Mass Spectrometry: Fragmentation

Chem 4010/5326:
Organic Spectroscopic Analysis

Initial Charge

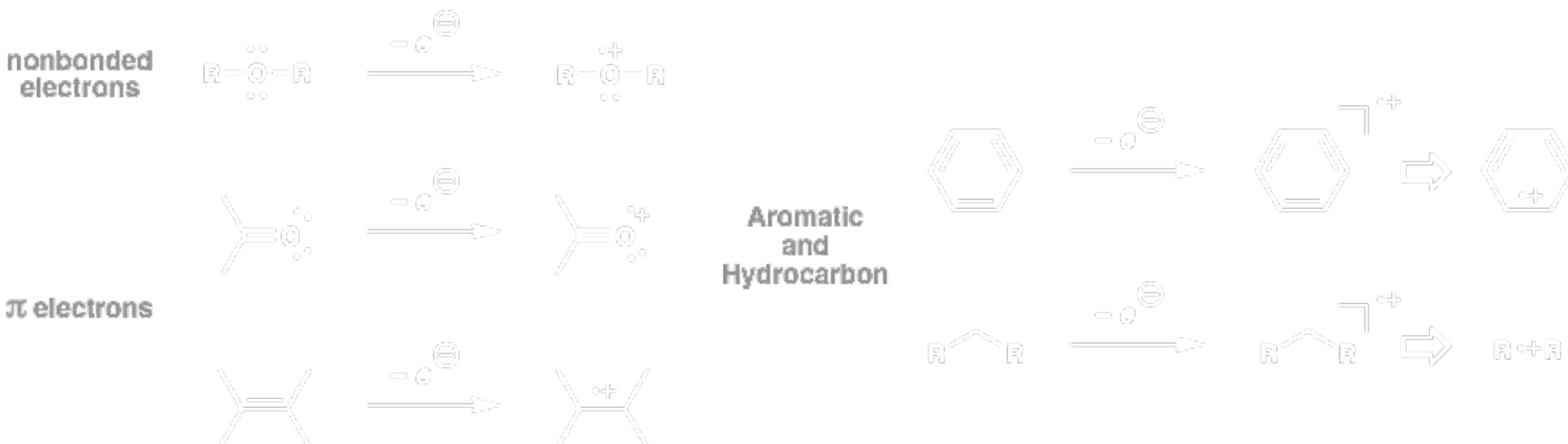
Where is it localized?

Where charge begins determines how all other fragments are formed

– In general HOMO-controlled → lost first

– Lost from heteroatoms in preference

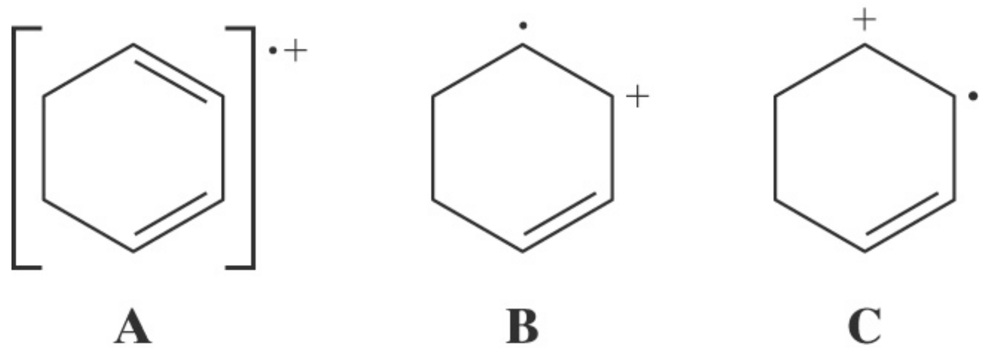
– Usually several fragmentation pathways occur



Fragmentation

How to Represent Initial Radical Cation

Three ways to represent molecular ion of 1,3-cyclohexadiene



A. Delocalized structure with one less electron

both electron and charge delocalized over π-system

B. & C. electron and charge localized on π-system

both are possible and each could give different fragments

Fragmentation

General Considerations

1. Even-electron ions cannot cleave to a pair of odd-electron fragments
   - from thermodynamics
2. Mass <u>loss</u> of 14 from M^+ is extremely rare
   - will see *separation* of 14 in hydrocarbons
   - arise from 2 different fragmentations
3. Order of radical/carbocation loss
   -
   -
4. Fragment ion stability takes precedence over radical
5. Vinyl radical loss is not favorable, but possible

Fragmentation

General Considerations

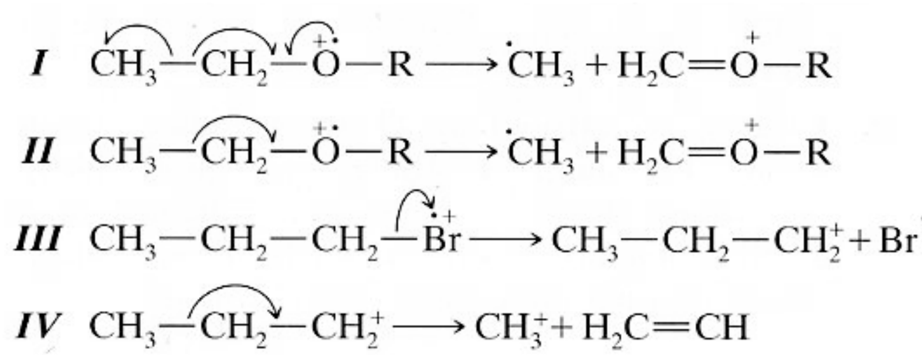
6. Several fragmentations can occur, especially if it leads to a highly stabilized cation/radical
7. If loss of stable neutral molecule is possible, will do so (simple alkenes, H_2O, CO, etc.)
8. Probability of cleavage is related to bond strength and stability of fragments.

