is derived. But you can see that, even for orbital angular momentum, it is h into square root of 1 into 1 plus 1 divided by 2π , almost similar case.

So, s , the value of s is plus half or minus half, depending upon whether it is precessing along the applied magnetic field or opposing the field. So, there are only 2 ways, a magnet a spinning magnet can align itself, it can either be along the applied field or opposing the field. So, it both the plus half and minus half assignments are basically arbitrary.

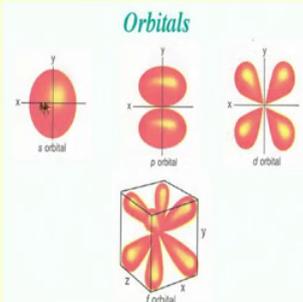
So, for each value of m there are 2 electrons, one opposing the, in the spin only. So, no 2 electrons within an atom can have their same 4 quantum numbers, this is the another rule that is known as Pauli exclusion Principle. So, this is a very important concept with respect to the electrons in the arrangement. So, each electron differs from every other electron at least by spin angular momentum in a given atom in its total energy.

So, the total energy is given by the 4 principal quantum numbers, s p n l s and m that is magnetic field. So, every electron may have almost similar properties except for the spin, that if we understand, that should be good enough for our purpose. So, now, let us look at how the electrons move around. So, this is the shape of the s orbital, and you can see that the nucleus is located at the center.

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Atomic orbitals

Knowledge of the exact order in which atomic orbitals are occupied is based on the interpretation of atomic spectra in terms of how spectral lines result from permitted electronic transitions. Heavier atoms have complicated atomic spectral patterns and overlaps occurring in the similar systems.



Orbitals

s orbital

p orbital

d orbital

f orbital

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And then there is a space describing there are x and y orbitals, x and y axis, and you can imagine a 3D space around this, and s orbital is spherical.

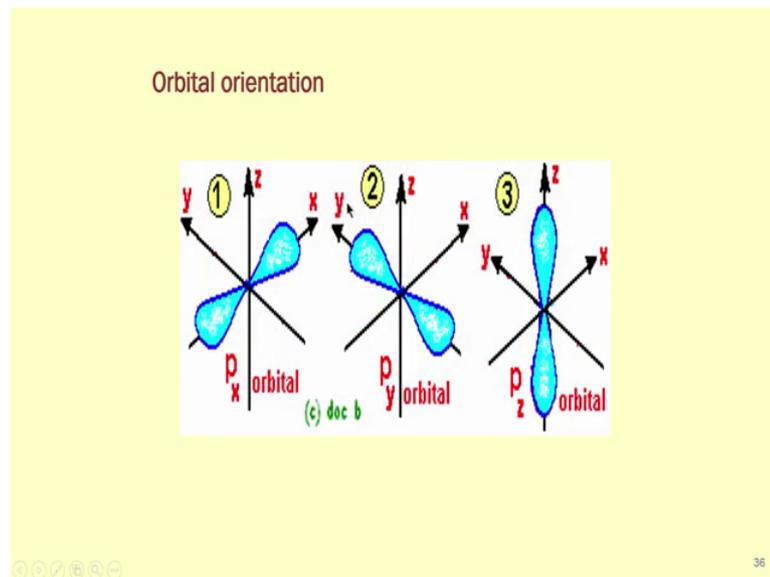
So, knowledge of the exact order in which the atomic orbitals are occupied is based on the interpretation of actual atomic spectra only, in terms of the how the spectral lines result from the permitted electronic transitions. So, when I say permitted electronic transition, it means that, all transitions are not visible or they are not permitted, some transitions are forbidden according to quantum mechanical rules, and some transitions are quite possible.

So, heavier atoms, obviously will have complicated atomic spectral patterns, and overlap occur, overlapping occurs in similar systems. Now coming back to the orbital structure, s orbital is spherical in nature, p orbital is dumbbell shape, and this orbital d orbital is actually planar, you know, imagine there were a table and the cut them into 4 corners for the, dumbbell shape is oriented along the corners of the plane. So, it is in only in x y plane.

So, I think you should be able to imagine that. First time is circular, the second one, p orbital, is along the x axis and y axis, that is above and below, suppose I have the atom here at the center, the p orbital will be located above the plane and one below the plane, the dumbbell shape. And similar dumbbell shape is possible with respect to the d orbitals, but these d orbitals are located along the, you may imagine a rectangle or a square, and along the corners in the space x y, you know, they are not in the 3D shape they are not above and below.

