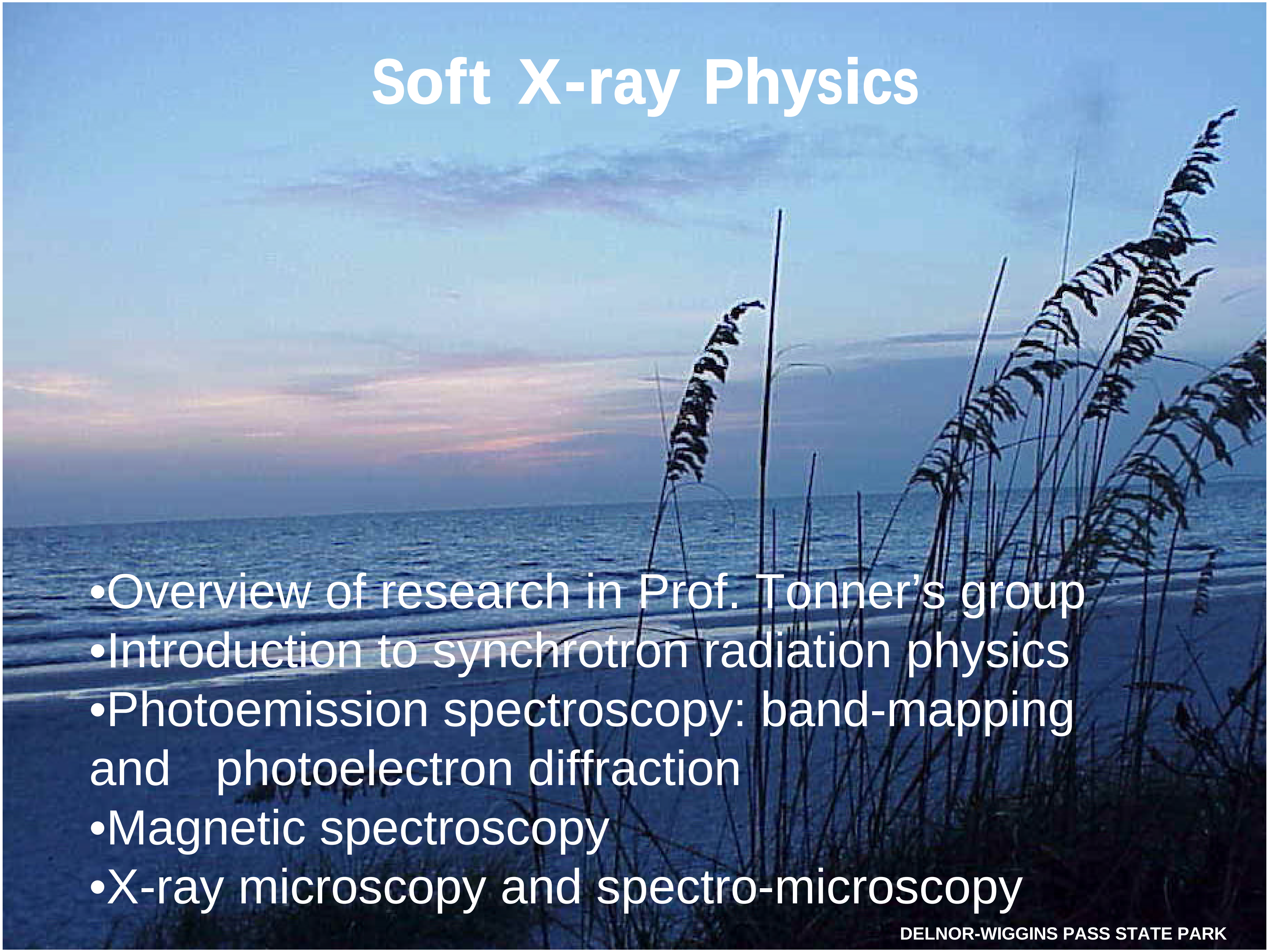
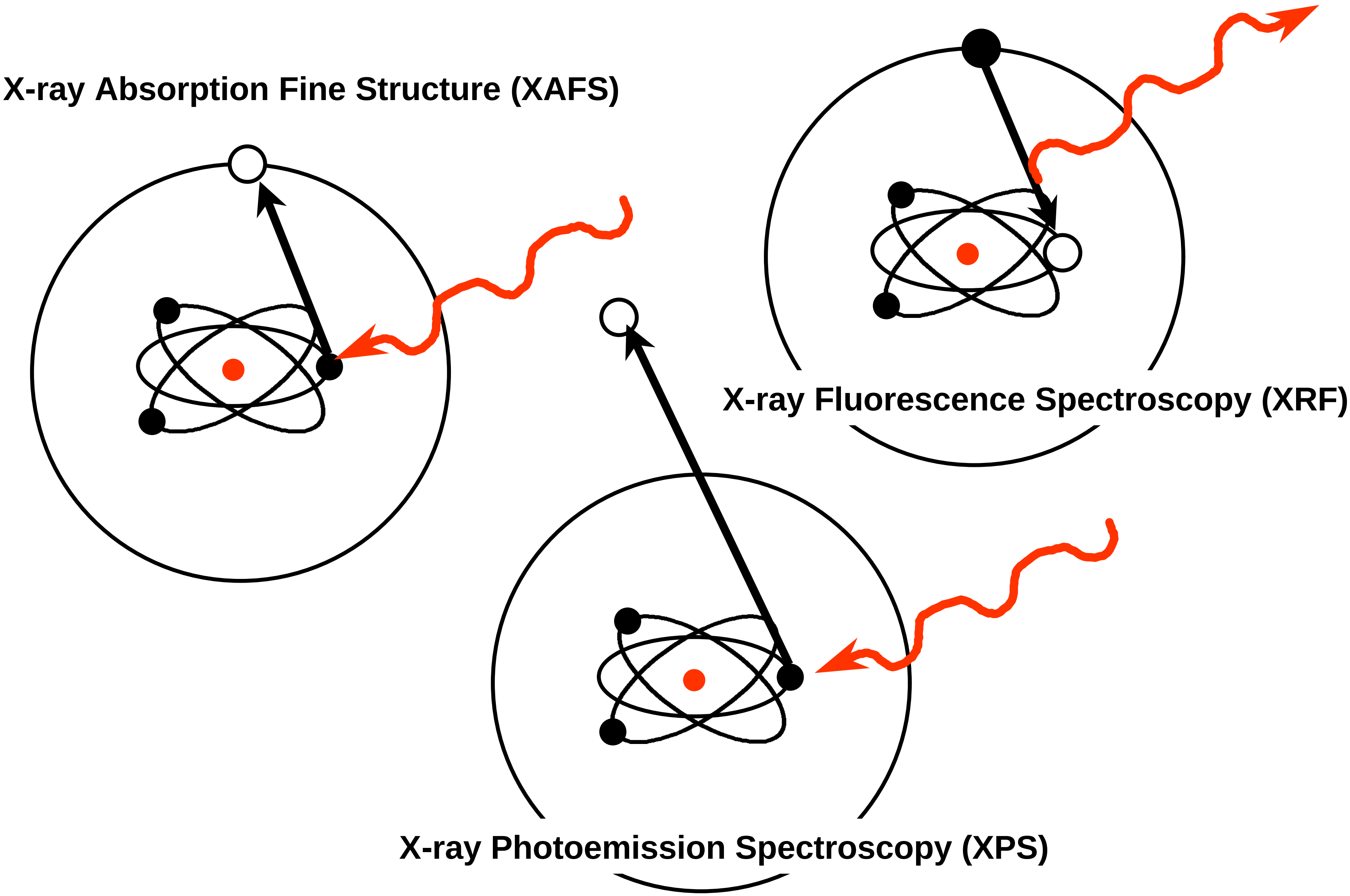
