Application of Spectroscopic Methods in Molecular Structure Determination

Prof. S. Sankararaman
Department of Chemistry
Indian Institute of Technology, Madras

Lecture - 24
Mass Spectrometry – problem session

Hello, welcome back to the course on Application of Spectroscopic Methods in Molecular Structure Determination. We are in module 24 now and in this module, we will consider some problems in mass Spectrometry. In other words, this is a tutorial session for the mass Spectrometry problems.

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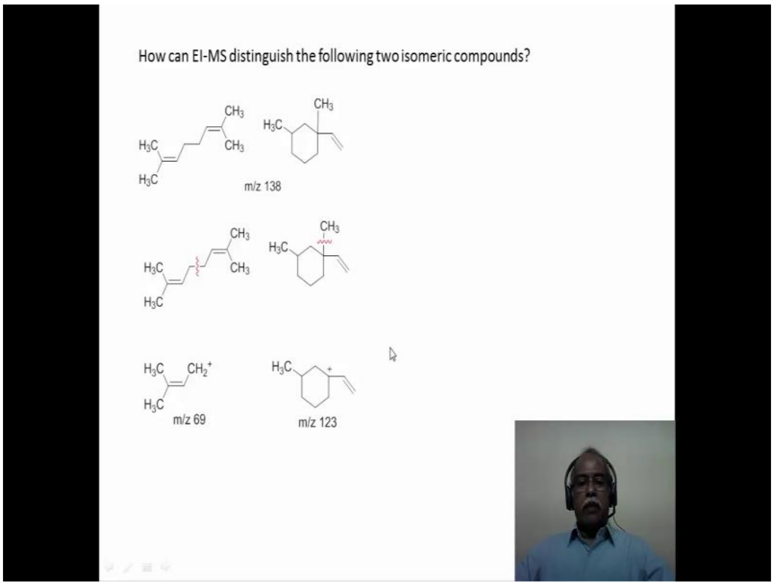

How can EI-MS distinguish the following two isomeric compounds?

Now, first question deals with these two molecules. They are essentially isomers, the same molecular formula the structures are different and the molecular weight is same for both compounds, it is 138. The question is, can electron impact ionization mass Spectrometry distinguish the following two isomeric compounds? Now, if we consider this molecule this is asymmetrical molecule and this is an unsymmetrical molecule. So, the fragmentation pattern has to be necessarily different for these two types of molecule. If we consider the most likely fragmentation of this particular molecule it is, probably going to break this carbon carbon bond, resulting in a an allylic kind of a cation, which is the stable cation and being symmetrical it does not matter whether you put the charge on this carbon or in this carbon the probabilities are equal.

On the other hand, if you look at this particular compound the most likely fragmentation is a loss of methyl group with the allyl cation generated as part of the ring structure here. This is depicted here, the fragmentation corresponding to the carbon carbon bond cleavage here and the fragmentation corresponding to the carbon carbon bond cleavage in this particular molecule here, this will essentially result in two types of fragmentation ions. The fragmentation ion resulting from this particular molecule will have m by z value of 69 whereas; from this molecule the loss of methyl group will generate 123. You can ask me this question. Why the methyl is not lost from this particular molecule?

Suppose, if you break a carbon carbon bond of the carbon methyl bond in this particular molecule that will generate vinyl cation. Vinyl cation in comparison to allyl cations are not relatively more stable. So, allyl cation formation is probably prepared, the last of a methyl group from this molecule probably will have a very low probability unlike this molecule where is actually produces a tertiary carbonium ion in this case. So, from the fragmentation pattern, one would have observe 69 mass fragment for this molecule 123 mass fragment for this particular molecule. Hence, they can be distinguish using the Mass Spectrometry based on their fragmentation pattern and the kind of fragments that one obtains in these two molecules.

