Chemical Crystallography
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Crystallographic Point Groups and Space Groups
Lecture - 06
2D Space Lattices

Welcome back to the course of Chemical Crystallography. In the second week, today we are going to start learning how to draw the 2D space lattices with symmetry elements incorporated in it. So, today what we plan to do is that we will try to draw and show you how to draw these 2 D space lattices having different symmetry elements. So, in case of 2 D lattices the first 2 D lattice that we can draw is termed as p1.

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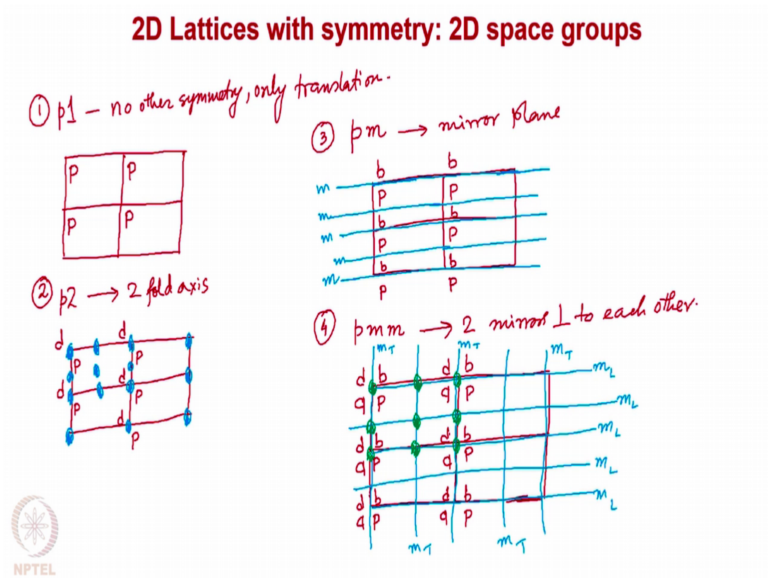

So, this is a lower case p you remember that lower case p here indicates a primitive lattice and one indicates there is no other symmetry other than translational symmetry. So, we do not have any other symmetry only translation. So, in this case if we draw the 2 D lattice like this which is actually a combination of 4 lattice 4 unit cells, if I start writing one object my molecule as p, I have chosen the letter p because, this letter does not have any symmetry of it is own. So, when we apply any further symmetry operations it will not hamper the molecule at all, so when I say p 1 I should have this p translated in all the

4 unit cells like that; the second type of 2 D lattice has a space group small p 2 which indicates it has a twofold axis how rotation.

This twofold axis of rotation is important to generate the symmetry related objects around it. So, I am again drawing 4 unit cells like this and then I have my object p here and the symmetry element that we have here is twofold axis. So, I am putting this twofold axis at every corner of the lattice of the unit cell and then the first important symmetry is a translational symmetry. So, I should have the molecules translated like that and then based on this twofold axis, if I rotate this the first p that we have here which is this particular p if I rotate it should come outside the unit cell and we should draw it like this which looks like d.

In the same manner other p s also can be symmetry operated and the corresponding translations related molecules can also be drawn. So, now what we see is that the symmetry between this particular molecule and the other molecule which is there they are further related by a twofold symmetry. Similarly, these two are further related by another twofold symmetry and there is a further twofold at the center of the unit cell, similarly there is a new twofold generator at the middle of the edge center of the edge and so on.

So, because of the presence of twofold axis at 4 corners what we have got are 2 folds generated at the edge centers and the center of the unit cell as well. The next type of 2 D lattice is termed as pm once again p is small and m means a mirror plane, so we have only 1 mirror present in the lattice. So, now if I draw again a 2 D space lattice and then I write the letter p which is my object and it is translational symmetry related objects are also drawn in the adjacent unit cells. Now, when I am saying that it has mirror symmetry I must designate where the mirror is the mirror as I said is designated as a bold line and I am assuming that mirror is along this edge.

This edge represents a mirror similarly this edge represents a mirror that edge represents a mirror. So, these blue lines are mirrors that are represent in this lattice. So, what happens when we apply this mirror to the object that I have taken I get mirrored image related objects like this, the translation comes here the mirror comes there. So, now p becomes b by a mirror of operation. So, now what we see is that a further mirror is generated in the through the middle of this unit cell as I am drawing those lines.

So, these are additional mirrors that were generated between the 2 parallel mirrors. So, in this particular case in 1 unit cell there are 2 molecules which are mirror related, in case of the previous lattice which is p 2 there also if you see in one unit cell there are 2 objects 2 molecules related by a twofold symmetry. So, in case of p 1 you have one molecule part as a unit cell in case of p 2 and p m you have 2 molecules per unit cell. Now, let us see the third type of a fourth type of lattice and this 2 dimensional space lattices is number 4 is p m m; that means, it has 2 mirrors perpendicular to each other.