Lastly...It is not possible to identify every peak in a mass spectrum. The key is to remember a few diagnostic fragment ions (e.g.   = 77, 91) and a few key mass losses in order to gain some insight into subunits.

Fragmentation

Fragmentation of Molecular Ion

The initial radical cation can fragment in a number of ways



I. Homolytic (one electron at a time) cleavage

- products are even-electron cation and a free radical

II. A less cluttered representation of reaction *I*

III. Heterolytic (two electrons at a time) cleavage

- electrons move toward charged site
- products are even-electron cation and a free radical

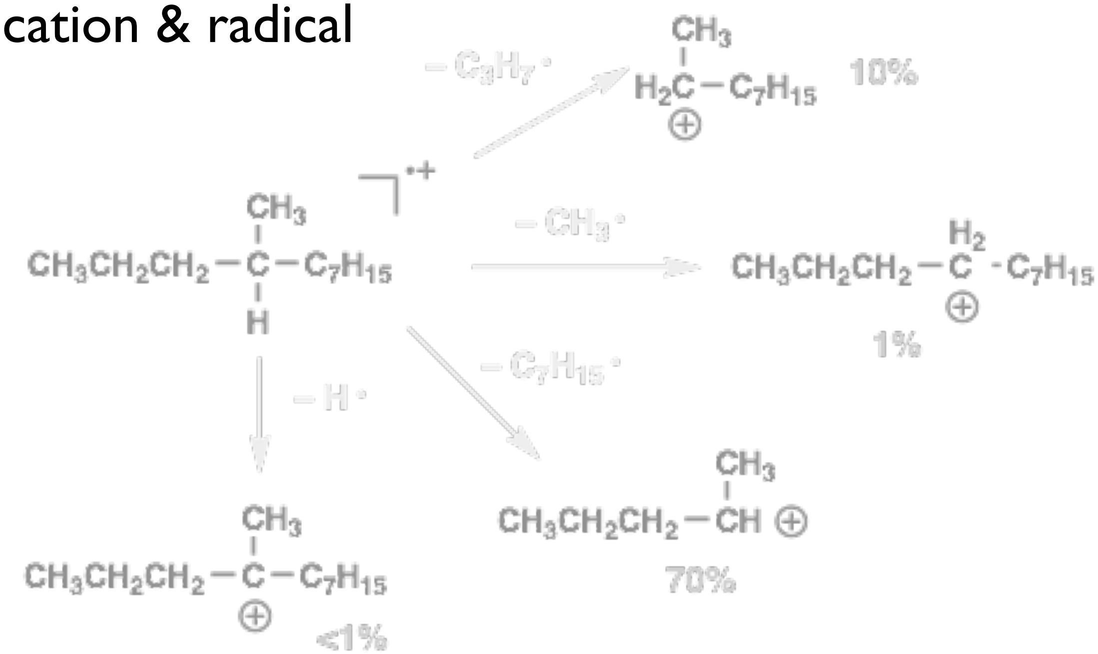
IV. Secondary fragmentation of even-electron cation by two electron process

Fragmentation

A Few General Mechanisms

A – one-bond σ-cleavage

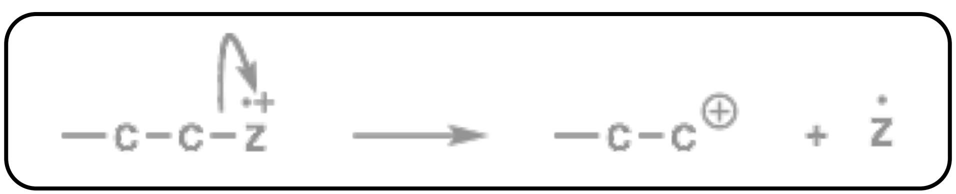
(a) cleavage at C–C producing cation & radical



in MS, loss of largest outweighs 3° cation

(b) cleavage at C–heteroatom producing cation & radical

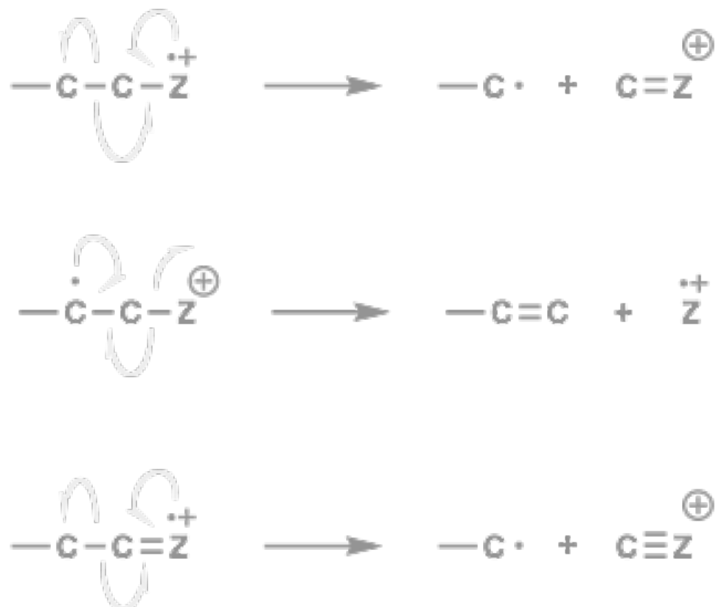
- 2 electron process
- works well for Z = O, halogen