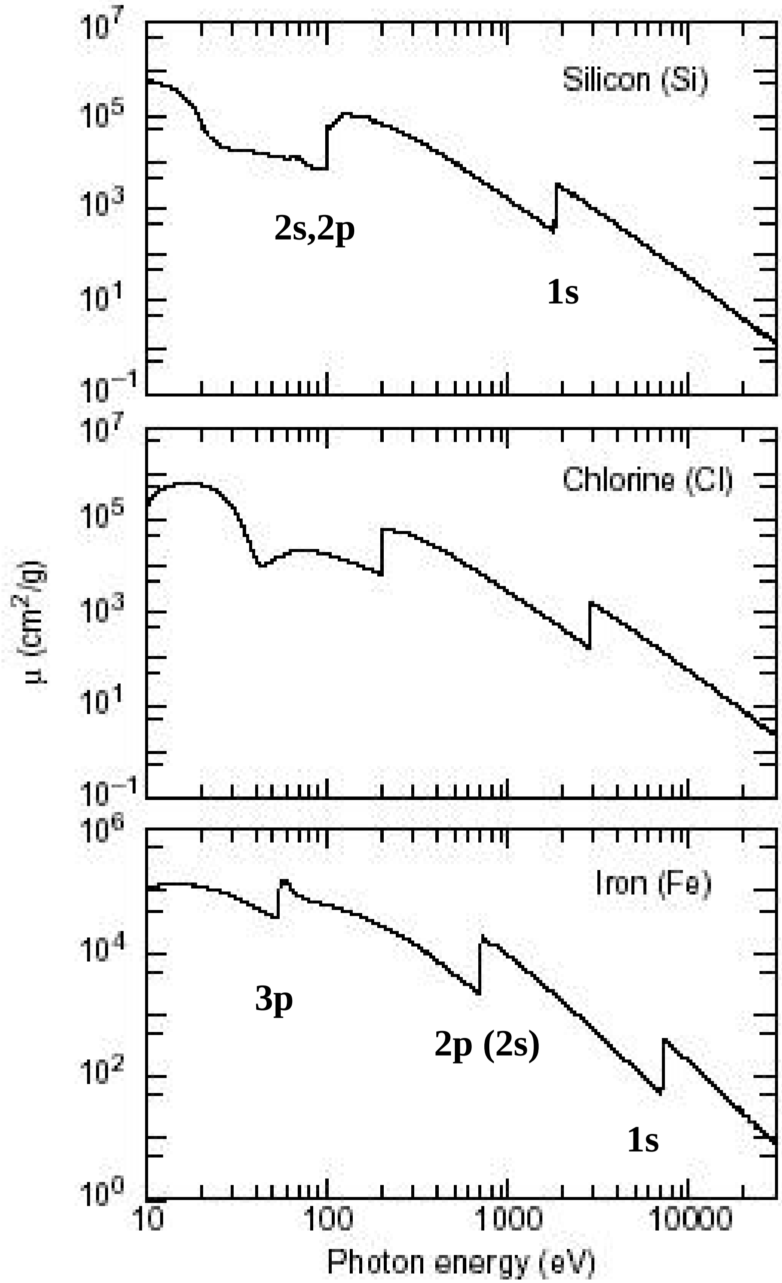