So, but the for the d orbital, you will have to imagine again a sort of a 3axis, one is x axis along the, one is horizontal, perpendicular to that this is x axis, perpendicular this is, facing towards you and perpendicular to that is y axis, and another axis is vertical that is x y z axis, and in that space, in that you will you can imagine f orbitals located like this. So, the atomic orbitals are always like this.

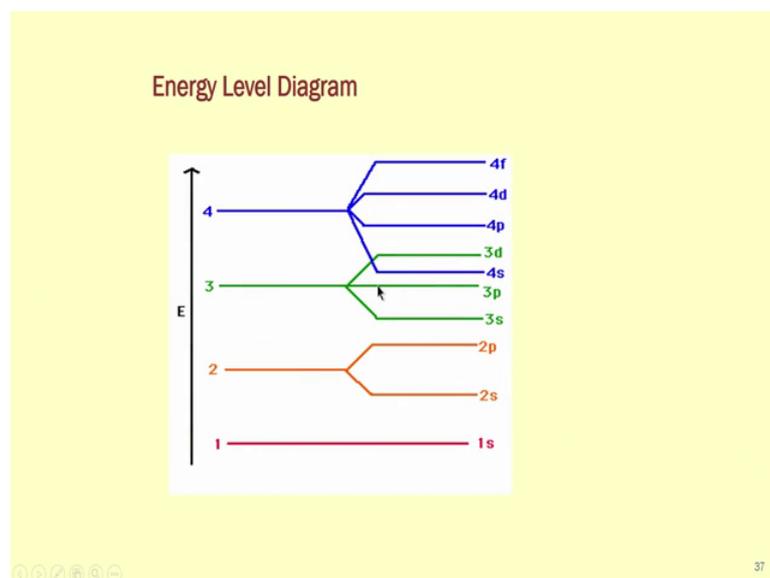
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When their orbital orientation would be something like this, this is p_x , this is p_y , and p_z , because the orbitals would be, they in the plane, in the vertical space etcetera, and there are 3p orbitals. So, each orbital can have 2 electrons, filling in this. So, one may be here, one may be here, I am showing, you can see that the space is defined like this, but the electron density is defined by white dots here.

If you look closely, you should be able to see them around here.

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So, that is in the x axis, one is in the y axis, another is in the z axis. So, the energies corresponding to these, x, p x, p y, and p z orbital are same. Because, they all have the same l values. So, if you draw the energy of a diagram, energy of an electron in different shells. So, the 1 s would be having lowest energy, and the next shell n is equal to 2, that is principal quantum number will have 2, 2 electrons, 2 sub shells 2s and 2p.

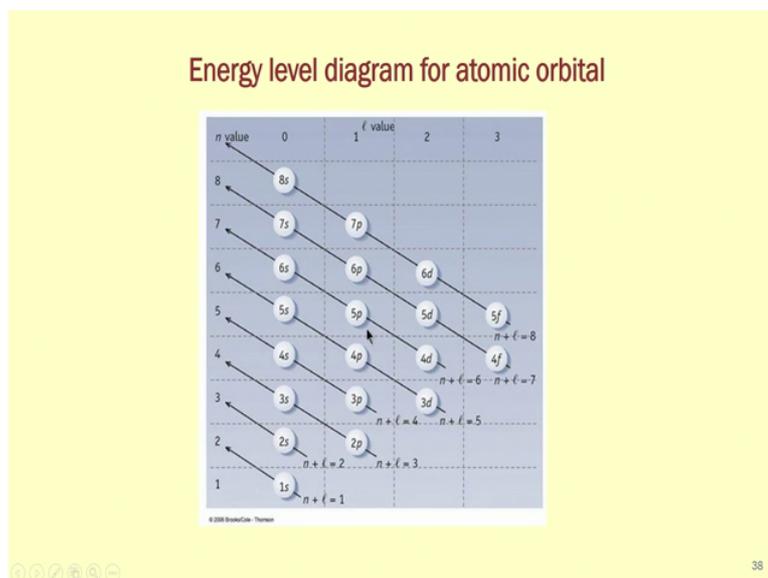
So, 2s is located above 1s, and 2p is located above 2s. Similarly as you move to higher quantum numbers, that is n is equal to 3, you will have 3d, 3s, 3p and 3d. Now that I had, I had depicted using green lines. So, here you can see that, 3d is located at higher energy level than 4s. So, this is a consequence of the electronic filling and quantum mechanical theory, it is in accordance with that.

