Lecture 7

Spectroscopy of atoms and molecules

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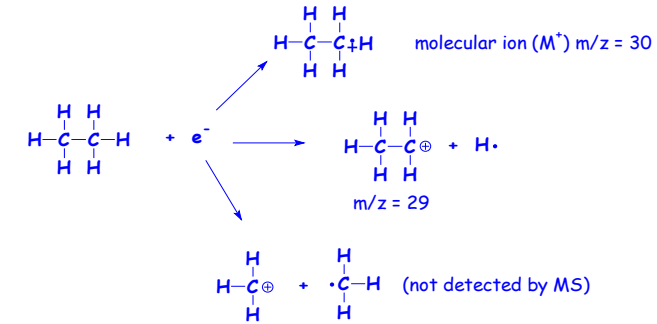
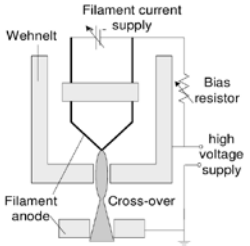
Mass spectroscopy - ionization methods

1. Electron ionization



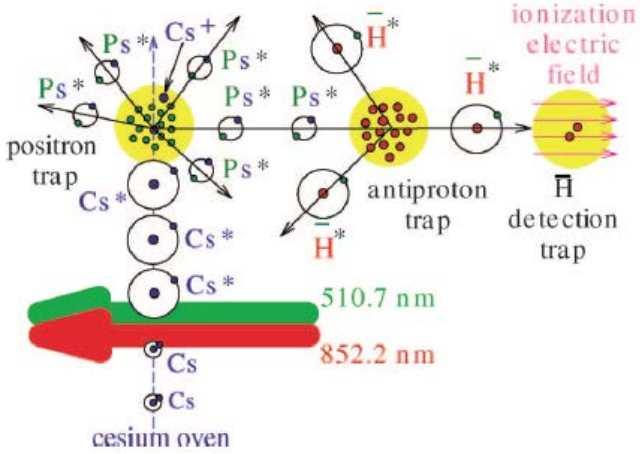


2. Chemical ionization:

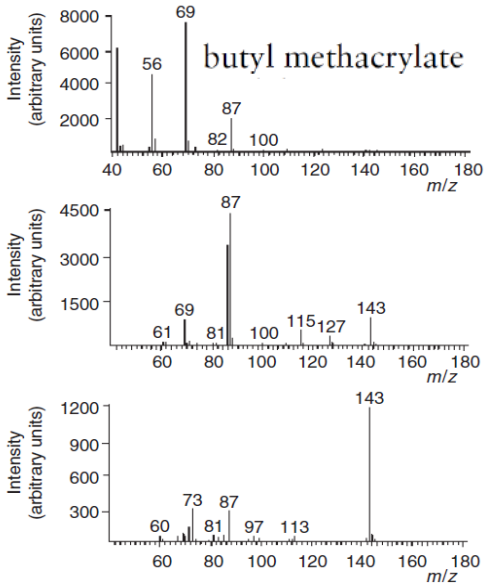
a) Charge transfer

$$Xe + e^- \longrightarrow Xe^{\bullet+} + 2e^-$$