Soft X-ray Physics
•Overview of research in Prof. Tonner's group
•Introduction to synchrotron radiation physics
•Photoemission spectroscopy: band-mapping and photoelectron diffraction
•Magnetic spectroscopy
•X-ray microscopy and spectro-microscopy
DELNOR-WIGGINS PASS STATE PARK

The Three Principle Soft X-ray Spectroscopies

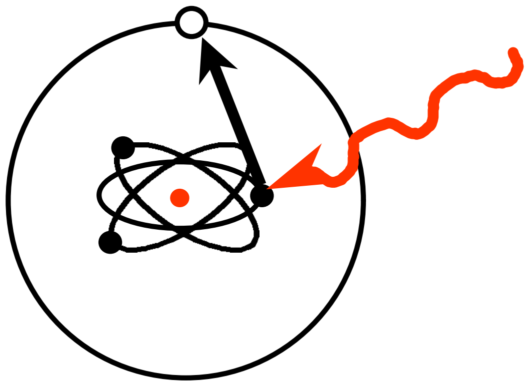


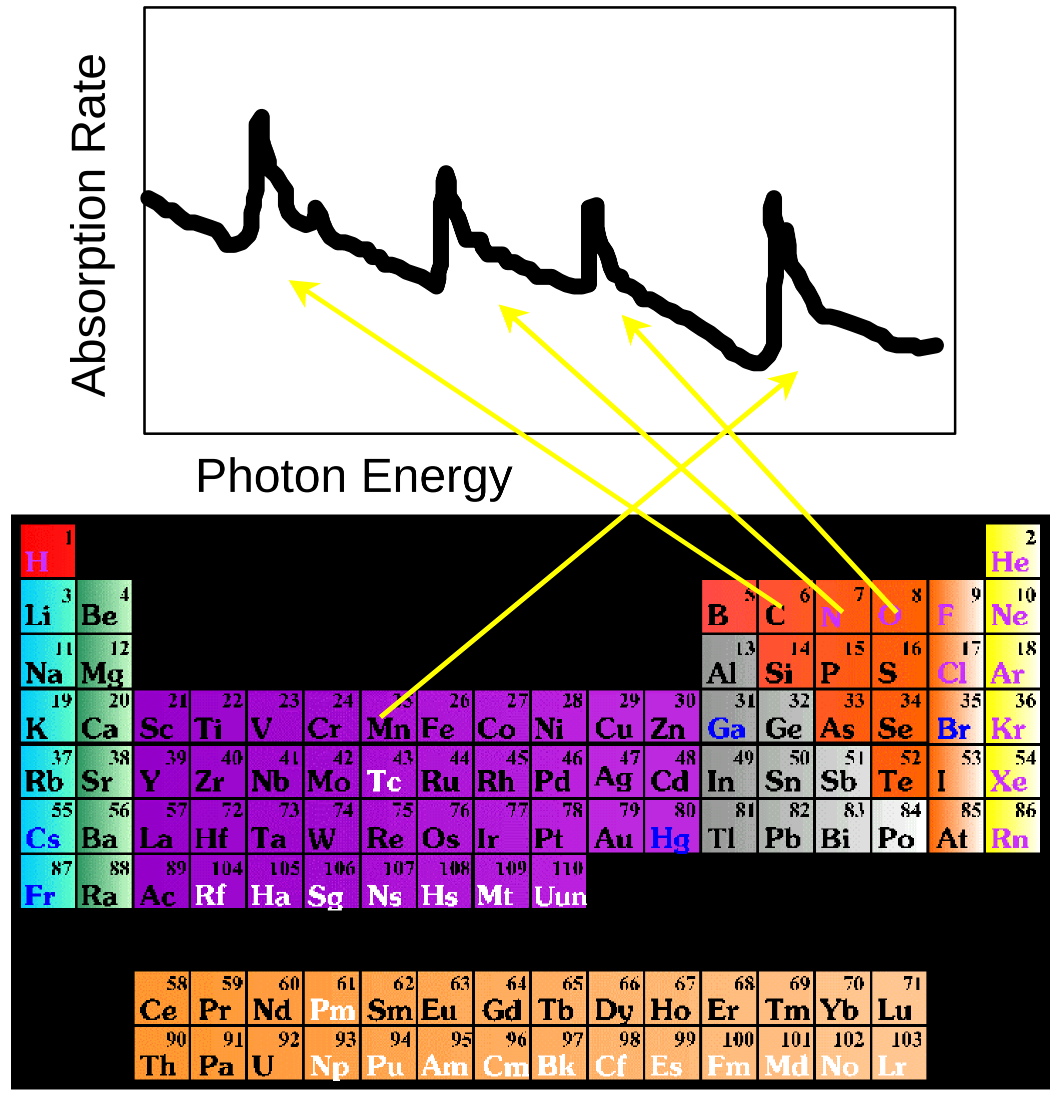
X-ray Absorption Edges

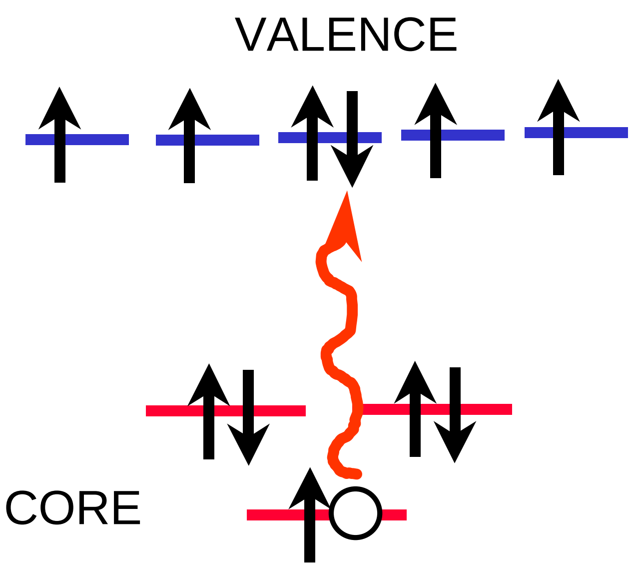
Note the increases in absorption at characteristic energies.



X-ray Absorption Spectroscopy



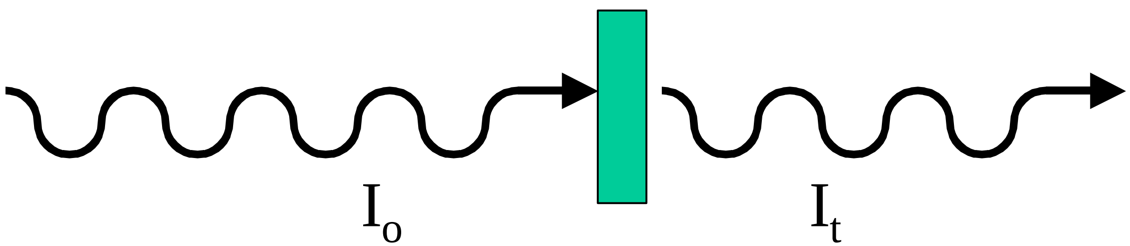




Three methods of XAS measurement

(X-ray Absorption Spectroscopy)