Fragmentation

A Few General Mechanisms

(c) α-cleavage



Z = N > O,π > halogens >> σ

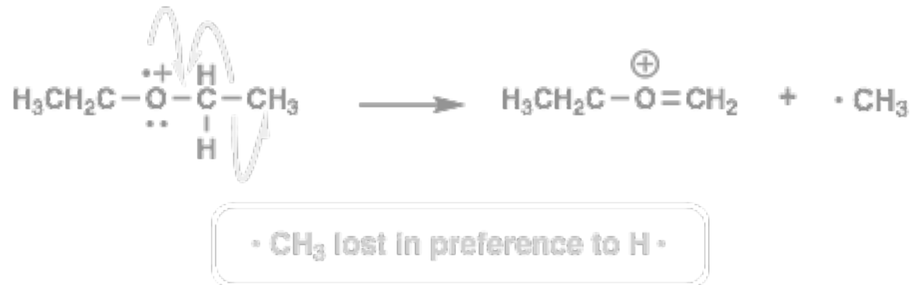
Charged species has heteroatom

-isotope patterns in fragment ions

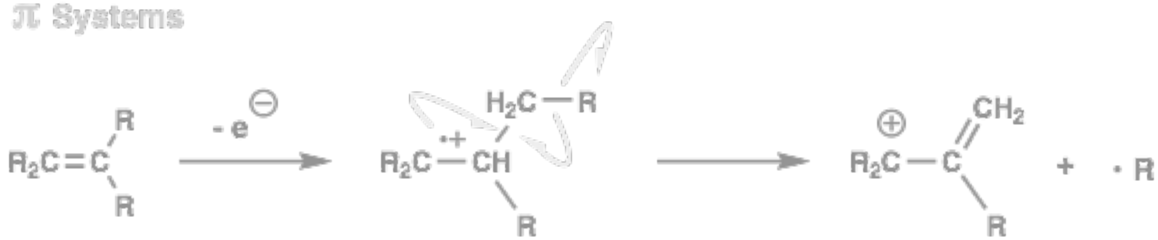
Fragmentation

A Few General Mechanisms

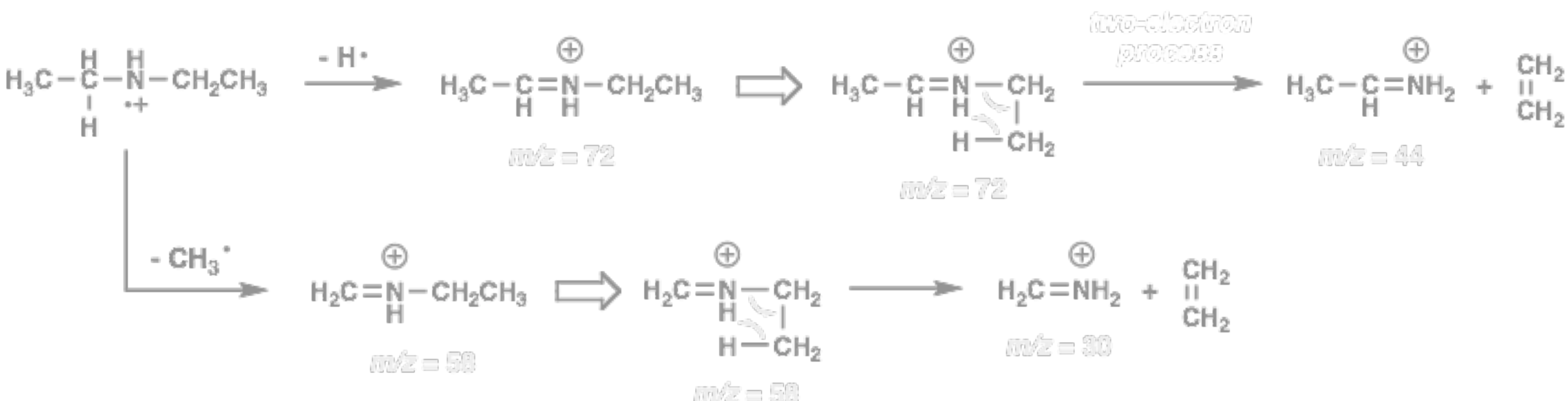
(c) α-cleavage



π Systems

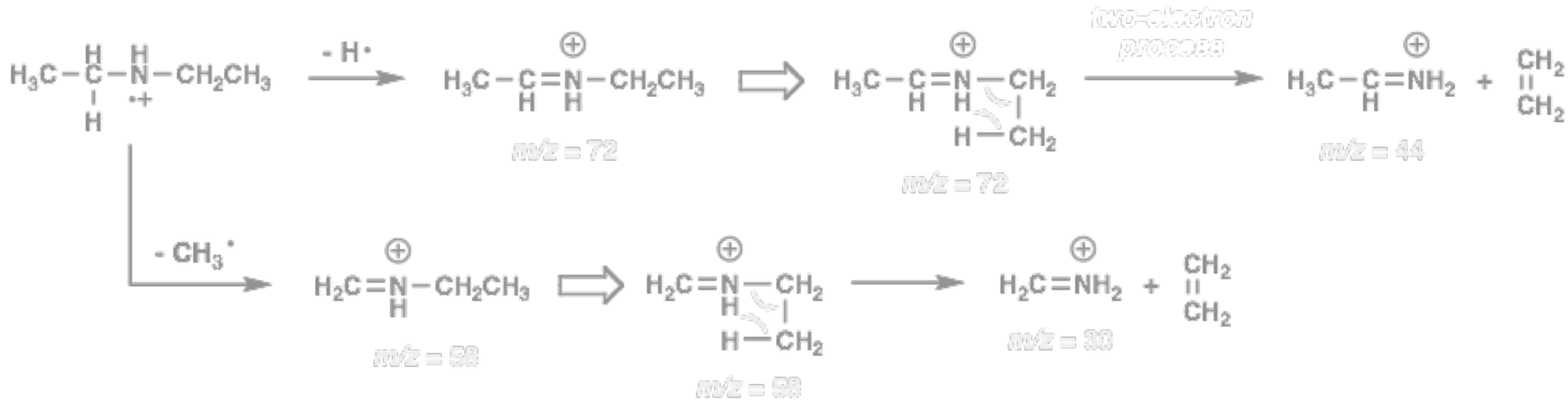


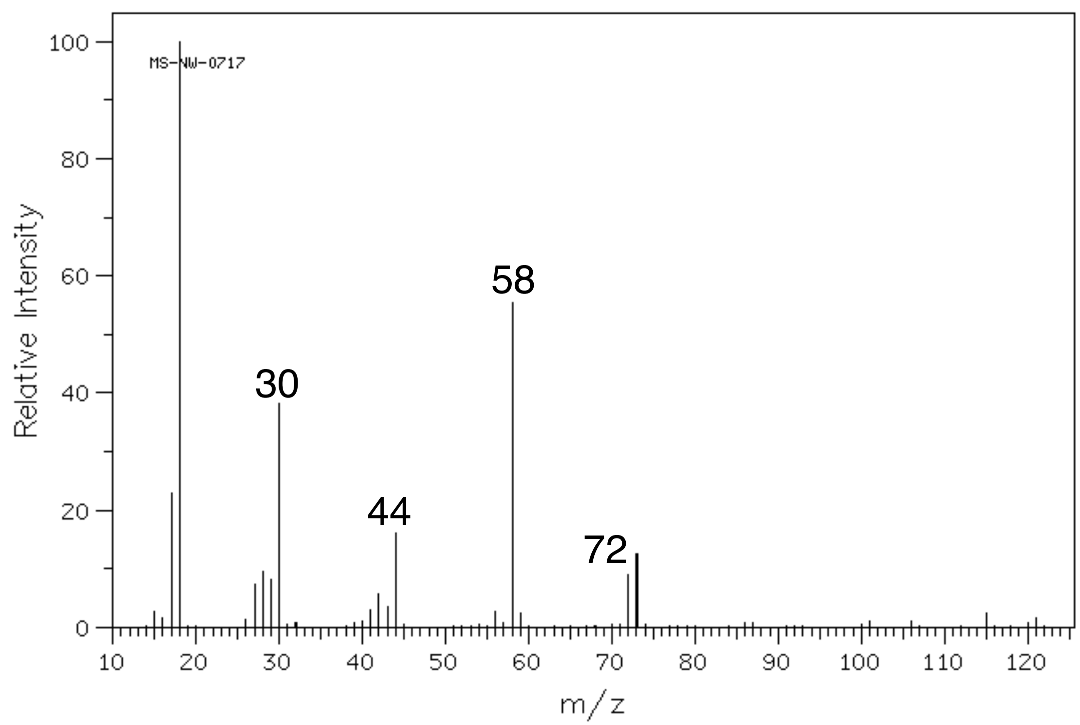
