

Mass Spectrometry: Fragmentation

Chem 4010/5326:
Organic Spectroscopic Analysis

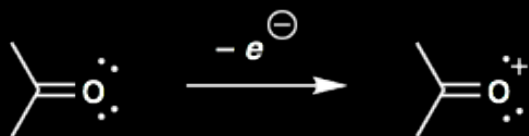
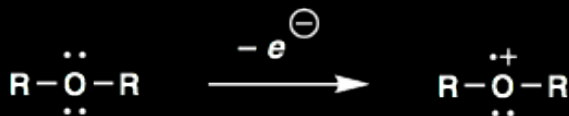
Initial Charge

Where is it localized?

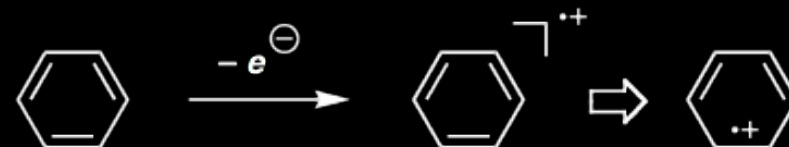
Where charge begins determines how all other fragments are formed

- In general HOMO-controlled → lost first
- Lost from heteroatoms in preference
- Usually several fragmentation pathways occur

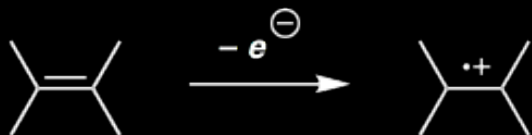
nonbonded electrons



Aromatic and Hydrocarbon



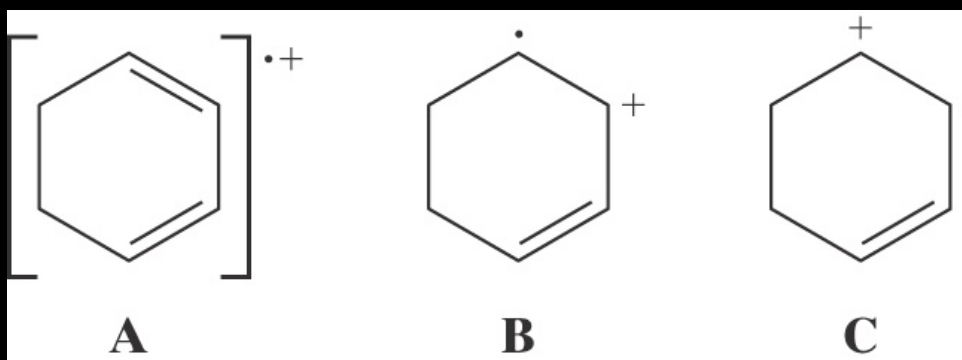
π electrons



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 loss 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
 - tertiary > secondary > primary > methyl > hydrogen
 - loss of longest is preferred
4. Fragment ion stability takes precedence over radical
5. Vinyl radical loss is not favorable, but possible

Fragmentation

General Considerations

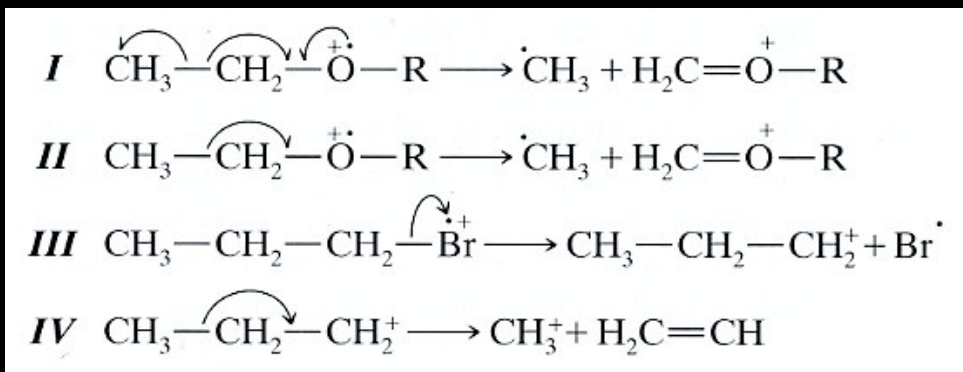
6. Several fragmentations can occur, especially if it leads to a highly stabilized cation/radical
7. If loss of stable neutral molecule is possible, will do so (simple alkenes, H₂O, CO, etc.)
8. Probability of cleavage is related to bond strength and stability of fragments.

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. $m/z = 77, 91$) 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