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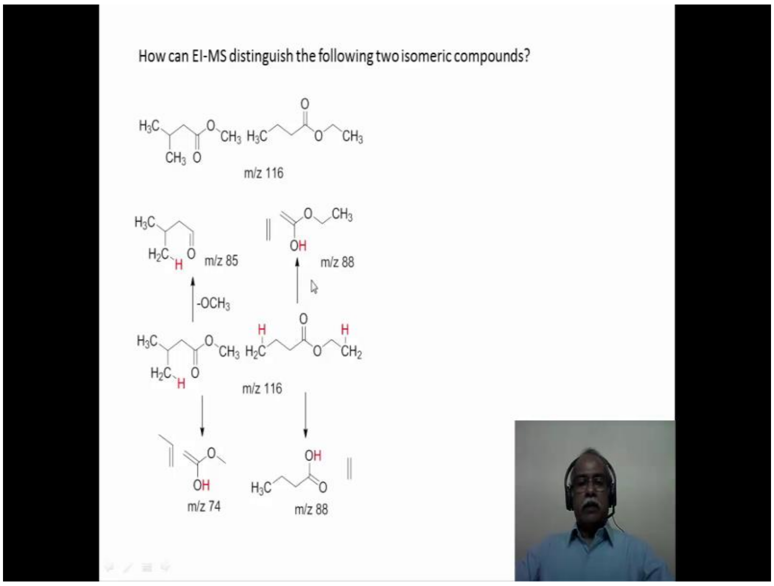

How can EI-MS distinguish the following two isomeric compounds?

Let us move on to the second problem. Now, these are also isomers, their molecular formula is same. So, molecular weight is also same can electron impact ionization mass spectrum distinguish these two isomeric compound is a question? Now, if you look at this molecule carefully this as alpha, beta, gamma. There are 6 gamma hydrogen in this molecule. So, Mclafferty rearrangement is probably going to have a high probability in this particular molecule. Whereas this molecule has alpha, beta, gamma. These three hydrogens are gamma hydrogen similarly, if you come on the other side of the carbonyl functional group this is alpha, beta and gamma. This CH 3 is also a gamma hydrogen CH 3. The hydrogens in the CH 3 are gamma hydrogen. So, there is double possibility of Mclafferty rearrangement in this particular compound. Where is a possibility of Mclafferty rearrangement in this compound also.

So, essentially the fragmentation pattern for this compounds will be entirely different. Let us take this particular compound first, this can undergo two types of simple fragmentation you can undergo. One is the fragmentation of the methoxy group to give a acyl cation, the charge is missing. So, one has to have a cationic charge for the this molecules. All the fragments should produce should be having a cationic charger a cation radical kind of a species is what we are discussing. But for the sake of convenience i have skipped the charges in this molecules. Let us say for a example, this is molecule fragments by loss of a methoxy group it will lose a mass unit of 31 in this particular case resulting in the formation of a fragment ion which is m by z value 85, on the other hand if it undergoes a Mclafferty rearrangement. It will produce this particular fragment here which has the molecular weight of 74 for example. So this, particular molecule will have two prominent fragments one corresponding to the alpha fragmentation the other one corresponding to the gamma hydrogen abstraction with the lose of in propylene unit in this particular case. So, the two fragments, one would observe or the 85 and 74 in this case.

On the other hand, in this particular molecule irrespective of whether you do a Mclafferty rearrangement with this hydrogen or with the Mclafferty rearrangement of this hydrogen. The molecular mass that is last is 28 that is ethylene is, what is last from either side of the molecule resulting in two types of fragment but, with the same molecular weight of 88 the m by z value for this fragment will be 88. The m by z value for this fragment also will be 88 because either of Mclafferty rearrangement essentially loses a molecule of ethylene from the parent molecule 116 minus 28 would correspond to 88. So, this molecule will produce a prominent peak at m by z 88. Whereas this molecule which is an isomer will produce m by z 85 and 74 has two fragments in this case. This molecule can also undergo loss of a ethoxy group, with the loss of an ethoxy group the corresponding acyl cation a can also be a fragment in this particular case which is not shown in the fragmentation pattern that is detected here.