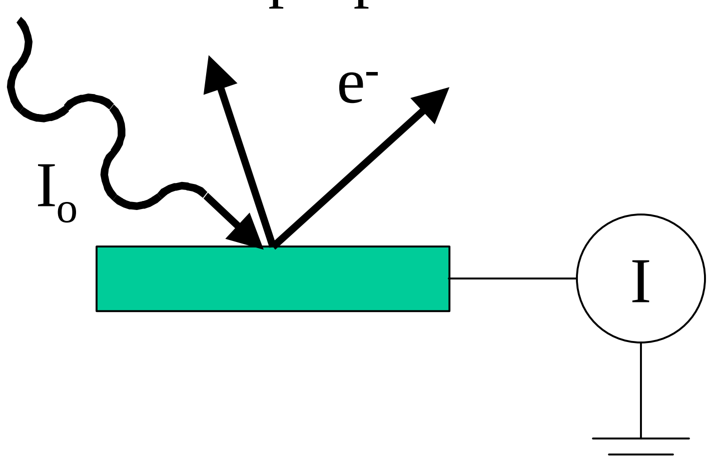
(a) Transmission—bulk properties



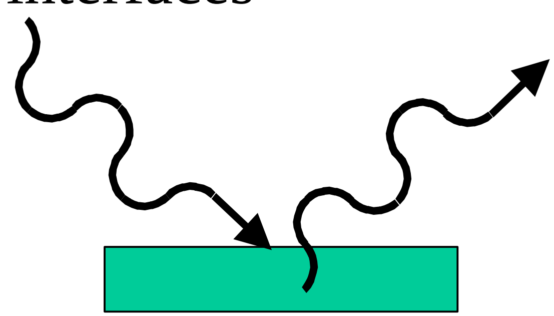
$$I_t = I_0 e^{-m(\hbar w)d}$$

$$m(\hbar w) = -\frac{1}{d}\ln\left(\frac{I_t}{I_0}\right)$$

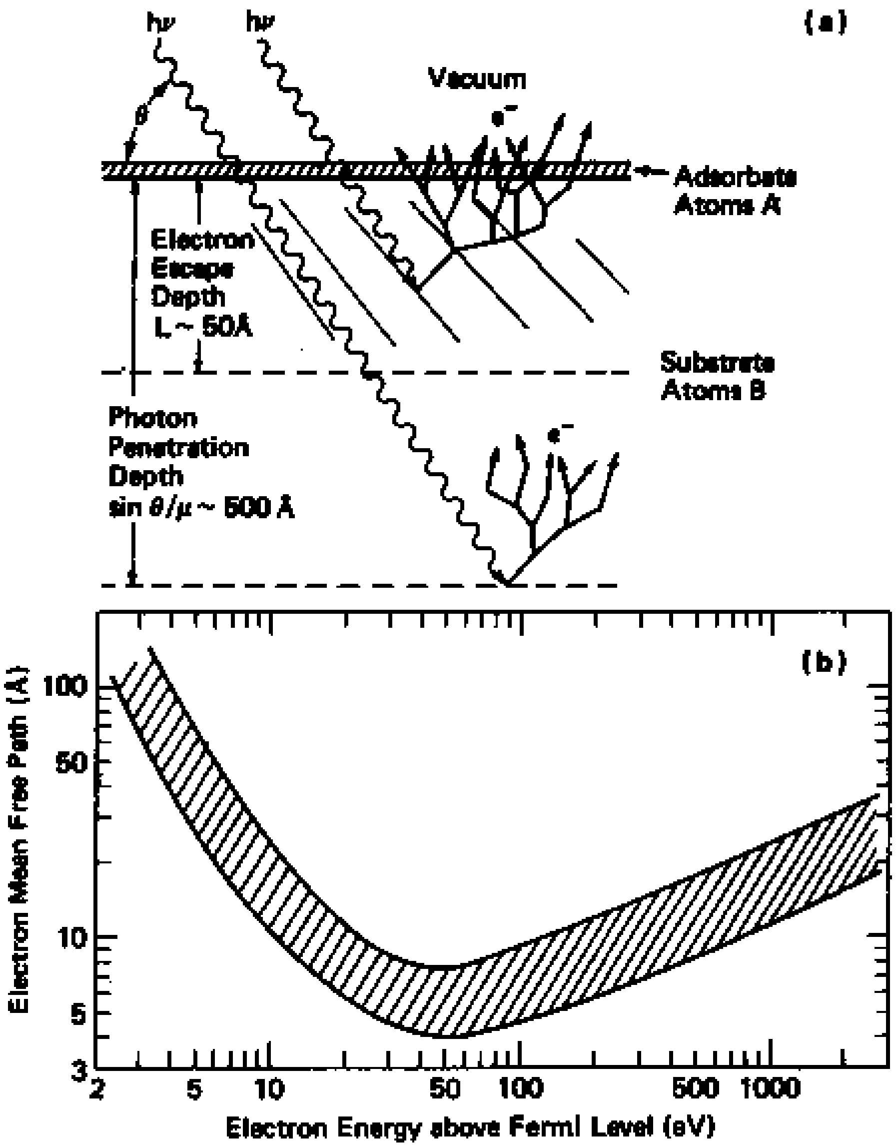
(b) Total electron yield —surface properties