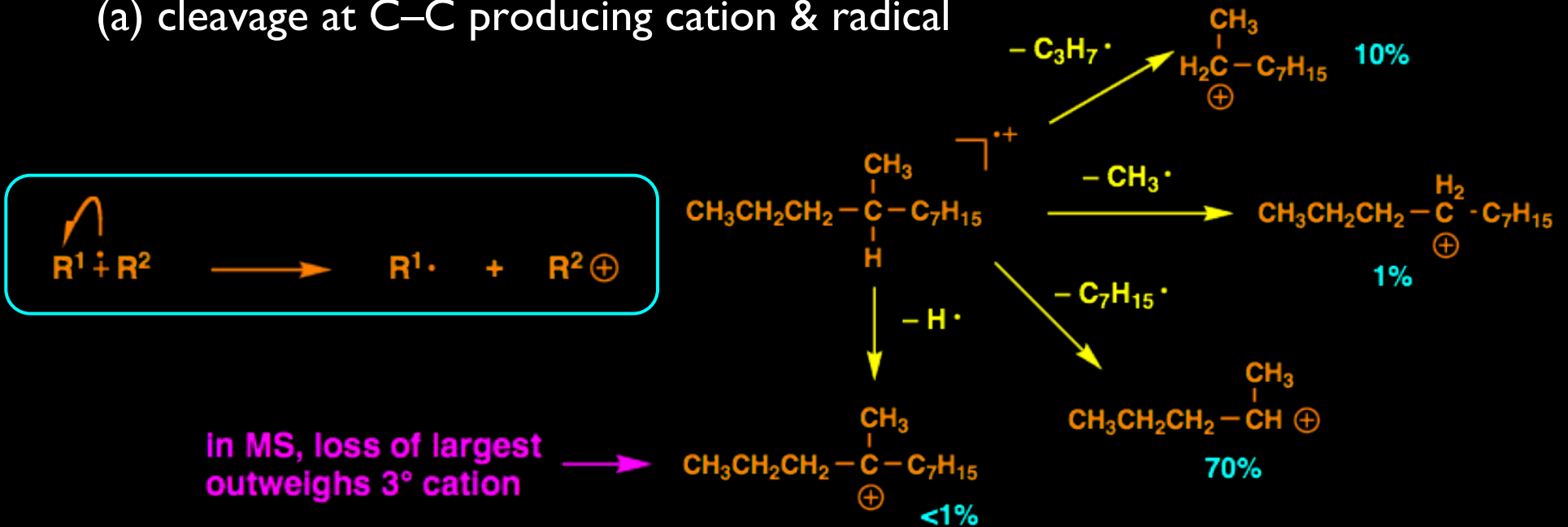
IV. Secondary fragmentation of even-electron cation by two electron process

Fragmentation

A Few General Mechanisms

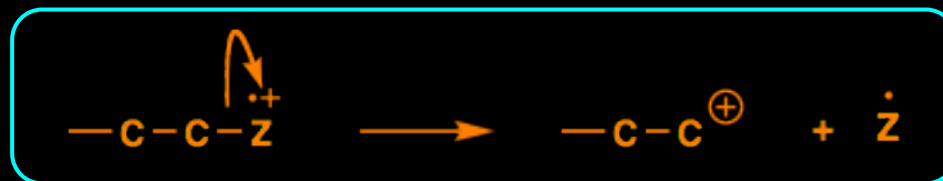
A – one-bond σ -cleavage

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



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

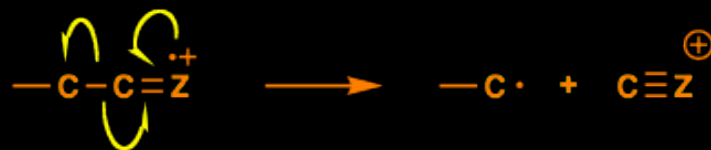
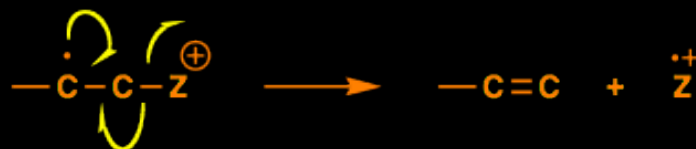
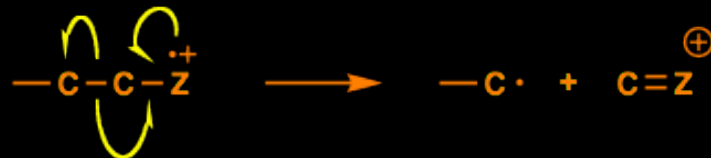
- 2 electron process
- works well for $\text{Z} = \text{O}$, halogen