If loss of stable neutral molecule is possible, will do so
(simple alkenes, H_2O, CO, etc.)



Fragmentation

A Few General Mechanisms





Fragmentation

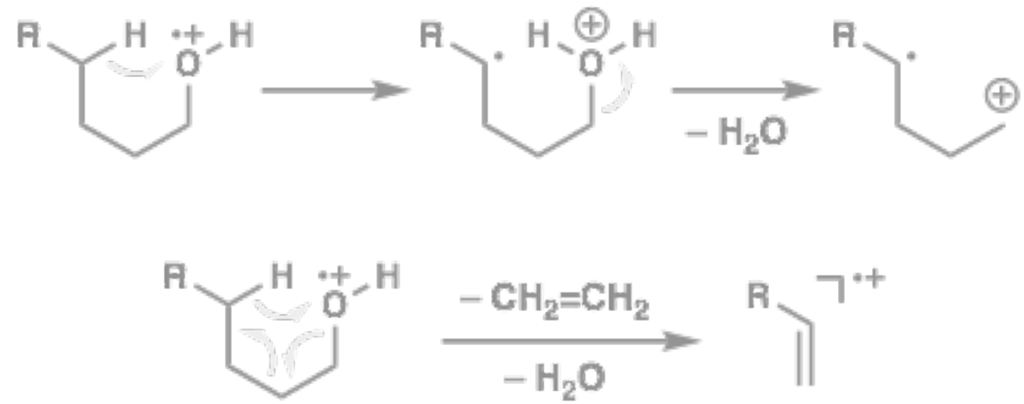
A Few General Mechanisms

B – two-bond σ-cleavage or rearrangement

(d) elimination of vicinal H and heteroatom

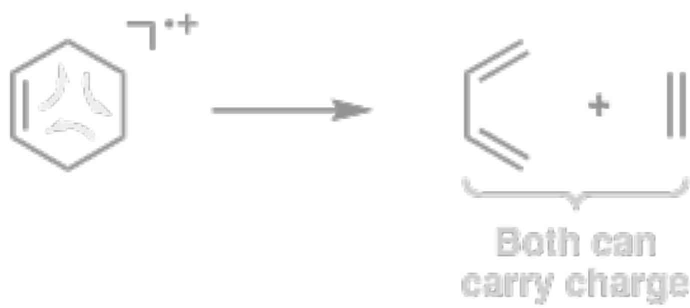
- common with alcohols
- difficult to see M^+