(c) Fluorescence—dilute species; Buried interfaces

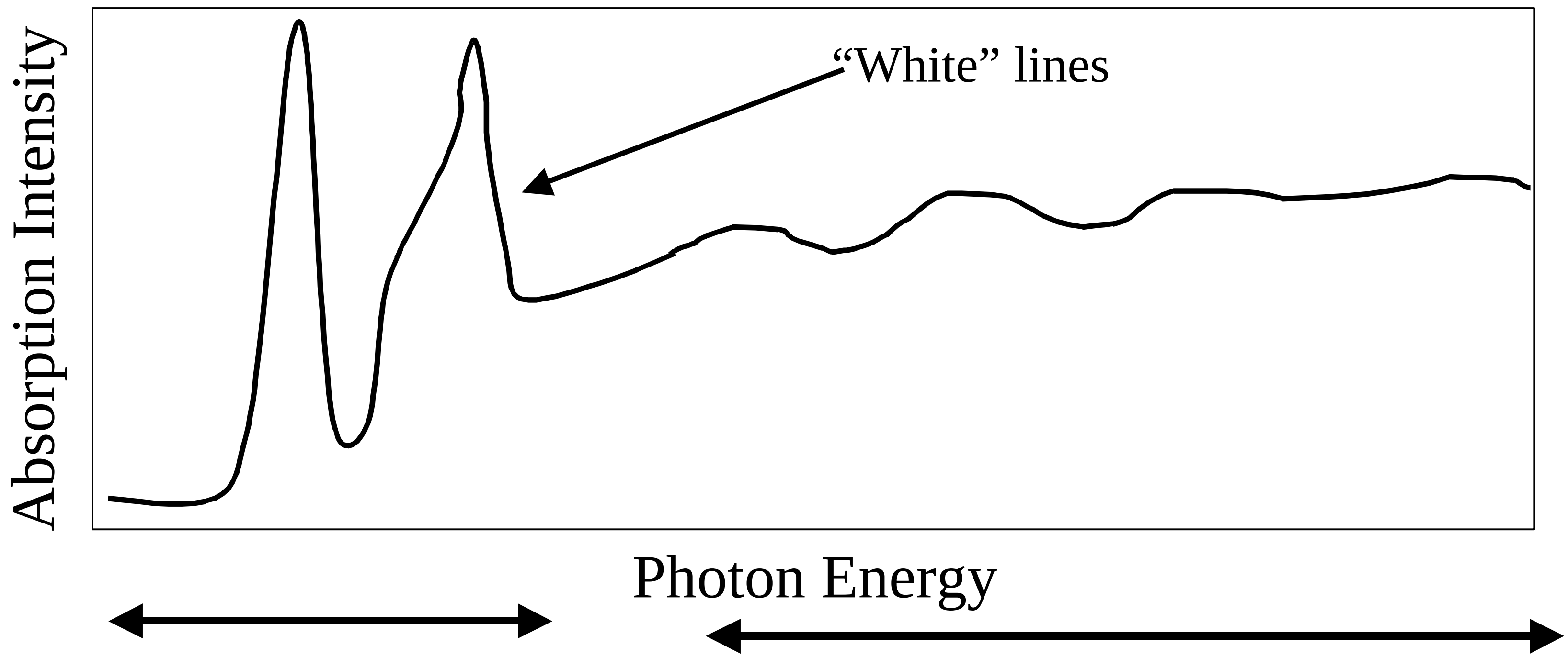


Electron yield X-ray Absorption Spectroscopy



$$i_{yield} \propto \hbar w m(\hbar w)$$

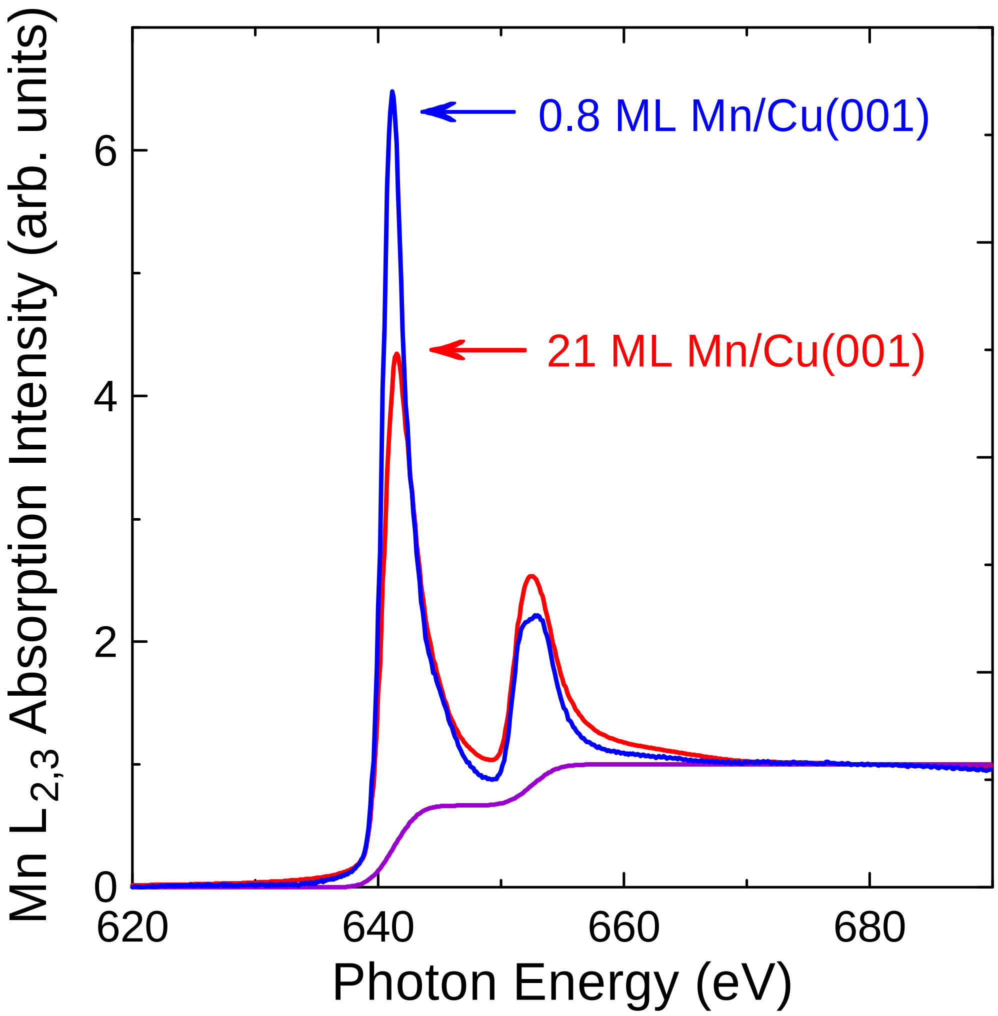
Information in X-ray Absorption Spectroscopy