Fragmentation

A Few General Mechanisms

(c) α -cleavage



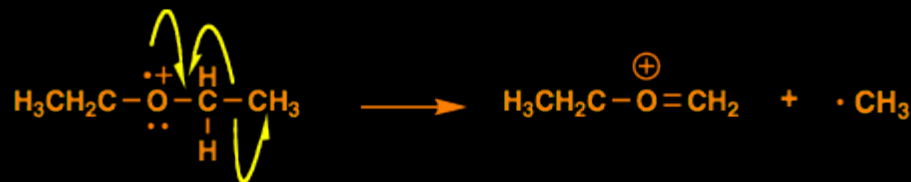
Z = N > O, π > halogens >> σ

Charged species has heteroatom
-isotope patterns in fragment ions

Fragmentation

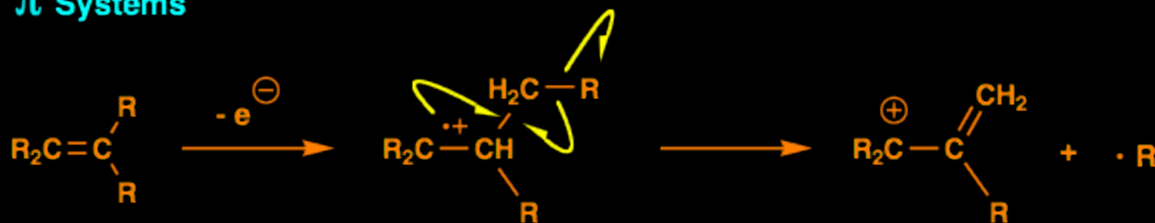
A Few General Mechanisms

(c) α -cleavage

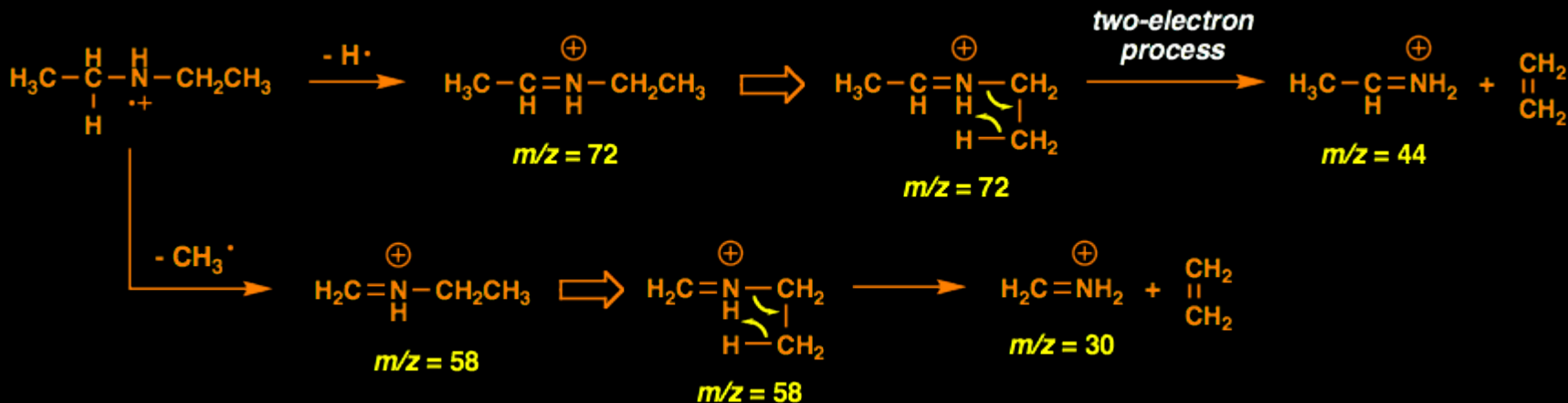


$\cdot\text{CH}_3$ lost in preference to H \cdot

π Systems

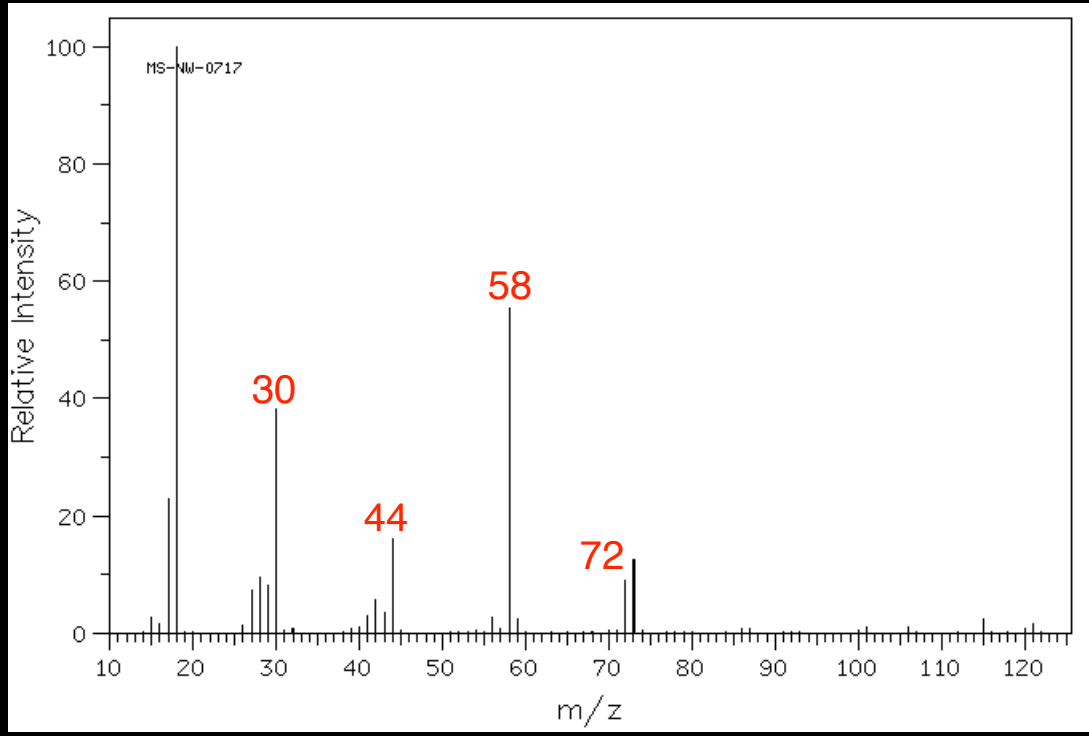
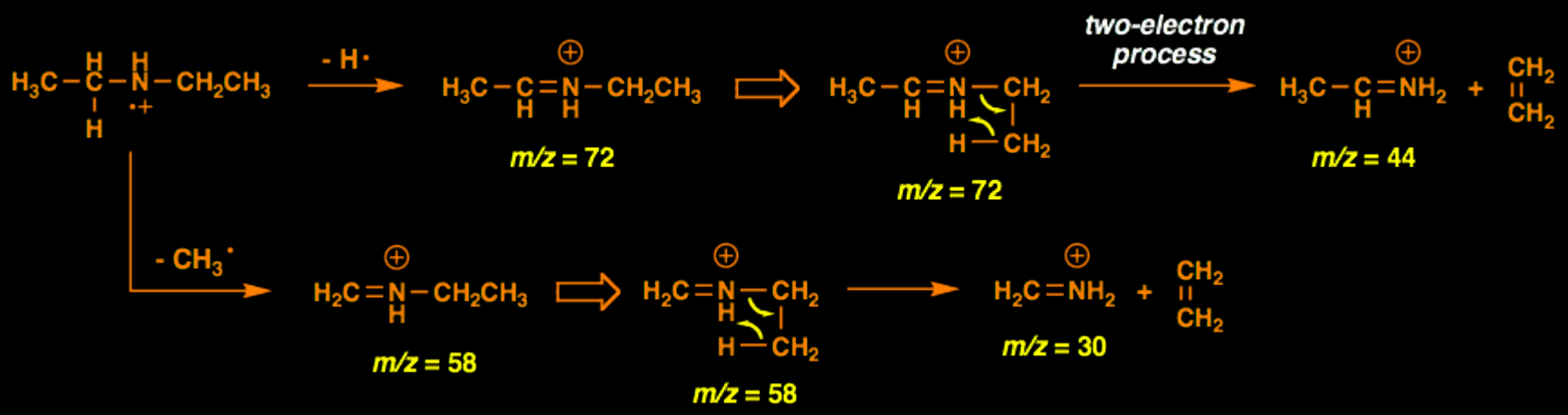