Similar fragmentations with alcohols



(e) retro Diels-Alder cleavage

- mechanism involving single electrons also possible



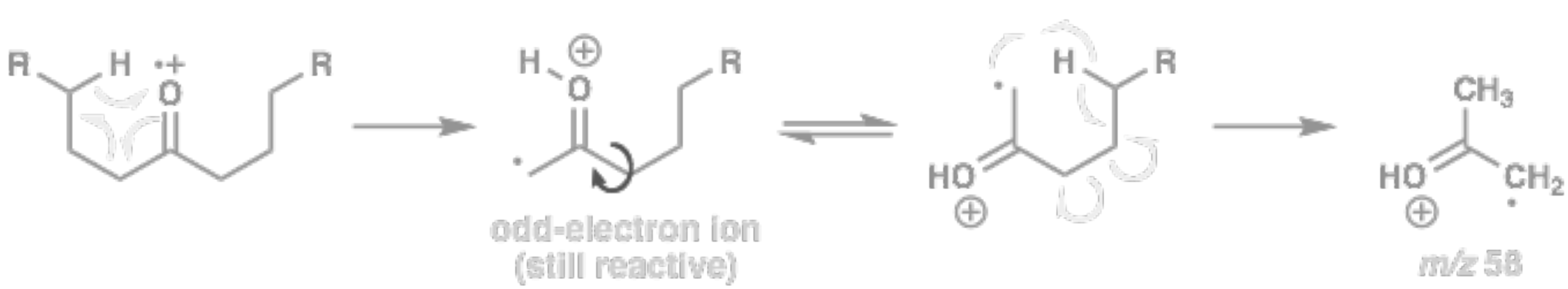
Fragmentation

A Few General Mechanisms

(f) McLafferty rearrangement

- common with ketones, esters, carboxylic acids

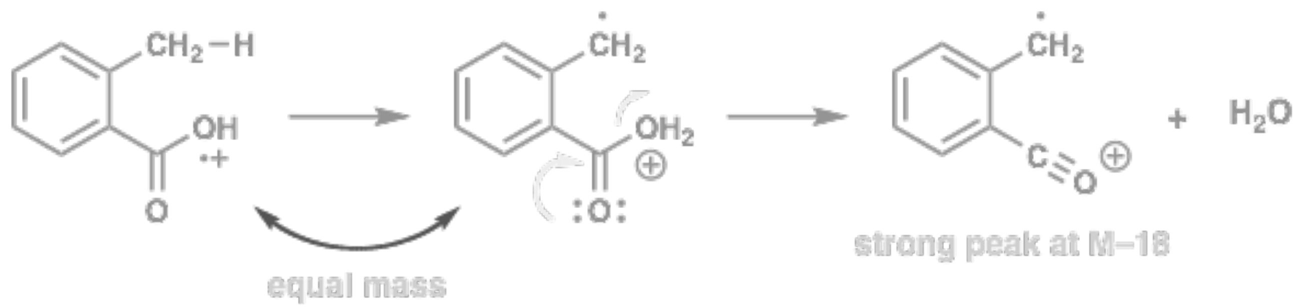
Multiple McLafferty is possible



Fragmentation

Other "Unusual" Mechanisms

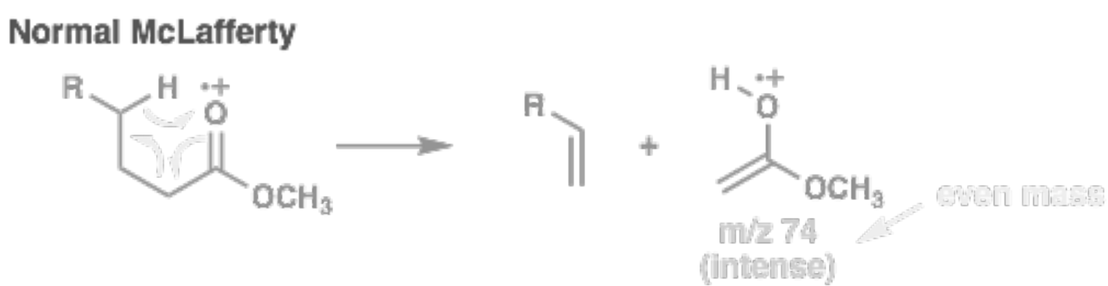
Ortho effect

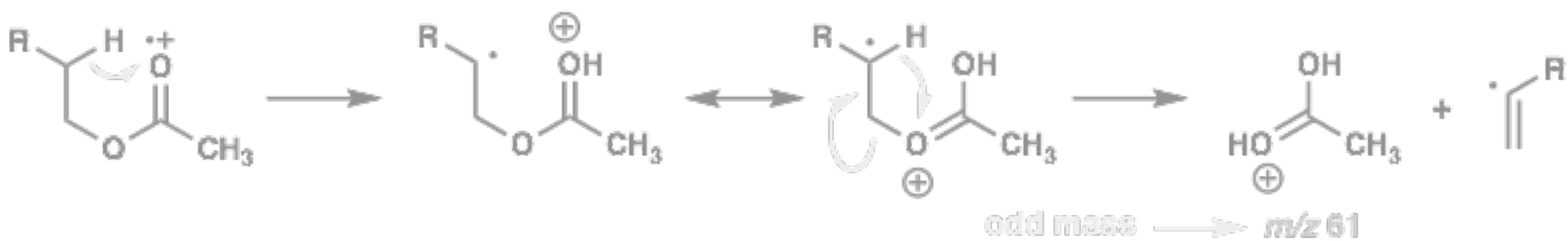


also with esters, amides, OH, etc.