$$Xe^{\bullet+} + M \longrightarrow M^{\bullet+} + Xe$$

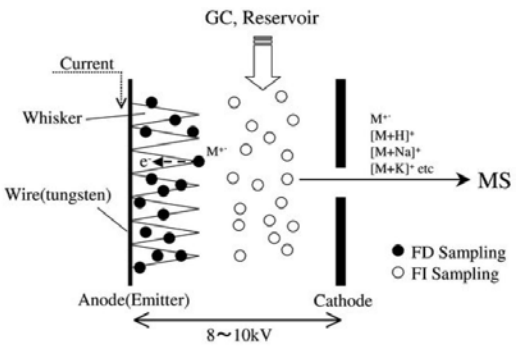


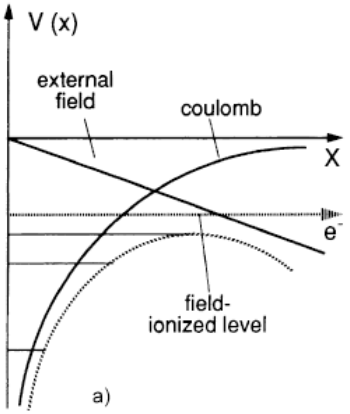
b) proton transfer



Mass spectroscopy - ionization methods

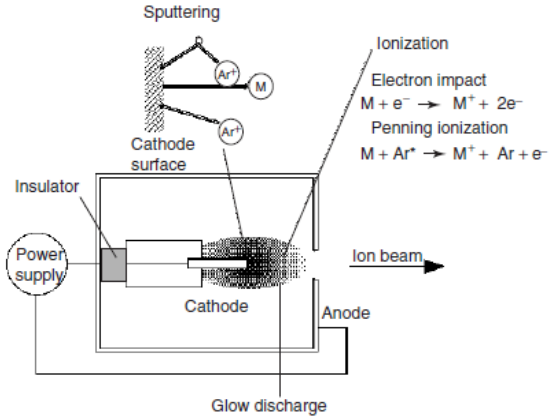
3. Field ionization



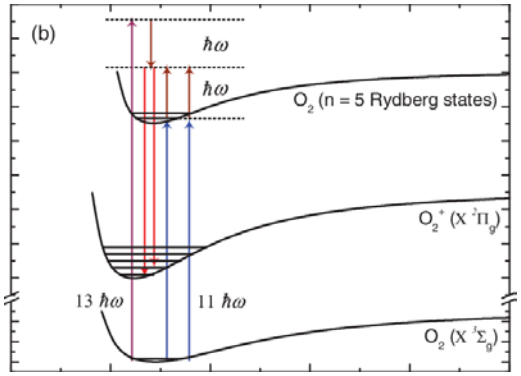


$$IP_{\text{eff}} = IP - \sqrt{\frac{Z_{\text{eff}} e^3 E_0}{\pi \epsilon_0}}$$