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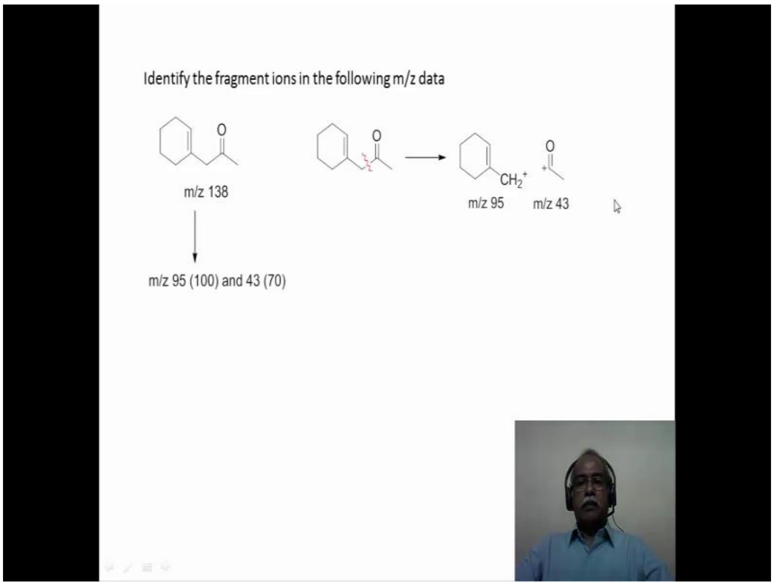

Identify the fragment ions in the following m/z data

m/z 95 (100) and 43 (70)

Now, can we identify for example, this molecule undergoing fragmentation to give a peak at 95 with a nearly 100 percent abundance in other words that is a base peak at another peak at 43 with the 70 percent abundance relative to the base peak in this particular case. One thing that one can immediately notice in this particular case is, if you add 95 and 43 will correspond to 138 in other words, this molecule has undergone a fragmentation process probably the fragmentation of this alpha carbon, carbon bond generating an acyl cation which is 43 in mass units and the cyclohexenyl methyl cation which is this particular cation with the CH 2 plus here, which is an allylic CH 2.

Therefore, the charge should be stabilized by delocalization on the allylic ring which corresponds to mass unit of 95 m by z value. So, the two mass units are easily identified by the fact that, 95 plus 43 gives 138 which implies that the molecule has simply undergone a fragmentation process of a carbon carbon bond breaking process, resulting in two fragments and the charge is residing in either of the fragment to some extent. So, both of them are registered in mass spectrum and hence all the problem of identifying the two fragments arising from this particular molecular ion. And that is the mechanism is this is the bond that undergoes the cleavage producing 95 and 43 as cationic charges in this particular case.

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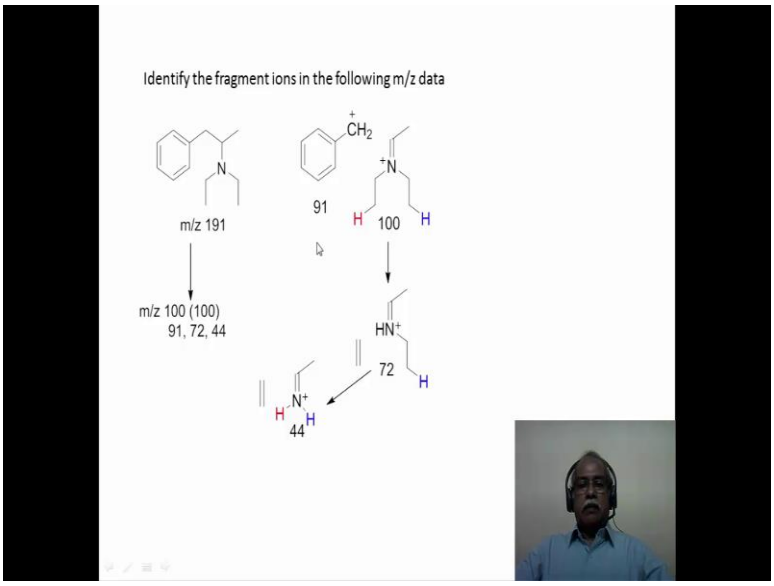