"McLafferty + 1"

- esters only





Fragmentation

Odd-electron vs. Even-electron
(Nitrogen rule revisited)

For non-nitrogen-containing molecular ions,
odd-electron ions occur as *even* mass.

molecular ions (OE) => even mass

↓ – fragment

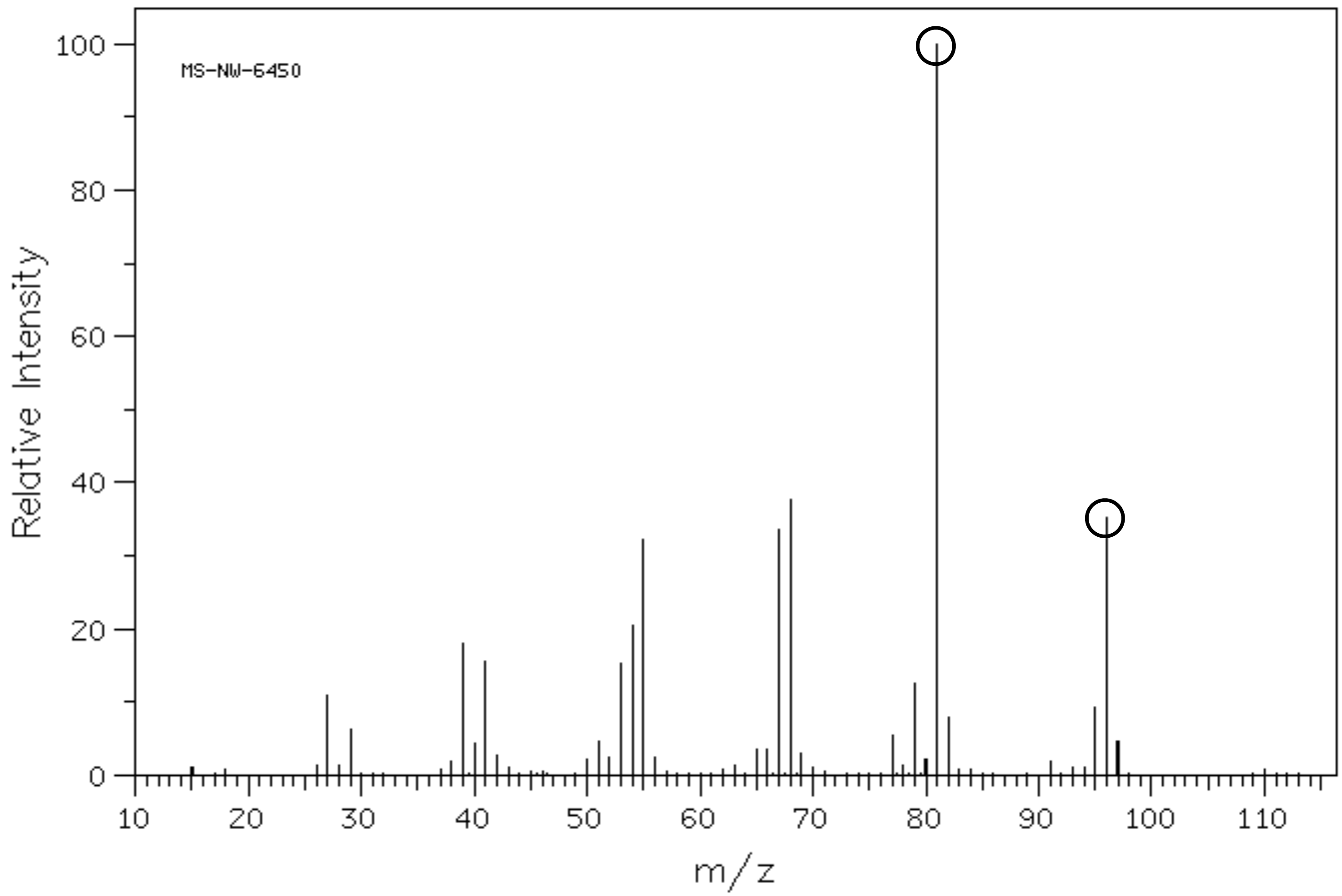
most fragment ions (EE) => odd mass

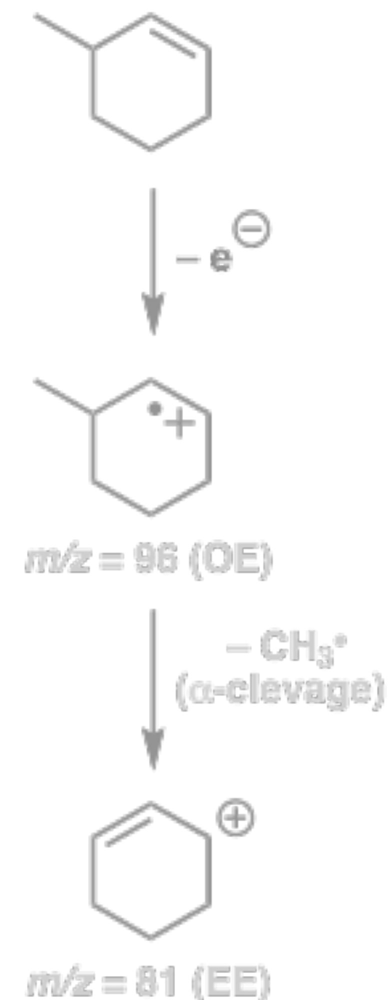
If ion has even mass then “unusual” fragmentation has occurred (e.g. retro Diels-Alder, McLafferty)