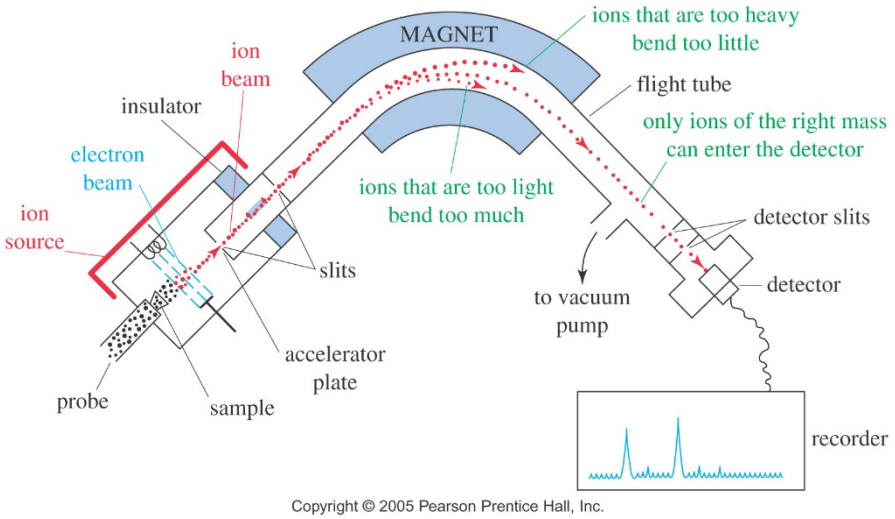
4. Glow discharge source

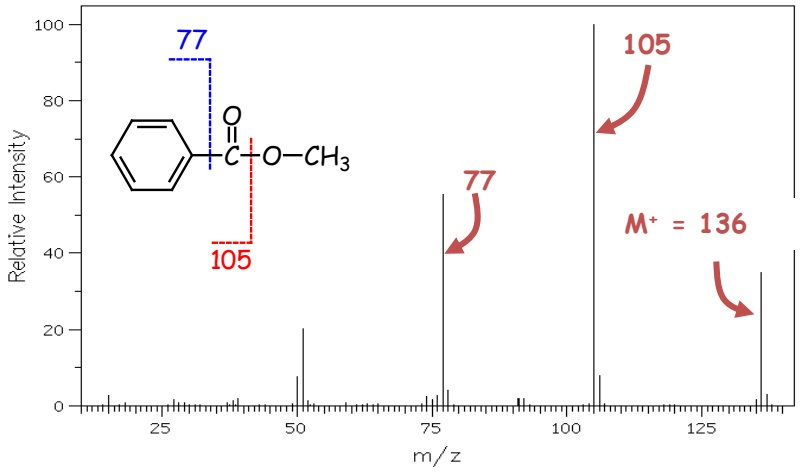


5. Photoionization



Mass spectroscopy



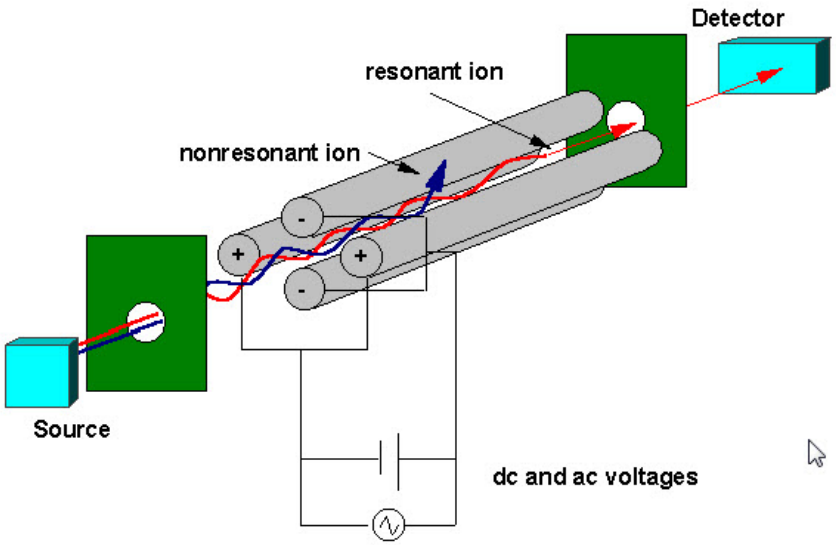


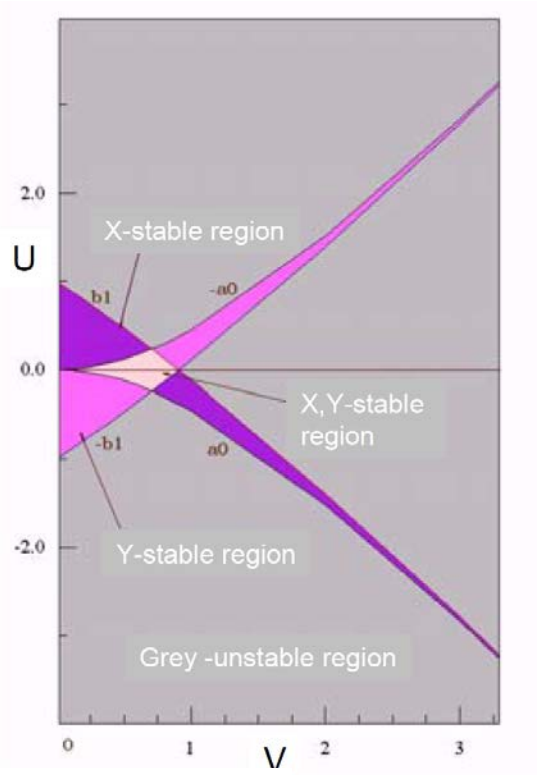
$$qvB = \frac{mv^2}{r} \quad \text{or} \quad mv = qBr \qquad \frac{m}{q} = \frac{r^2B^2}{2V_s}$$

Most elements occur naturally as a mixture of isotopes.