Identify the fragment ions in the following m/z data

Now, identify the fragment ions in following m by z data, in other words this molecule which is a tertiary amine with the molecular weight of 191. We immediately notice that because of the nitrogen, the hard mass is obtained in this particular molecular formula and the fragments that are produced are with the m by z value of 100 resulting in the formation of a base peak 91, 72 and 44 are the fragments that are produced. Once again you can see here if you add here 191. It corresponds to the 191, which is a molecular and in other words this is undergoing a simple fragmentation processes by cleavage of probably this particular bond because it will produce benzyl cation as well as a iminium cation in this particular case. Resulting in the formation of 91 which is benzyl cation or the tropylium cation as it is normally called benzyl cation, rearranges to tropylium cation under mass spectrometry condition. So, 91 would corresponds to the tropylium cation arising from the carbon carbon bond fragmentation of the alpha carbon of the amino compound and 100 is probably the residue that is resulting iminium cation is 100 in this particular case.

Let us have a look at the fragmentation process. A simple fragmentation of this carbon carbon bond leads to 91 and 100. Now, this kind of iminium ions undergo beta hydrane migration to give the corresponding illumination product in other words, you can lose one molecule of ethylene from this ethylene group, another molecule of ethylene from this ethylene group by a migration of a either the red hydrogen on to the nitrogen or the blue hydrogen on to the nitrogen. This probably happens in a sequential manner, first let us assume the red hydrogen migraine it does not matter which hydrogen migrate because this is symmetrical structure.

The red hydrogen migrates to the nitrogen producing another iminium ion which is the secondary iminium ion in this particular case resulting in a fragment with the loss of 28 mass unit corresponding to 72. Once more the hydrogen migration takes place from the beta position to the onium ion. Resulting in the loss of another ethylene molecule producing a molecular ion of 44 which is 72 minus 28 correspond to 44. So, 100 minus 28 is 72, 72 minus 78 it 44. Resulting in the formation of a stable iminium ion which is particular fragment that is resulting this case this being a resonance stabilized ion is fairly stabled and this is produced in nearly base peak in 100 percent abundance in this particular fragmentation process.

Tertiary amines are very rich in their fragmentation process because of the iminium ion formation and the subsequent hydrade migration and all those thing are very interesting features of a tertiary amine fragmentation process and that is why this problem is discussed here.

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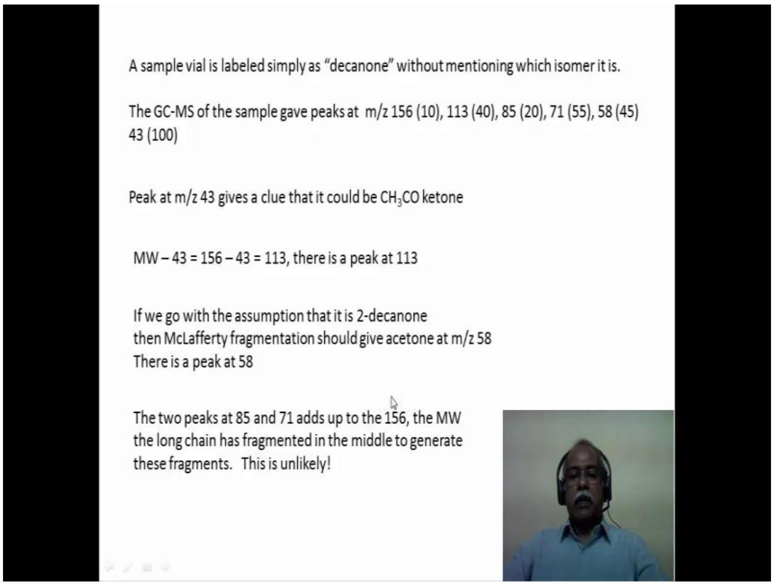

A sample vial is labeled simply as “decanone” without mentioning which isomer it is.