If loss of stable neutral molecule is possible, will do so
(simple alkenes, H₂O, CO, etc.)



Fragmentation

A Few General Mechanisms



Fragmentation

A Few General Mechanisms

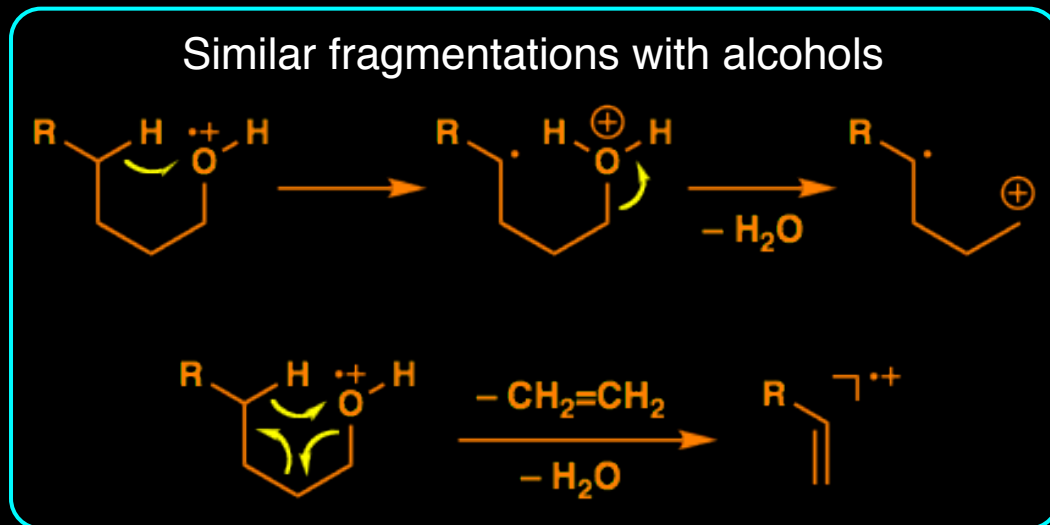
B – two-bond σ -cleavage or rearrangement