- The presence of significant amounts of heavier isotopes leads to small peaks that have masses that are higher than the parent ion peak.
- M+1 = a peak that is one mass unit higher than M^+
- M+2 = a peak that is two mass units higher than M^+

Quadrupole Mass Filter





Mathieu's equations

$$\frac{d^2x}{dt^2} = -\left(\frac{e}{m}\right)\frac{[U + V\cos(\omega t)]}{r_0^2}\,x,$$

$$\frac{d^2y}{dt^2} = \left(\frac{e}{m}\right)\frac{[U + V\cos(\omega t)]}{r_0^2}\,y,$$

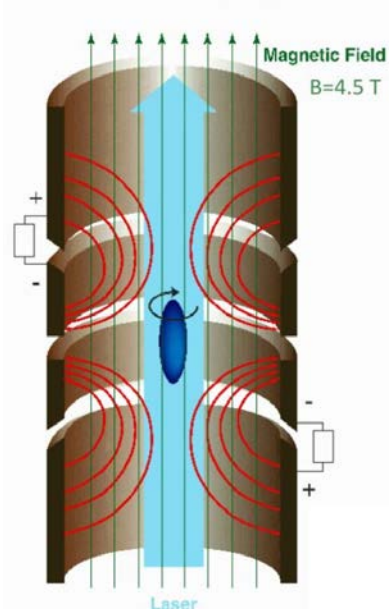
$$\frac{d^2z}{dt^2} = 0.$$

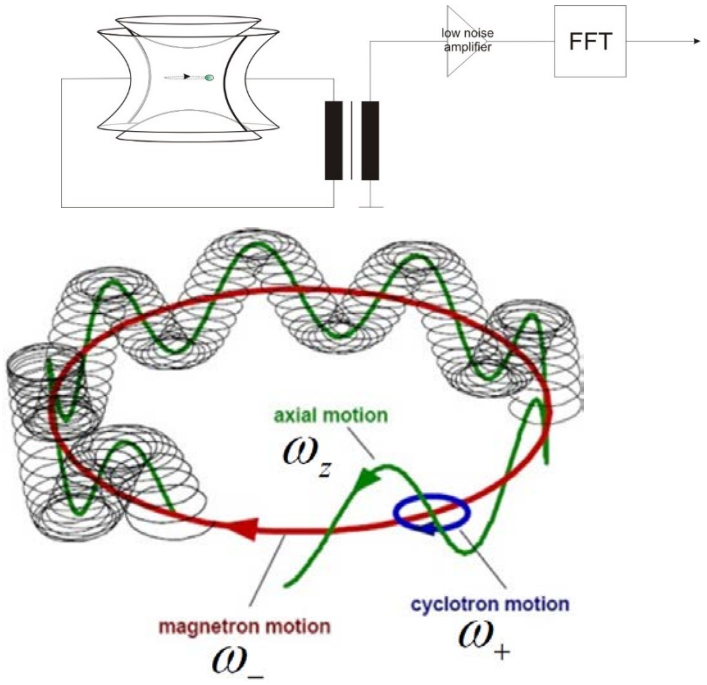
$$\frac{\mathrm{d}^2u}{\mathrm{d}\xi^2} + (a_u - 2q_u\cos 2\xi)\,u = 0$$

$$a_u = a_x = -a_y = \frac{8zeU}{m\omega^2 r_0^2}$$

$$q_u = q_x = -q_y = \frac{4zeV}{m\omega^2 r_0^2}$$

Penning trap mass spectrometry





$$\omega_c = \frac{q}{m} B$$

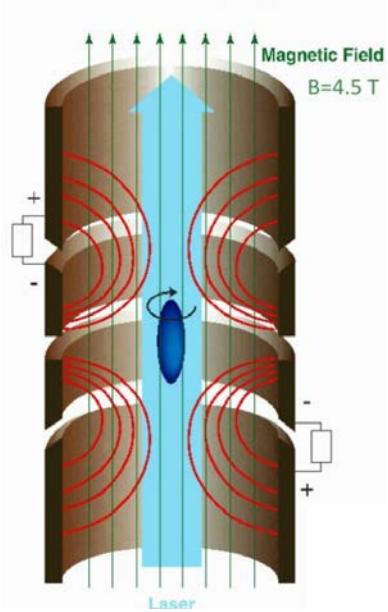
$$\omega_z = \sqrt{\frac{qU_{dc}}{md^2}},$$