The GC-MS of the sample gave peaks at m/z 156 (10), 113 (40), 85 (20), 71 (55), 58 (45) 43 (100)

Peak at m/z 43 gives a clue that it could be CH_3CO ketone

MW – 43 = 156 – 43 = 113, there is a peak at 113

If we go with the assumption that it is 2-decanone
then McLafferty fragmentation should give acetone at m/z 58
There is a peak at 58

The two peaks at 85 and 71 adds up to the 156, the MW
the long chain has fragmented in the middle to generate
these fragments. This is unlikely!

Here is another problem. There is sample vial which is simply labeled as decanone. Which isomer of the decanone is not specified in the labeled. So, one has to use now the Mass Spectrometry fragmentation pattern to identify which isomer of decanone is responsible for this particular label. Now the GC-MS of the sample gave the following fragmentation point. The molecular ion peak for the decanone is 156. So, the molecular ion is a fairly weak ion with only 10 percent of abundance; however, there are other fragments which are prominent fragments that one can see in this fragmentation pattern.

One striking feature of the fragmentation pattern is the 43 ion, which is the base peak in this particular case, for a ketone gives a 43 m by z value 100 percent abundance is most likely a methyl ketone. CH 3 CO plus is the fragment that corresponds to 43 most likely this is a methyl ketone. So, that much of an information can be obtained from the peak 43 of 100 percent abundance in this particular case. Now if you look at 58 since you have 43 which is CH 3 CO it can produce a Mclafferty rearrangement product which would be acetone. Acetone cation radicle would correspond to 58. So, this two fragments are essentially consistent with respect to each other in terms of the structural element being CH 3 CO, CH 2 kind of a fragment is present in this particular molecule. One other noticeable thing is that, the 113 and 43 adds up to 156 which is the molecular weight of this compound. So, the acetyl lose essentially gives a fragment to which corresponds to 113 which is likely to be stabled cation species in order for it to survive and so on.

So, let us have a look at the possibility of the fragmentation process, resulting in the compound identification 43 could be because of the methyl ketone. Which you have already said, 43 minus molecular weight minus 43 correspond to 113. So, there is a peak at 113 of 40 percent abundance for example. Let us assume for example, it is two decanone which is a methyl ketone then the Mclafferty rearrangement will give a 58 peak at m by z value 58 corresponding to acetone formation acetone cation radical formation. So, 58 is also present there now, there are two peaks at 85 and 71 which adds up to the molecular weight of 156. In other words, the molecule is fragmenting somewhere in the middle of the molecule to give nearly the same molecular weight fragments m by z value of 70 and 85. So, it cannot be a long chain compound, in other words cannot be a linear chain compound, it should be highly branched chain because only branched chain alkyl derivatives undergo fragmentation right in the middle of the a chain to gives to fragments of this type 71 and the 85. So, one can rule out the possibility that it is 2 decanone because 2 decanone will have a long chain. So, it does not give a long chain pattern for example, 14 mass unit difference of various peaks corresponding to the fragmentation of the long chain.

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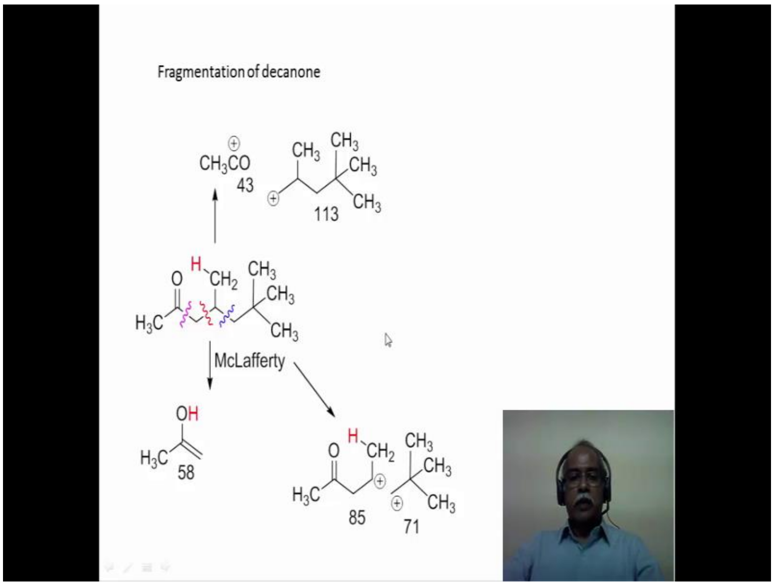