So, how does it going to look like once again we first need to draw the combination of 4 lattices 4 unit cells rather, I am going to draw only the translation related objects as usual. Now, we have one set of mirror as before along 1 particular edge, so if I apply that mirror like before we should generate the objects as I am drawing here and then the second set of mirrors that are there or that one can consider is a transverse mirror like this, which is perpendicular to the previous mirror. So, this is longitudinal mirror and the new one is a transverse mirror.

So, now we see what is happening, now we try to reflect the objects that are here p and b against the mirror transverse, now we get these objects which are now mirror image of the previous one, one can complete all these by drawing the corresponding mirror images. So, now what has happened if you look at this particular drawing very carefully, first of all because of parallel that we have here we have generated one additional longitudinal mirror here through the middle of the unit cell and one transverse mirror through the middle of the unit cell as well perpendicular to that.

So, this diagram completes the p m m, now I would like you to see one more interesting aspect here, wherever I have a point of intersection of 2 mirrors at those points I have edge twofold generated. So, wherever 2 mirrors are intersecting a new twofold has been generated. So, overall this p m m lattice or p m m space group contains 2 perpendicular mirrors mL and mT and wherever those mL and mT coincide or they cross each other the point of intersection is a twofold axis that is generated in this case.

Now, we go to some more slightly complicated 2 dimensional space groups and mind you it will not be possible for me to draw all of these in this class, but I would like you to see these drawings and understand yourself from a text book by FA cotton the chemical applications of group theory chapter eleven all these drawings have been done there, but some of those things which I felt is required to discuss in the class I am trying to draw them as far as much as possible.

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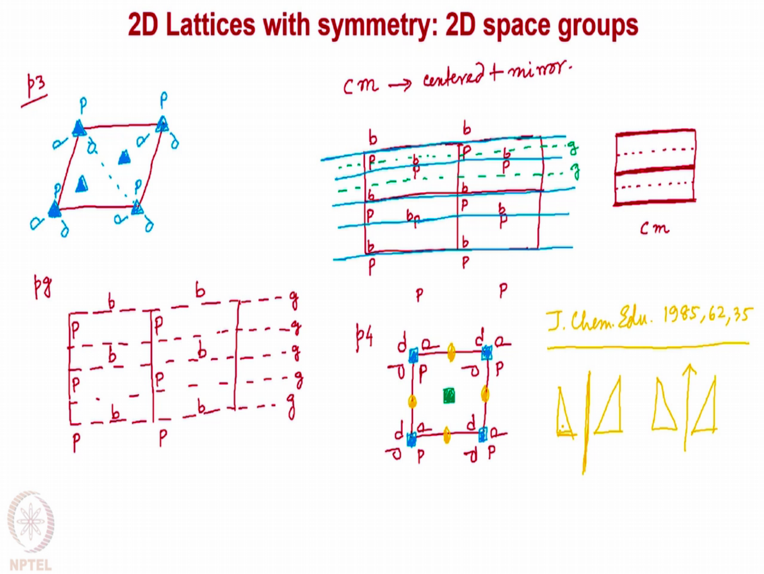

So, the next one is p 3, so which means I have a threefold symmetry present at the corners. As you know we draw threefold as a triangle, so I am drawing those threefold axis at the corners of the unit cell and then I am writing the letter p here and then when we try to apply a threefold symmetry on this p this gets rotated like that.

So, by applying that p if we try to fill the unit cell, what happens is that in between the 3 threefold axis the 3 corner threefold axis these 3 threefold axis are further related by a new threefold and similarly the other 3 threefold axis are related by another threefold axis. So, p 3 looks like this as I have drawn with threefold axis present at 4 corners and 2 opposite centers of the half triangular portion of this oblique lattice. Now, let us try to draw another 1 which is p 3 I am only going to do the ones which may be difficult to understand rest of it I would like you to go through the textbook and do it yourself.

As I said it is glide so the glide symmetry is drawn as dashed lines. So, the unit cell is drawn with bold line, but the glide is drawn as a dashed line. So, now if I have my object which is here what I am going to do is I am first going to draw the translation related objects and then we will draw the objects which are related by the corresponding glide which is here; what is a glide plane a glide plane means you do a reflection followed by translation. So, if I was going to just reflect it would have appeared here so that means it is just a mirror, but no I do not want only a mirror rather I want it to be translated as well.