(d) elimination of vicinal H and heteroatom

- common with alcohols
- difficult to see M^+

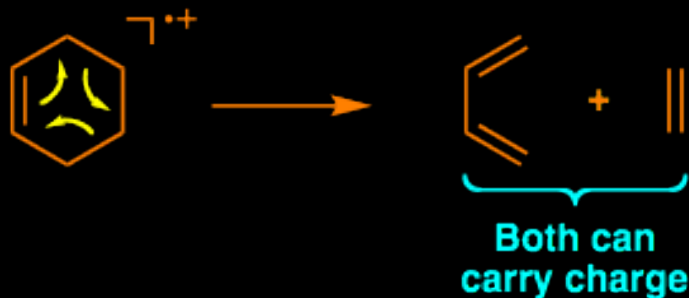


Similar fragmentations with alcohols



(e) retro Diels-Alder cleavage

- mechanism involving single electrons also possible

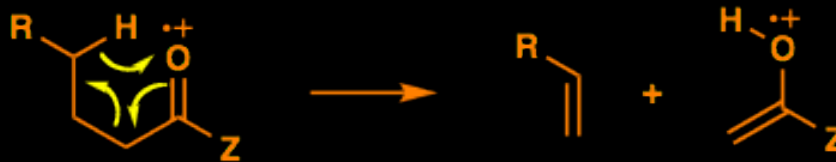


Fragmentation

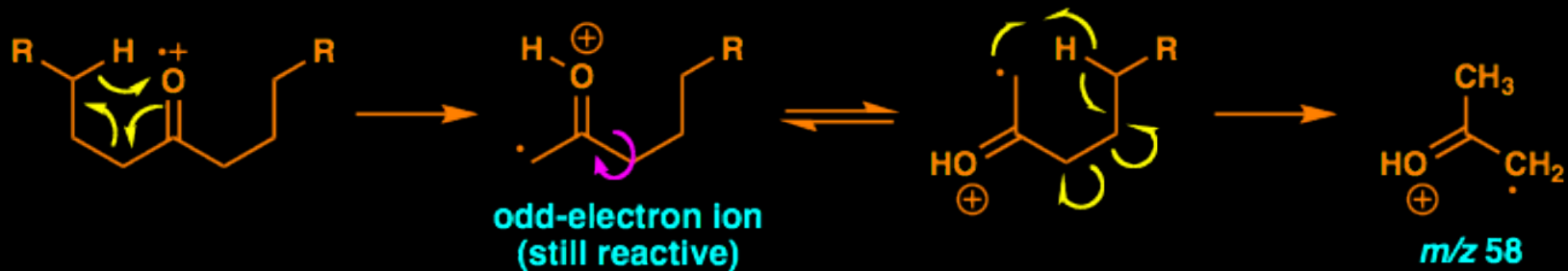
A Few General Mechanisms

(f) McLafferty rearrangement

- common with ketones, esters, carboxylic acids



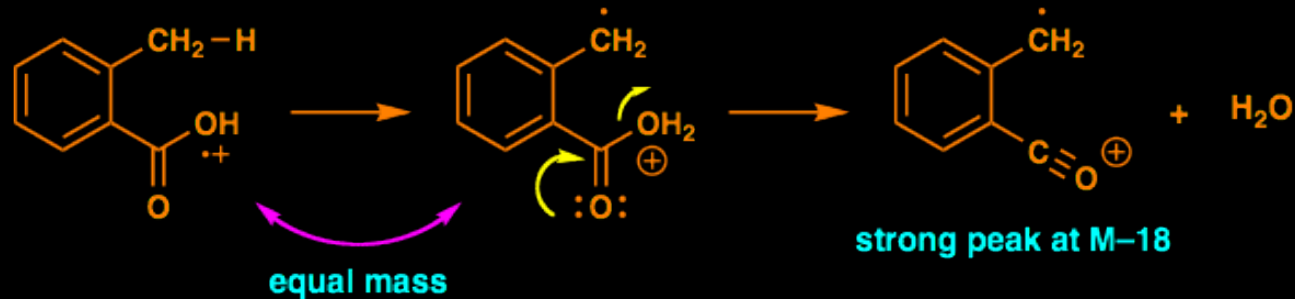
Multiple McLafferty is possible



Fragmentation

Other "Unusual" Mechanisms

Ortho effect

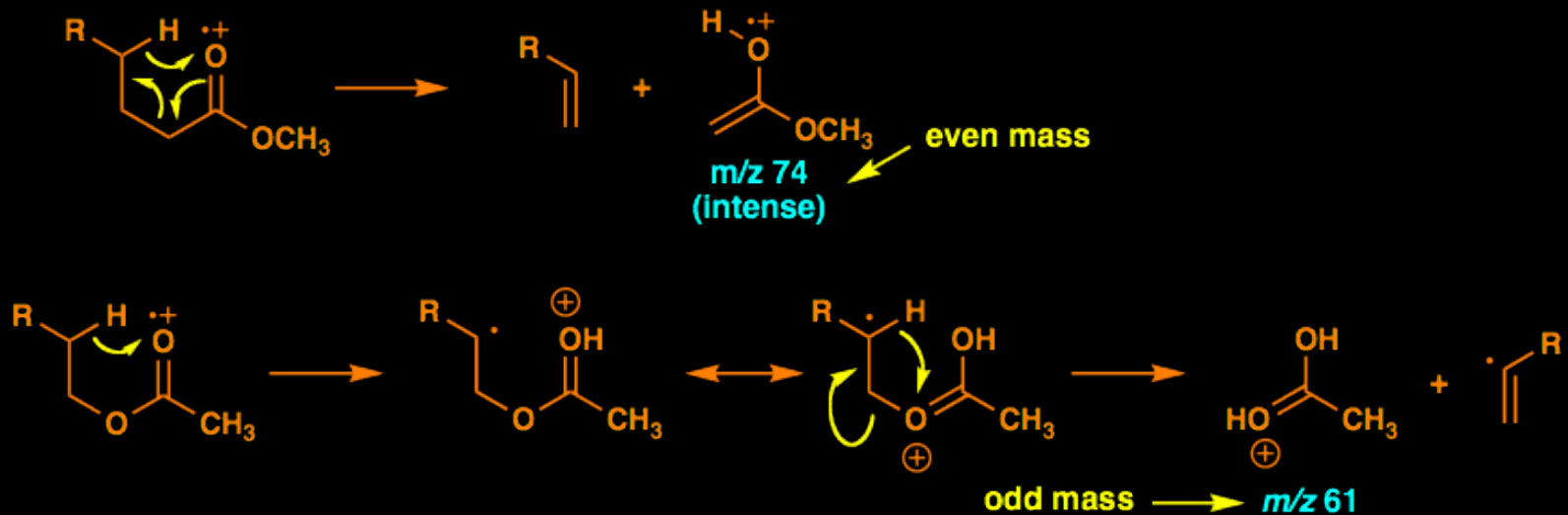


also with esters, amides, OH, etc.