Fragmentation of decanone

So, most likely the compound is this particular compound, the compound should be undergoing Mclafferty rearrangement to give the acetone cation radical. So, it should have a gamma hydrogen that is why this methyl is placed here, it should have an acetyl groups. So, that it gives 43 and 113. Now this looks like a the primary cation but, it can always undergo a migration of the hydrogen give a tertiary cation. Which is a stable cation. So, one can write a rearranged structure of this particular compound, this particular fragment to give a tertiary carbonium ion in this particular case.

Now i have particularly put the rest of their molecule, in the form of highly branched structure. So, that the blue line fragmentation can result in two fragments, which are resulting in the formation of 85 and 71. Now the 71 is actually a neopentyl kind of a primary carbonium ion but, it can undergoes a migration of a methyl group to give a tertiary carbonium ion. So, although initially it produces a primary carbonium ion, it can undergo migration gives stable carbonium ion which is a tertiary carbonium ion. These reasonable ions that it could be produced from the molecule of this type.

This molecule is fairly Spectrometry hindered between these two carbon carbon bond. So, as a result of this carbon carbon bond is likely to be weak in this molecule that is why this fragmentation occurs. So, one can logically say that this molecule decanone most likely is this particular isomer it is definitely a methyl ketone. It is definitely having a gamma hydrogen all this is confirmed by the fragmentation corresponding Mclafferty and simple acetyl formation.

The only question that is still sort of remaining is whether it is likely to produce 85 and 71 by the fragmentation of this particular; one can always put the methyl group in this position also instead of leaving it here, that would make it again highly sterically hindered certainly this is not a long chain decanone. This is highly branched chain decanone is what we are dealing with this a conclusion we can draw from the mass spectral fragmentation.

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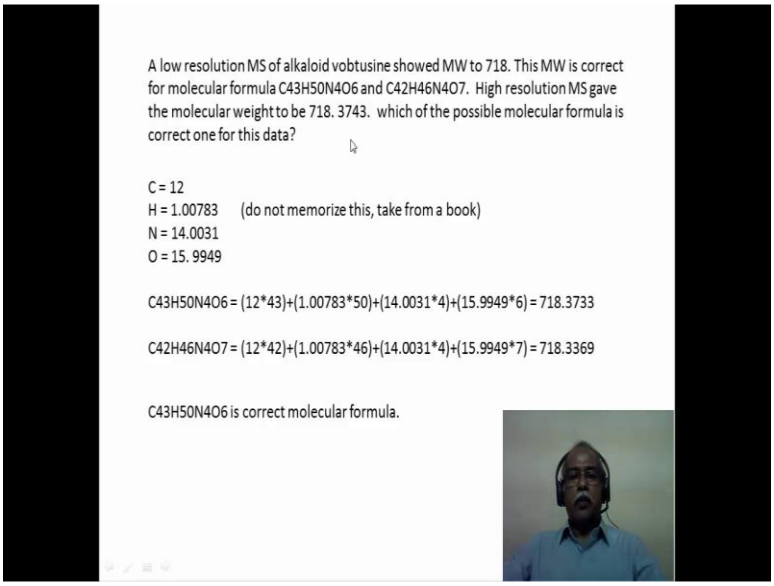

A low resolution MS of alkaloid vobtusine showed MW to 718. This MW is correct for molecular formula C43H50N4O6 and C42H46N4O7. High resolution MS gave the molecular weight to be 718. 3743. which of the possible molecular formula is correct one for this data?

C = 12
H = 1.00783 (do not memorize this, take from a book)
N = 14.0031
O = 15. 9949

C43H50N4O6 = (12*43)+(1.00783*50)+(14.0031*4)+(15.9949*6) = 718.3733

C42H46N4O7 = (12*42)+(1.00783*46)+(14.0031*4)+(15.9949*7) = 718.3369

C43H50N4O6 is correct molecular formula.