Fragmentation

Odd-electron vs. Even-electron
(Nitrogen rule revisited)

Example – 3-methyl-1-cyclohexene





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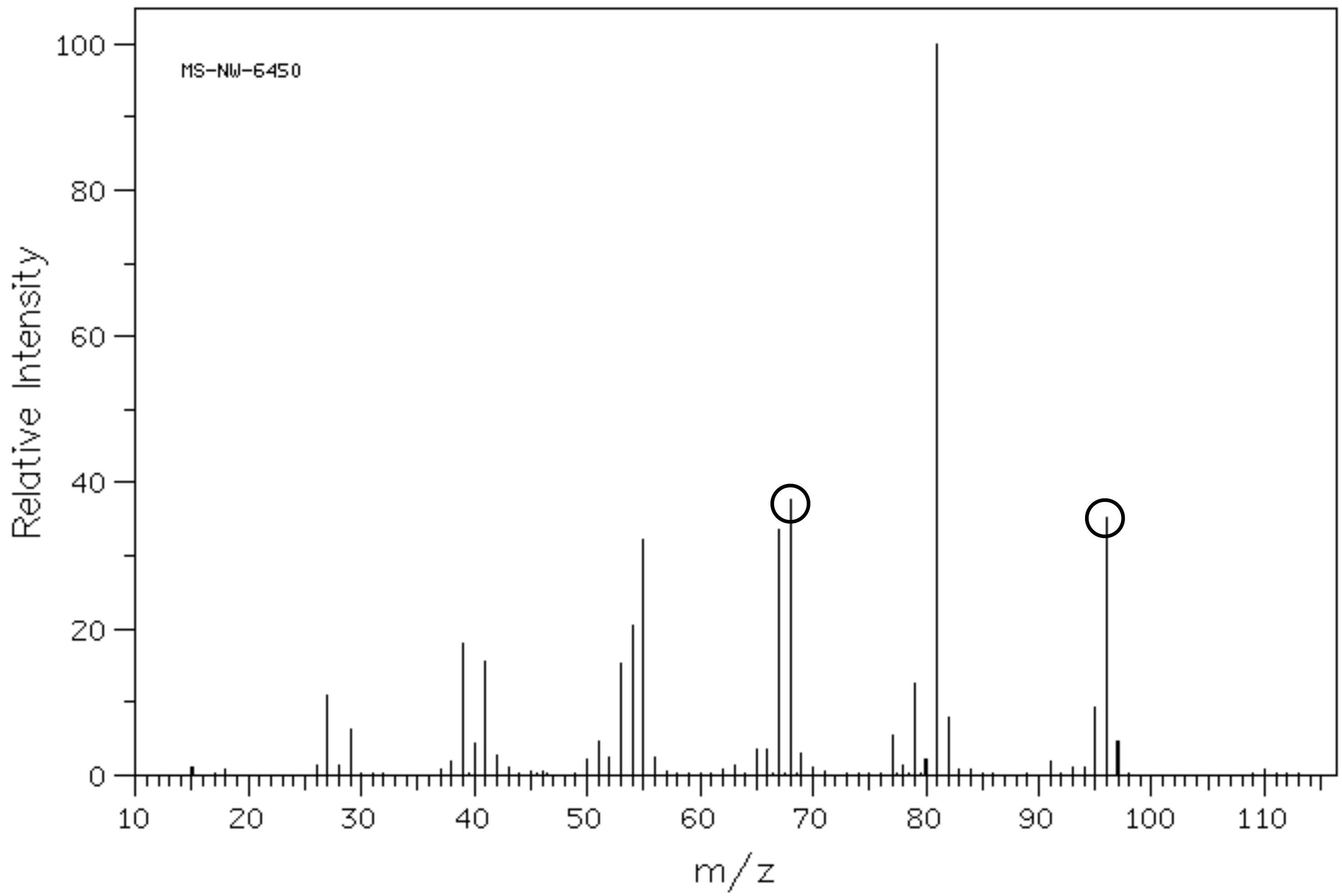