"McLafferty + 1"

- esters only

Normal McLafferty



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

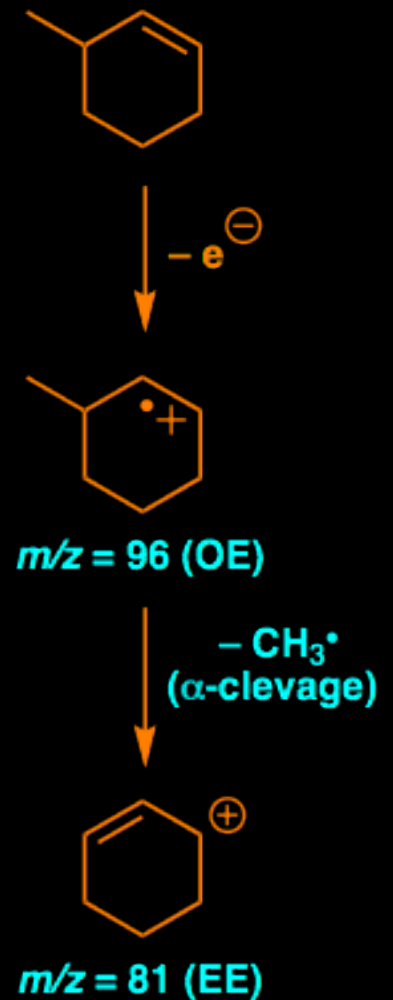
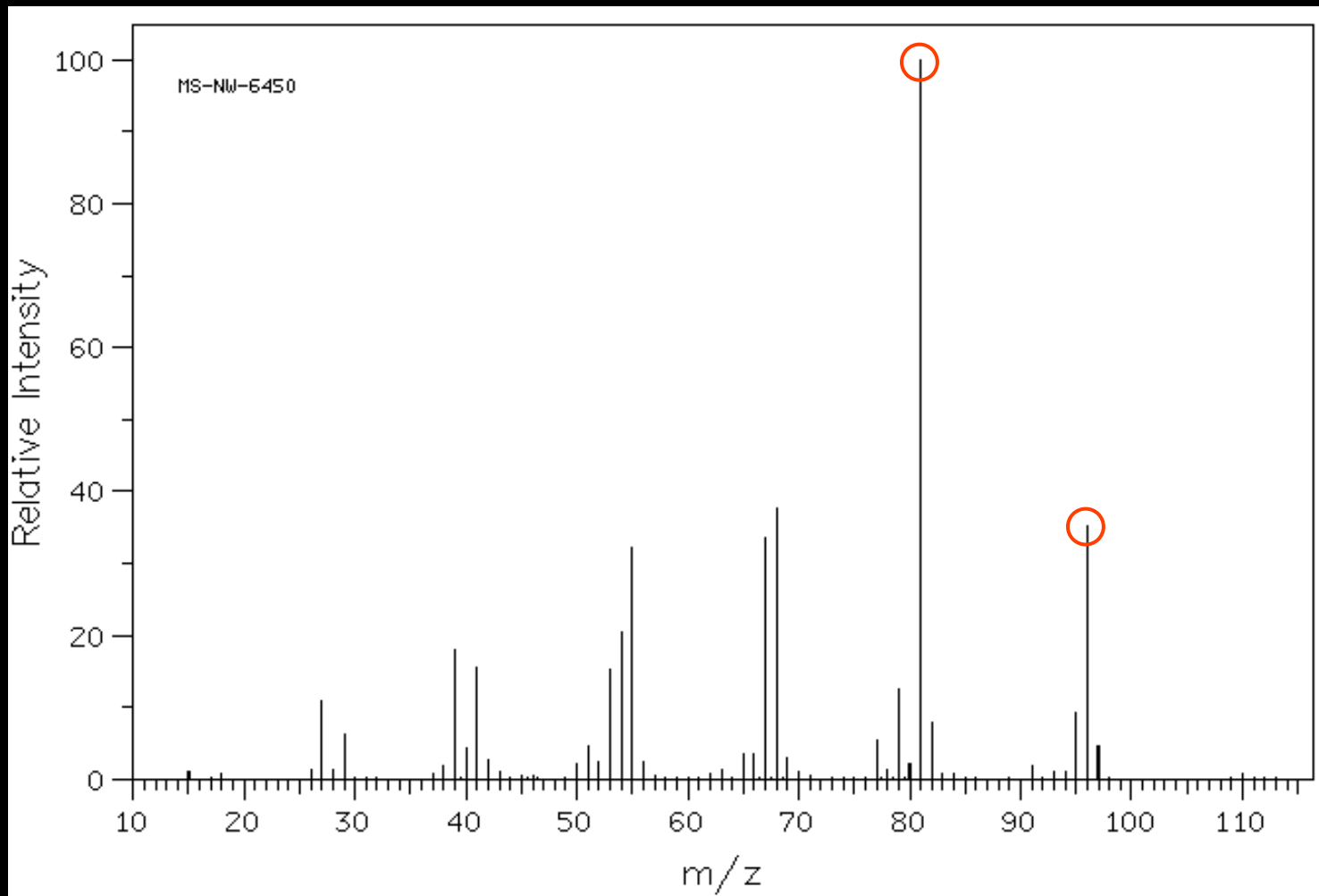
most fragment ions (EE) => odd mass