Let us go on to the next problem. The lower solution mass spectrum of an alkaloid Vob-tusine is showing a molecular weight of 718. The molecular weight is correct for two molecular formulas that are given, C43H50N4O6 as well as C42H46N4O7 these are the two molecular formula that are given. Now i need to identify which one of this molecular formula corresponds to Vob - tusine in order to do that, the high resolution mass spectrum was recorded and the high resolution weight happens to be 718.3743 then, which of the possible molecular formula is correct one for this data is the question. That we need to address, please remember that the molecular ion which is measured in the high resolution mode to extend of 4 decimal places gives accurately the composition of the molecular formula of this particular compound.

One need not memorize this information, one can always take it from a textbook saying that carbon 12 is 12 isotope carbon. 12 scale hydrogen is 1.00783 this is the reason that you have the fractional weights added to the high resolution mass. So, if you one can for example, find out what would be the high resolution mass calculated high resolution mart for this particular fragment or this particular molecular formula and this particular molecular formula separately.

Then one can identify depending upon which one is the close to the actual experimentally measured spectrum. This has been done. There are 43 carbons. So, 43 times 12 there are 50 hydrogen. So, 50 times 1.00783 there are 4 nitrogen. So, 4 times 14.0031 and so on. For oxygen for example, 15.9949 times 6 oxygen's are present in this molecular formula. So, that adds up to 718.3733. If you use the other molecular formula do the same calculation for the accurate mass, that produces a molecular ion which is 718.3369 clearly, this molecular formula the high resolution mass is closer to the actual experimentally measured mass which is 7183743 this is 37433 is the calculated value.

Based on in this information on comes to the conclusion that this is the most likely molecular formula of Vob-tusine which is an alkaloid in this particular case. So, is an interesting example of how the high resolution mass is used to differentiate between two molecular formulas because the fractional weights significantly differ in there two molecular formulas therefore, it is possible to identify the molecular formula of this compound for a given high resolution mass spec data. So, the essentially illustrates the use of the high resolution mass data and identifying the molecular structure molecular formula of the compound.

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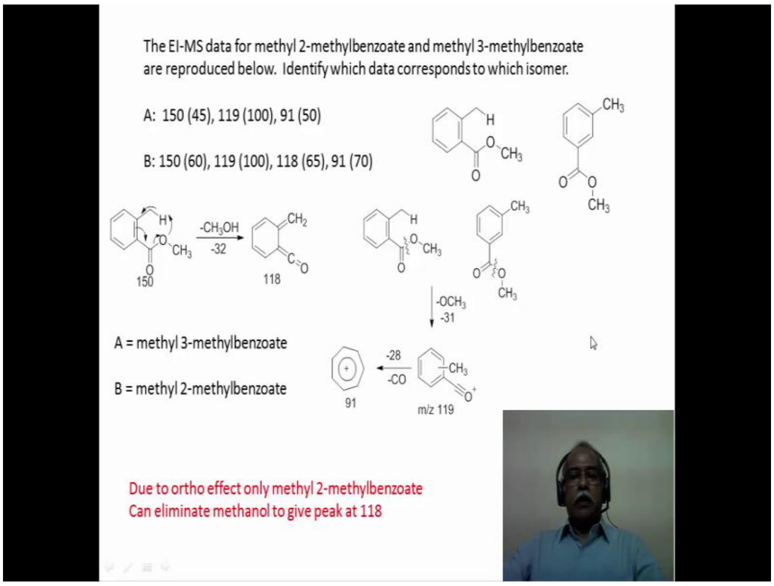

The EI-MS data for methyl 2-methylbenzoate and methyl 3-methylbenzoate are reproduced below. Identify which data corresponds to which isomer.