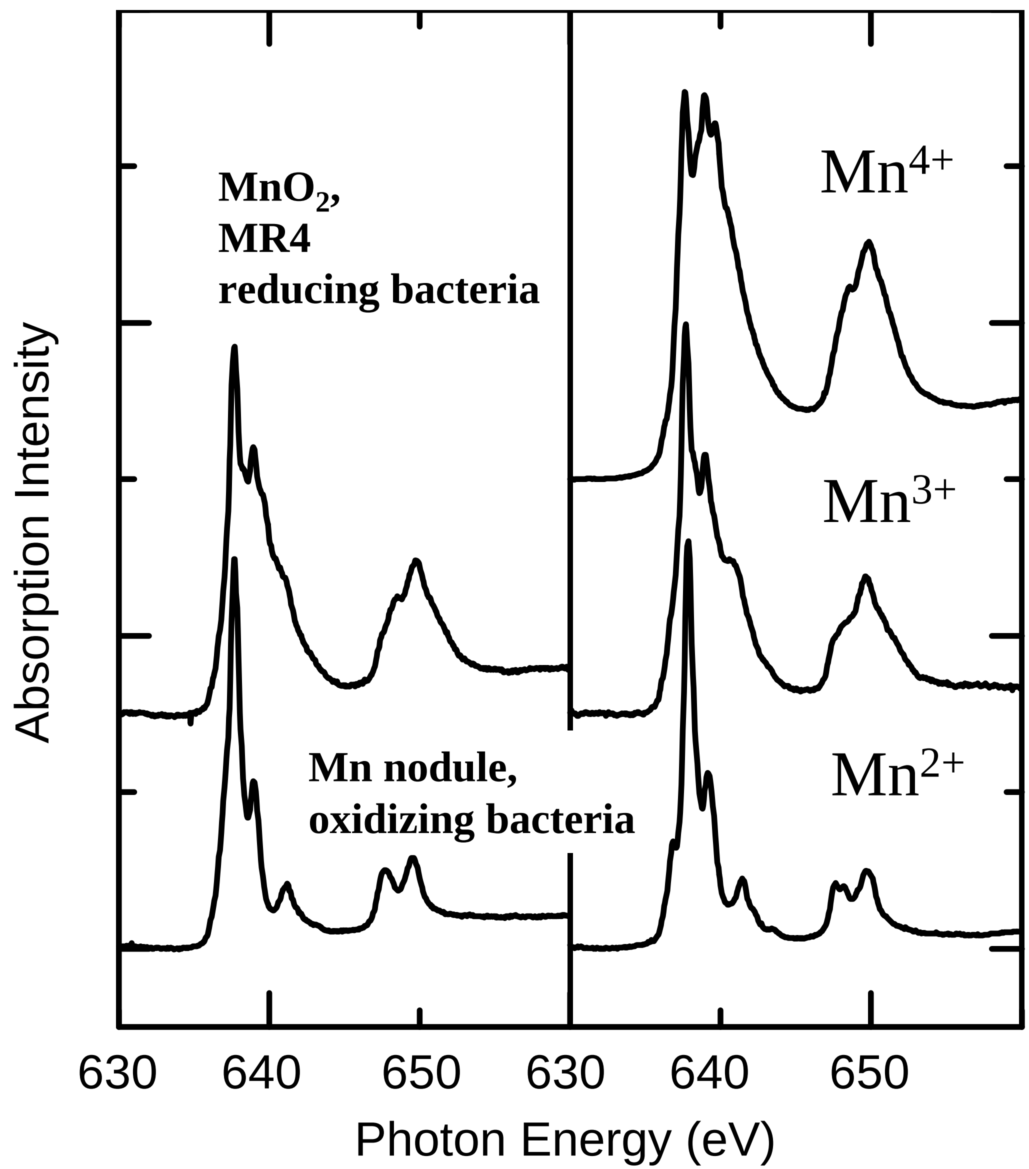
Near-edge region
0-50 eV
Valence transitions
Multiple-scattering theory
Chemical bonds
(NEXAFS or XANES)