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)*

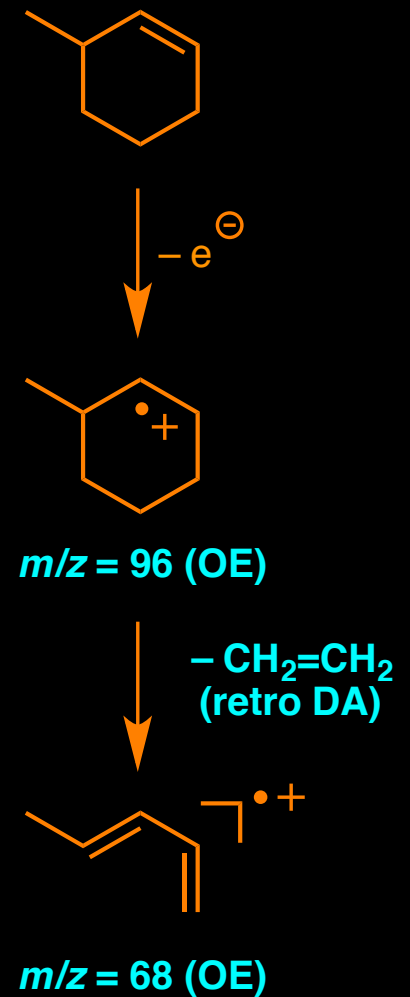
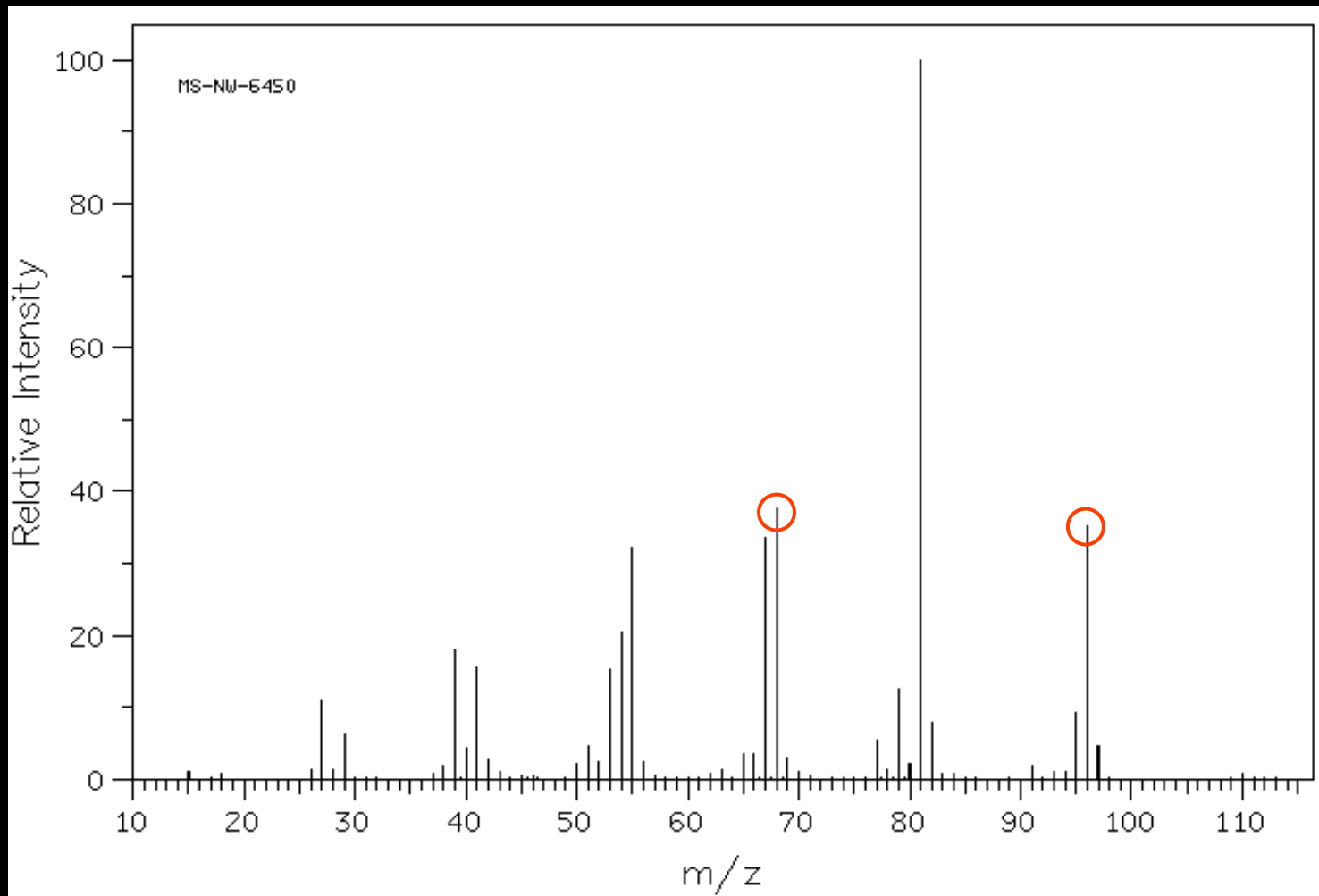
Example – 3-methyl-1-cyclohexene