A: 150 (45), 119 (100), 91 (50)

B: 150 (60), 119 (100), 118 (65), 91 (70)

A = methyl 3-methylbenzoate

B = methyl 2-methylbenzoate

Due to ortho effect only methyl 2-methylbenzoate
Can eliminate methanol to give peak at 118

Here is a problem which deals with the methyl ester of 2 methyl benzoate. In other words there is methyl ester of 3 methyl benzoate and 2 methyl benzoate the electron impact ionization mass spectral data is produced here. One has to identify which data corresponds to which isomer. Both of them are isomers. So, the molecular weight is same. So, the molecular and peak is a essentially same 150 is the molecular ion peak; however, if you look at it carefully the fragmentation 119 and 91. 119 and 91 are common for this. So, there are 3 common fragments that are available for both the compounds which cannot distinguish the compound; however, there is one unique fragmentation, which is at 118 for the isomer b for example, we need to identify which isomer it is corresponding to a fragment that is being given at 118.

Now, these are 2 molecules we are talking about. In this particular case this is a ortho isomer and this is a meta isomer. So, is there a special effect for the ortho isomer that we need to consider. In order to account for the molecular ion, in order to account for the fragment ion which comes around 118 or so. Now, the simple fragmentation like a methoxy last in both cases would produce the acyl cation, which is 119 molecular weight and it loses the carbon monoxide molecule to give the tropiline ion. So, 119 and 91 are accounted for both the structure irrespective of which isomer it is does not matter. This fragmentation is likely it occur and that is why in addition to the molecular ion you have the ions at 119 and 91 for this 2 isomers of this molecule. However, if you consider this unique fragment this is possible only if you have the ortho substituents present in the system. In other words the abstraction of the hydrogen by the methoxy to eliminate a molecule of methanol would lose 32 mass unit from the molecular weight of 150 resulting in the formation of this particular cation radical which is 118 and that is present only in the case of the ortho isomer it cannot be present in the meta isomer because this two substituents are far away from each other in the meta isomer.

So, compound A is actually the 3 methyl benzoate and compound B is to the 2 methyl benzoate, which produces this unique ion in the fragmentation pattern. So, one need to understand the effect is because of the ortho effect of the methyl, two methyl benzoate this can eliminate methanol to give a peak at 118. So, this particular fragment is what is responsible for the distinction of these two types of ions in this particular fragmentation problem.

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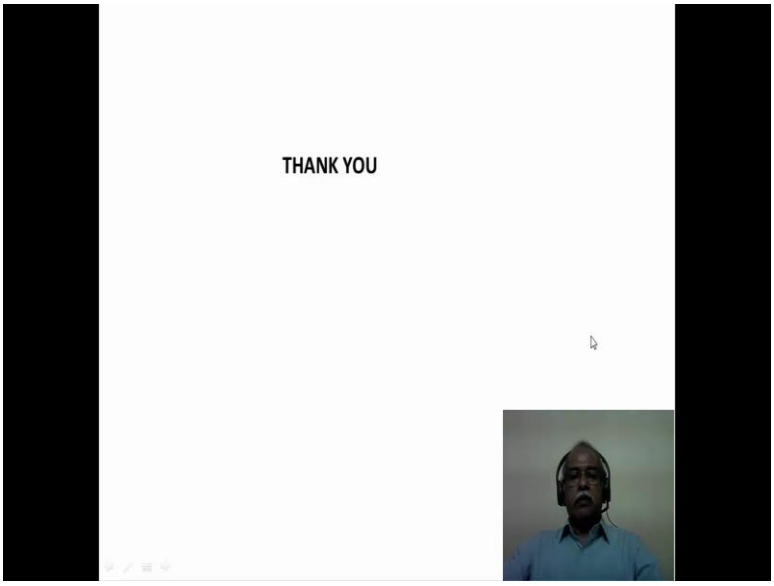

THANK YOU

Now, what we have seen is a few examples of how Mass Spectrometry can be used to identify certain compound, purely based on the mass spectral fragmentation alone. It is not necessary that one always deals with mass spectral data alone for structural elucidation. But there are cases where mass spectrum can be extremely valuable tool for the identification of an organic compound.

Thank you very much for your attention