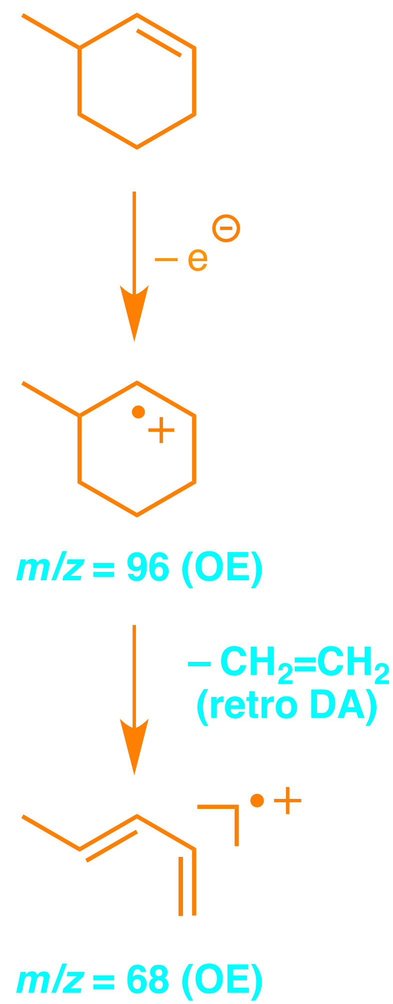

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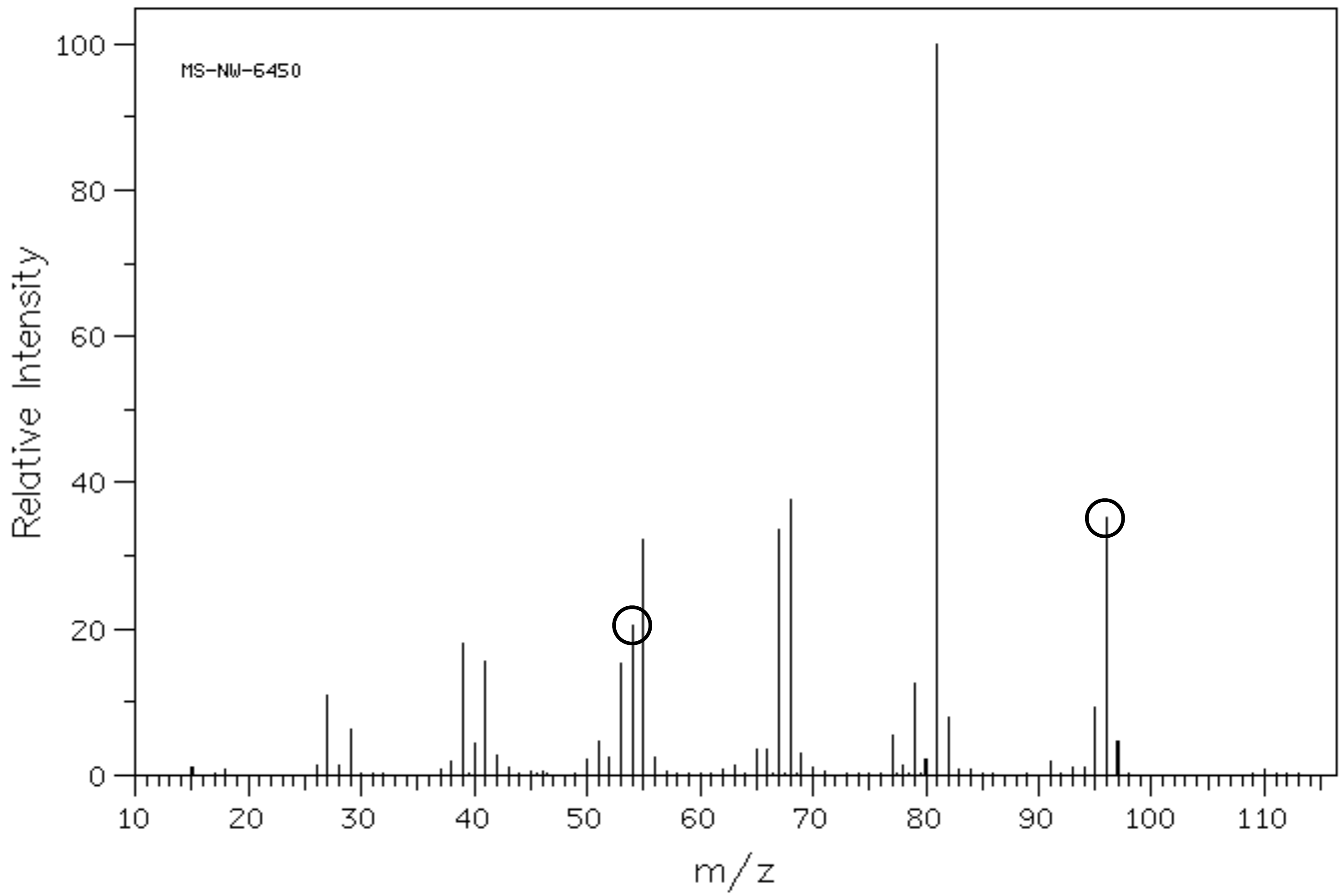

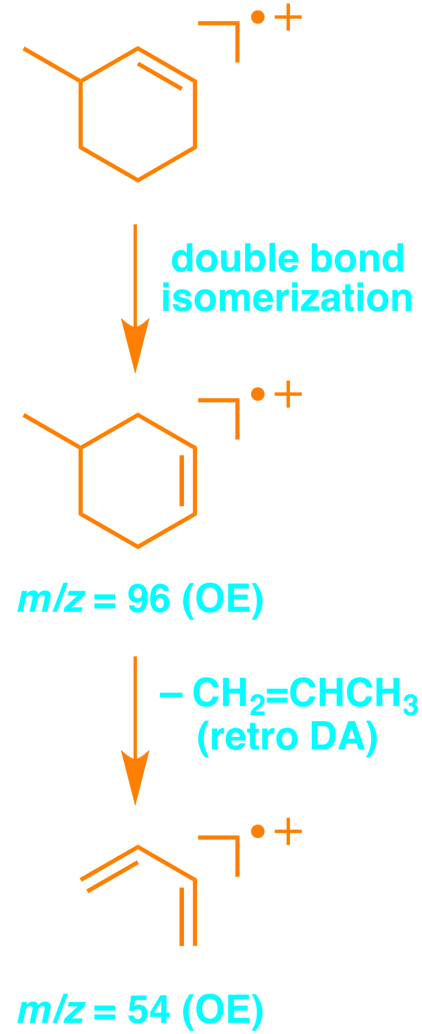

Fragmentation

See Pretsch Chapter 8 for common fragmentation pathways of various functional groups/compound classes