Fragmentation

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

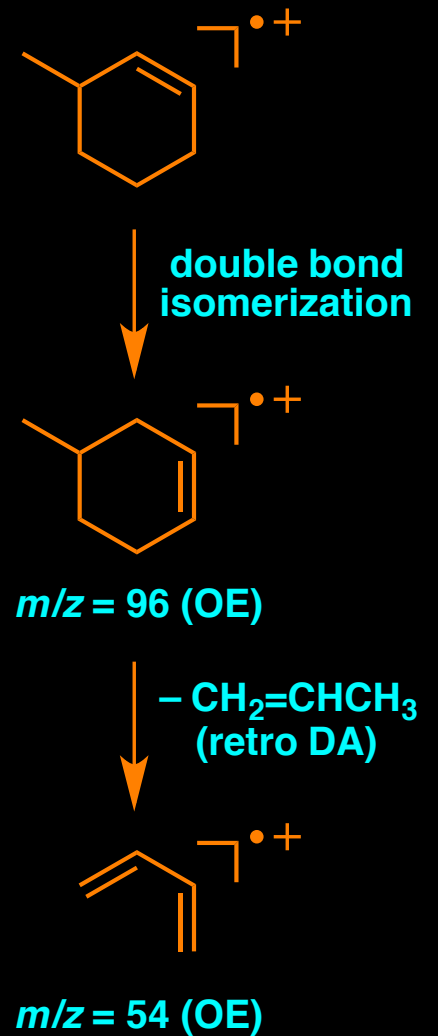
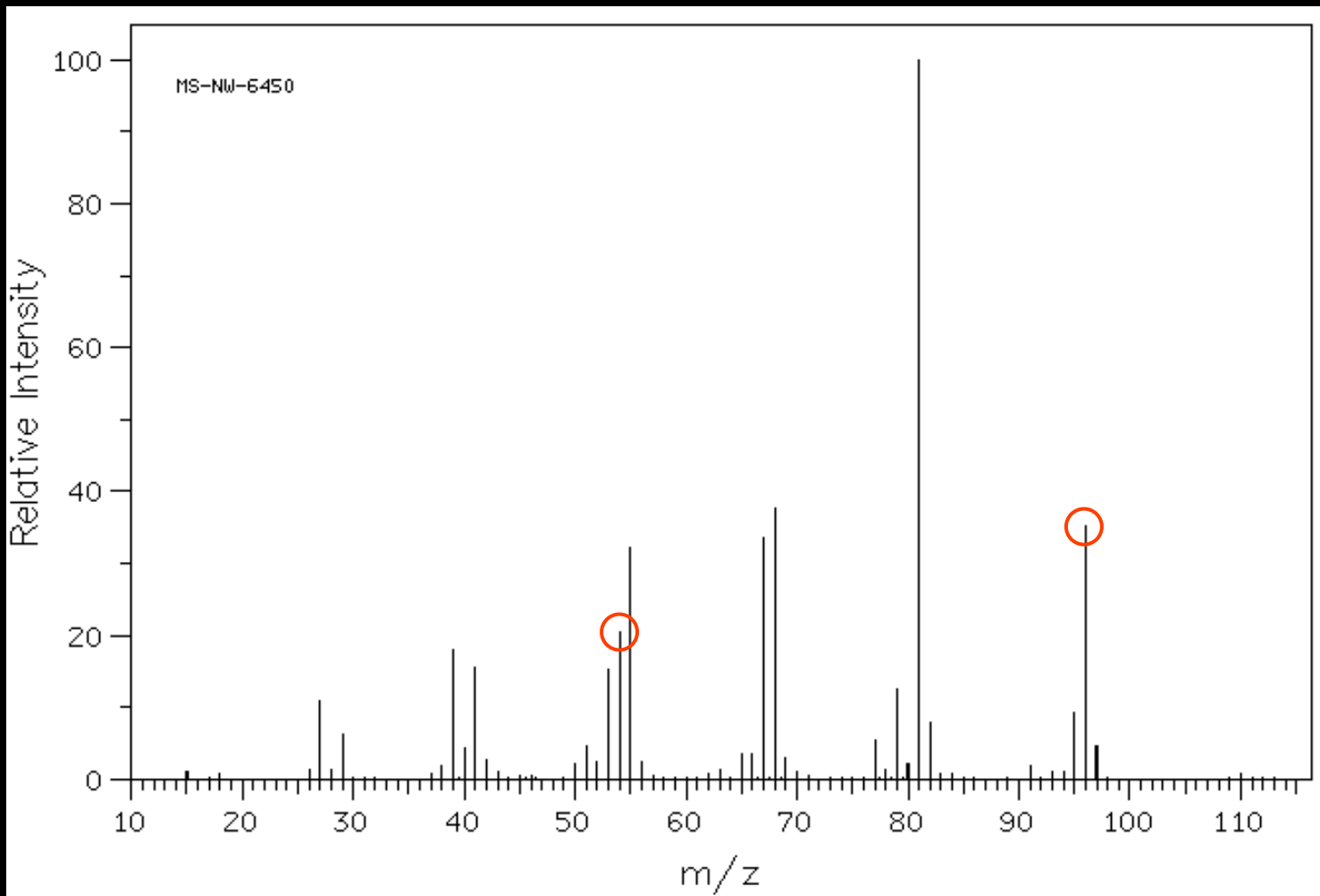
Example – 3-methyl-1-cyclohexene



Fragmentation

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

Example – 3-methyl-1-cyclohexene



Fragmentation

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