So, when n is equal to 4, it will have 4s, 4p, 4d, and 4f. But 4s is lower, having lower energy than 3d therefore, what happens is, if we, if I have so many, if I choose any element having principal quantum number 4, it can have so many electrons, and each size will have, each energy level is populated by minimum 2, 2 electrons. So, this first n is equal to 1 will have 2, here a 2s is 2 again, 2 p would be 2 2 2 that is 6 electrons, and then 3s would be having 2, 3p would be having 6, 3d will have 5 orbitals.

So, 10 electrons. So, after the 4f, we would be having 18 electrons. So, if you count all the things, you can keep on filling the electron for example, if I have only hydrogen, I can the, I can confidently say that 1s, the electron will occupy 1s orbital, and hydrogen, next element is helium, the second electron also will be there in the 1s and the 2 electrons are distinguished by n is equal to 1, l is equal to 0, and m is equal to, m is equal to 1, 2l plus 1, and s would be plus half or minus half. So, that is for hydrogen and helium. Lithium will have the 2 electrons in this, 1s, and then the third electron will be going to the next higher energy level that is 2s.

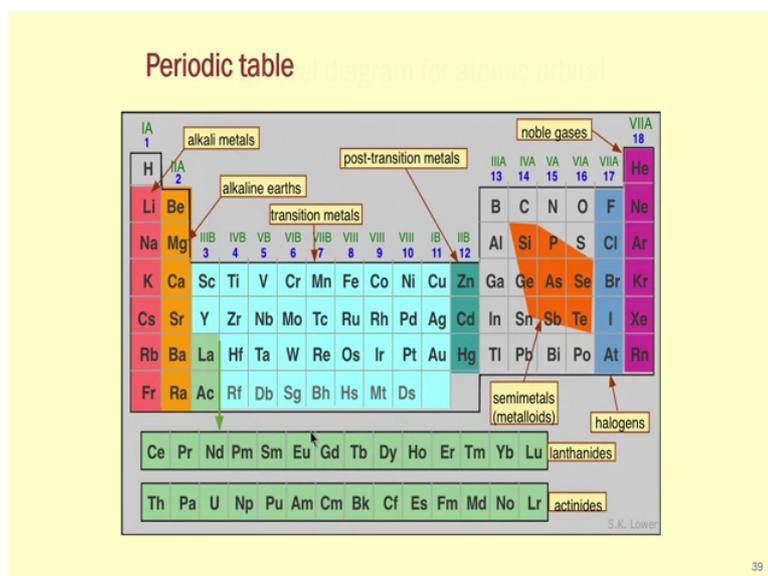
Similarly, you can keep on filling the electrons around the, all the orbitals. And our current knowledge of the filling of the electrons, in different states is based upon this kind of knowledge, where we keep on filling one electron after another in different shells and sub shells etcetera. And there will be gradation of electrons, and properties, chemical properties, and everything, will keep on changing depending upon how the electrons are filled.

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So, now you can imagine the energy level diagram for the atomic orbital. So, if I have the n value here, and then this is l value 0, 1, 2, 3, n can be 1, 2, 3, 4, 5, 6, 7, 8 and this will have 1s electron, 1s orbital n plus 1 is equal to 1, and there will be 2s electron so, 2s, 3s, 2p and similarly there will be other electrons filling up, I keep on filling up 1s, 2s, 2p, 3s, 3p, 3d and then 4s etcetera. So, all these things will be, this is a very simple pictorial representation available in the Google.

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So, our periodic table, that brings us to the periodic table and this is what I am showing you is one of the current understanding, just like the understanding of our electrons, and the electronic atomic structure has undergone changes since last 200 years attempts have been made, to put the all the elements in order. So, that we can understand the properties of the elements, and even before the structure of atoms was known, the attempts to put the elements, known elements in a in a table have been progressing, and the subsequent development stages of the periodic table, itself is a very fascinating aspect of human endeavor.

How beautifully things known to us, and their properties have been organized in a periodic table. So, some other time, if your college is interested, if you people are interested, I will come and talk to you about the periodic table and the beauty of periodic table as we understand, we will have a discussion sometime later, but in between, this is how, I can give you some sort of introduction to the periodic table. So, the, all the elements, are we know, most of the elements, since almost 200 years, except maybe radioactive elements and some isotopes etcetera.

So, hydrogen, helium, lithium, beryllium, boron all those things were known quite some time, and some elements were discovered later, and the initial attempts to classify the, to classify the elements into a group of, into a table, were always based on the chemical properties for example, they thought, they will put all the gases in one place, that is hydrogen, helium, lithium, beryllium, chlorine, nitrogen etcetera. And then there was an attempt for the, for putting the elements according to the similarity of the properties.