So, when we do a reflection followed by half translation the object comes here, similarly the object which is in the lower unit self do a 2 do a glide plane it comes somewhere there; for this the atom comes there for the fourth 1 the atom comes here and if I have this in the outer unit cell as well the corresponding points come there. So, now what we see is a relationship between the 2 objects inside the unit cell is also a glide in between.

So, this is the picture this is the representation of the 2 D space lattice pg, now the as I indicated there may be a lattice where you have a C centering a lattice centering a centered lattice. So, let us try to draw 1 of those centered lattices when we write cm it means we it is a centered lattice plus it has a mirror. So, first let us draw a simple centered lattice a centered lattice means in addition to an atom at the corner, I should have another atom in the center of the face.

So, I should first draw the corresponding translation related objects in all the unit cells that we have drawn here. So, these are just the corresponding translation related objects for a C centered lattice or a C lattice. So, now as I said there is a mirror plane and this mirror plane is a transverse mirror. So, we take that mirror along the edge this is my transverse mirror and this transverse mirror is further represent in the middle of the lattice like this. So, now with the transverse mirror we try to apply the mirror symmetry on these points, so what I get is the object here the object there the object here object there and so on.

In that process what has happened is what we see here the points identified here and point identified there they are further related by a glide in between. So, if we try to draw it this glide with a different colour the glide should come like this. So, in a nutshell if we try to just draw this unit cell without drawing any object it should be drawn like that, these are mirrors which we have as I indicated mirrors are drawn as bold lines and the glide planes are drawn as dashed lines this is the representation of cm with only symmetry elements indicated.

The other one that I want to draw is a fourfold symmetry which is p 4. So, now as we see it is a fourfold symmetry the immediate requirement is that it should be a square lattice not a rectangular lattice anymore, because a should be equal to b. So, now I am going to draw a square lattice rather a square unit cell which is my p 4, which is which we where I will draw the p 4 and I am going to place my fourfold axis at 4 corners of this lattice.

Now, let us take the same object p and do a fourfold operational p along those symmetry elements. So, when you rotate this p anti clockwise direction you get something like that on further rotation it gives you this and further rotation it gives you that and the same is present due to translation at all the 4 corners. So, now as a result you can see that a fourfold is generated at the center of this unit cell as well, before ps inside the unit cell are related by a fourfold symmetry and further there are 2 folds which got generated at the middle of the edges.

So, these are the symmetry operations that got generated because of the presence of 4 fourfold axis at 4 corners and at the center. So, all these drawings all these 2 dimensional space lattices are important to understand the 3 the growth of 3 dimensional space lattices in the future classes. So, I would like all of you to go through the textbook by FA cotton the chapter eleven and these drawings are taken from this particular journal, journal of chemical education 1958 volume 62 page number 35; it is required for all of us to draw these diagrams ourselves to make us understand that these how these symmetry related objects are generating.

Because this is the most important aspect of x ray crystallography because, we are trying to understand how one molecule is trying to see another molecule and then when we are trying to see two different molecules in space, how they are oriented in space ? Here I would like to give you a small demonstration where suppose this is a remote control of AC which has 2 sides different.

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So, now if I have one object here I apply a mirror plane like this the object is reflected here. So, the digital side is always facing you, but then if I have a twofold axis like this in space this object when it rotates it rotates like that. So, the digital side is now towards me instead of towards you. So, while drawing a mirror compared to a twofold there should be a distinction in our drawing.

So, if we are trying to draw some triangle and a mirror it should show like this, if I am trying a triangle and I do a true fold that also shows like that. The sign for twofold is this and sign for mirror is a bold line, but to distinguish between these two what one should do is identify the face with a dot, here the face is identified with this digital side facing towards you.

So, when I do a mirror plane the digital side remains towards you, but when I do the same for a twofold it rotates and the side changes. So, this change of side indicates if I have a dot here the dot goes behind, so in representation of 3 dimensional symmetry when you represent something which is not in the front, but in behind we represent it as an open circle instead of a dot.

So, we will use these notations in future lectures so that we are able to represent 3 dimensional objects 3 dimensional symmetry elements 3 dimensional symmetry operations, as a projection in 2 D that is our pen and paper or blackboard or whatever we should be careful about what we are drawing whether we are drawing a mirror or we are drawing a twofold whether we are drawing a glide or we are drawing a 2 1 it should be distinguished appropriately.

So, today what we learnt is how to draw the 2 D space lattices with the objects, in the next class we will discuss we will try to draw these the same lattices without any object, but by placing only the symmetry elements and then we will learn a few new things like what is the difference between p 3 m 1 and p 3 1 m. So, with this I would conclude this lecture today and we will discuss further in the next class.