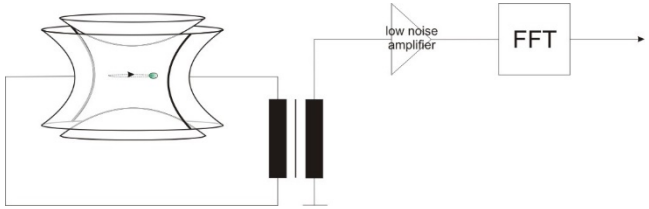
$$\omega_+ = \frac{\omega_c}{2} + \sqrt{\frac{\omega_c^2}{4} - \frac{\omega_z^2}{2}}$$

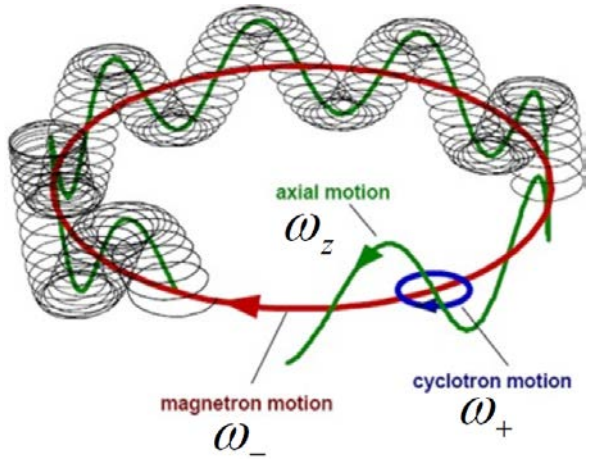
$$\omega_- = \frac{\omega_c}{2} - \sqrt{\frac{\omega_c^2}{4} - \frac{\omega_z^2}{2}}$$

$$\frac{|q|}{m} B^2 > 2\frac{|U_{dc}|}{d^2} \text{ and } qU_{dc} > 0$$

Penning trap mass spectrometry







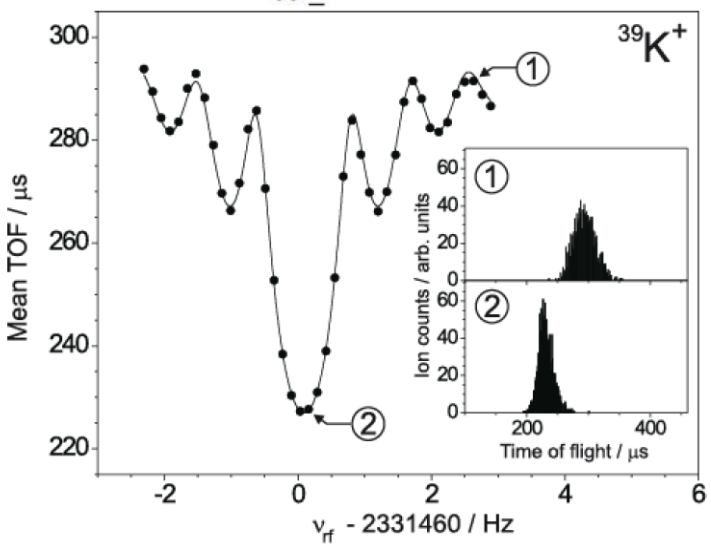
$$\omega_c = \frac{q}{m} B$$

$$\omega_z = \sqrt{\frac{qU_{dc}}{md^2}},$$

$$\omega_+ = \frac{\omega_c}{2} + \sqrt{\frac{\omega_c^2}{4} - \frac{\omega_z^2}{2}}$$