So, there we had, what is known as triads for example, if you look at this table f, e, c, o, n, I, r, u, r, h, p, d, ruthenium, rhodium, palladium, iron, cobalt, nickel, osmium, iridium, and platinum, all these things are known as triads, and then they people have tried to put very reactive elements in 1 group, that is lithium, sodium, potassium etcetera. These are known as alkaline earth metals, magnesium, calcium, strontium all these things form alkalis.

And then we have, what is known as, in the green color this is known as transition element. These are all coinage elements, you can, metals basically. So, scandium, titanium, vanadium, chromium, manganese, iron, cobalt, nickel most of these things have been known to us, since quite a few centuries also.

But subsequently we also know that, many of them are nonmetals boron, carbon, nitrogen, oxygen etcetera and aluminum, silicon etcetera are there, but most of the modern understanding of our periodic table is based on the atomic weight, that is described by Mendeleev, who described that, he could arrange the atomic weights, all the elements in increasing atomic weights. So, this is what he tried, and that a, then he also used a lot of intuition to put it into, put all the elements in this shape.

Now, for example, you can see hydrogen here, he arranged them into horizontal rows and vertical columns, and then he said, first let us put hydrogen, lightest element, next should be helium but, hydrogen is very reactive, helium is not at all reactive. Then he said, let us put lithium, lithium is as reactive or at least comparable in reactivity to hydrogen. Similarly lithium, and sodium, potassium they all have properties which are very similar to each other, then he thought, he can make a column out of this. So, then he put hydrogen, lithium, sodium, potassium etcetera together, and then with increasing atomic weight, next element is beryllium, and then sodium, next is magnesium the etcetera, these he called alkaline earth elements.

And then he keeps on increasing the atomic weight, put beryllium, carbon, nitrogen, oxygen, fluorine and then comes the neon. So, this neon is again inert gas, then he thought this helium, neon, argon they are all inert gases. So, why not, I put all of them together. So, you, he was not able to fit many elements like this, after magnesium it is aluminium, but after calcium his next column is in gallium. So, zinc. So, these elements he called this as transition elements, where he was not able to appreciate the electronic structure at that time, but atomic weights were known, but somehow the intuition the beauty of the science is intuition and with the with his intuition he thought that most of these elements are similar with respect to arrangement of electrons.

Because their valency and other things remain same, but metals look different, metals reactions are similar, but actual products are different, like that he was able to identify several characteristics and that itself forms a fascinating study of human endeavor, and he also put the elements like fluorine, chlorine, bromine, iodine actinides etcetera as very reactive elements, and then next after this, the next atomic weight are all inert elements and these are semi metals, they behave as metals as well as semi metals.

For example silicon, phosphorus, selenium, arsenic all these things are semi metals, are also known as metalloids. So, all these kinds of metal, electrons, atoms, elements he was able to put forward in terms of atomic weight, and he made some intuitions, he also suggested that, some of the elements are not found, he said there could be possibility that many of these elements need to be discovered.

So, he deliberately left gaps in the periodic table, you, if you look at your periodic table, history of the periodic table, especially original. Mainly he will see that, he has left a lot of space vacant, and the vacant space represents an element not discovered at that time for example, this germanium was left vacant earlier and which he called a ca germanium, and then similarly with the element this krypton and xenon. So, here, he was able to leave some gaps suggesting that, work is needed to be to discover those elements, and lanthanides again, they are all very similar in properties then he said they, do not fit anywhere except here this green structures la lanthanum and ac actinium, the last part here the, if you look at the atomic weight there is a 72 year.

So, there are about 18 elements here, 4 plus 4 is 8, plus 4 is 12, and about 13 elements. So, the modern understanding of our periodic table is based not on the atomic weight, but on the atomic number, it is the consequence of the understanding of the atomic number, and first basically it is the realization that the protons or number of electrons are the basic building blocks for each element.

So, the modern periodic table as it looks now, is based on atomic number, where the atomic number keeps on increasing by 1 unit, hydrogen 1, helium is 2, lithium is 3, beryllium is 4, like that this is the current modern periodic table, and now I think we, we will stop our discussion at this level, because basically what we have covered is, how an atomic structure, understanding of atomic structure tells us about the metals, and nonmetals, etcetera, and with the same building blocks, like electrons, protons, neutrons and other things.

So, if with this much of understanding of the atomic structure, what we will do in the next class, is we will discuss about the basis of spectroscopy. That is interaction of a electromagnetic radiation, because the electron radiation is the one which is used in all spectroscopic techniques.

And the interaction of the electromagnetic radiation with the matter gives rise to the spectroscopic techniques. Therefore, we will study that aspect in our next class.