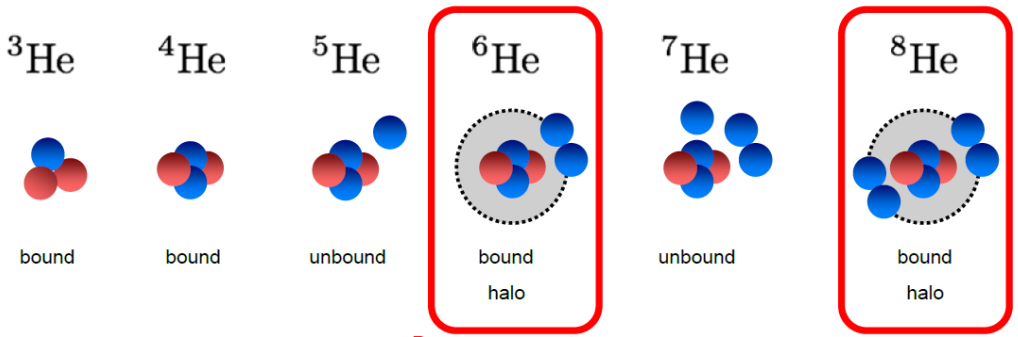
$$\omega_- = \frac{\omega_c}{2} - \sqrt{\frac{\omega_c^2}{4} - \frac{\omega_z^2}{2}}$$

$$\frac{|q|}{m} B^2 > 2\frac{|U_{dc}|}{d^2} \quad \text{and} \quad qU_{dc} > 0$$



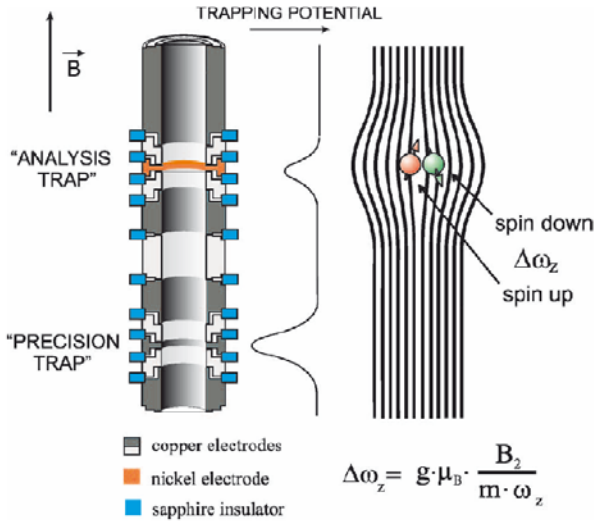
Penning trap mass spectrometry

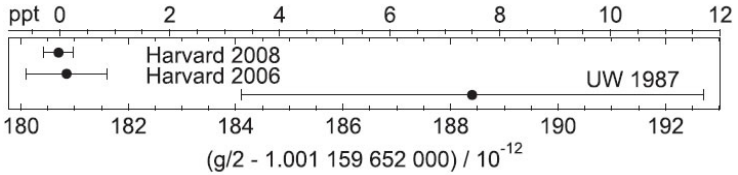
Binding energy measurements



Borromean system

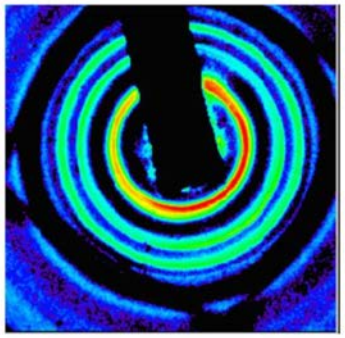
Most exotic nucleus "on earth"



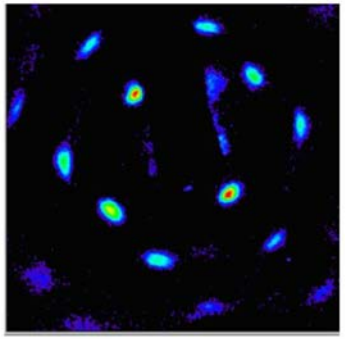


$g/2 = 1.001\,159\,652\,180\,73(28) \quad [0.28\ \text{ppt}].$

time averaged Bragg scattering



camera strobed by the rotating wall



- determine if crystal pattern due to 1 or multiple crystals
- enables real space imaging of ion crystals

Electron/proton g-factor measurements