Extended X-ray Absorption Fine Structure (EXAFS)
>50 eV to several 100’s of eV
Near-neighbor geometry

Background Removal of Continuum Contributions



Mn L-edge XAFS of Bio-inorganic compounds

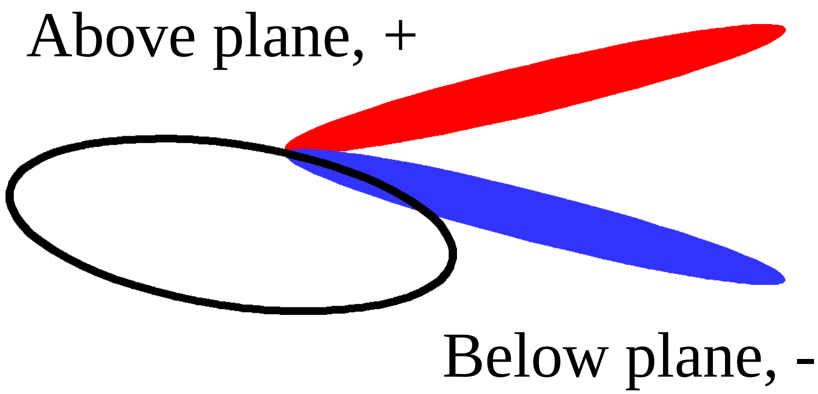


L-edge structure from 2p to 3d dipole allowed transitions

Structure in near-edge can often be explained by atomic theory of crystal field effects

Many materials do not agree with atomic theory, because they have more de-localized orbitals—need a many-body theory

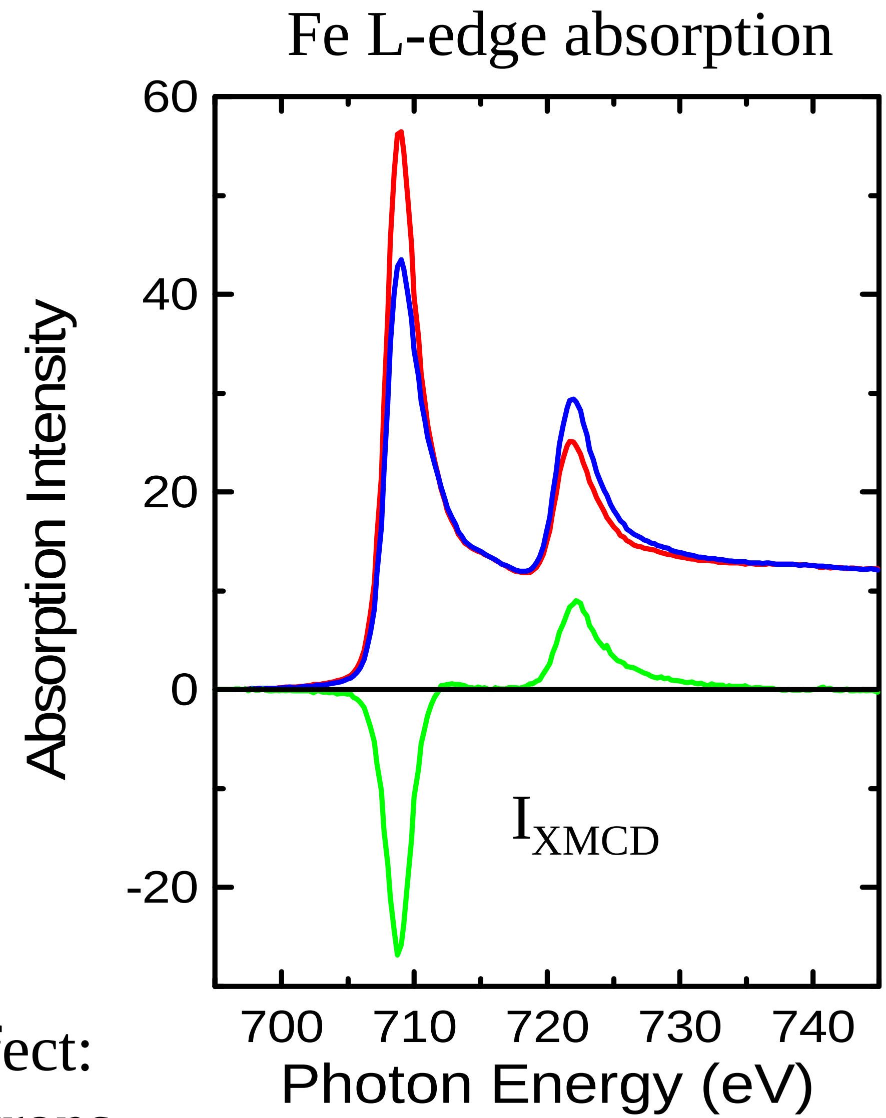
XAS with Circular Polarization



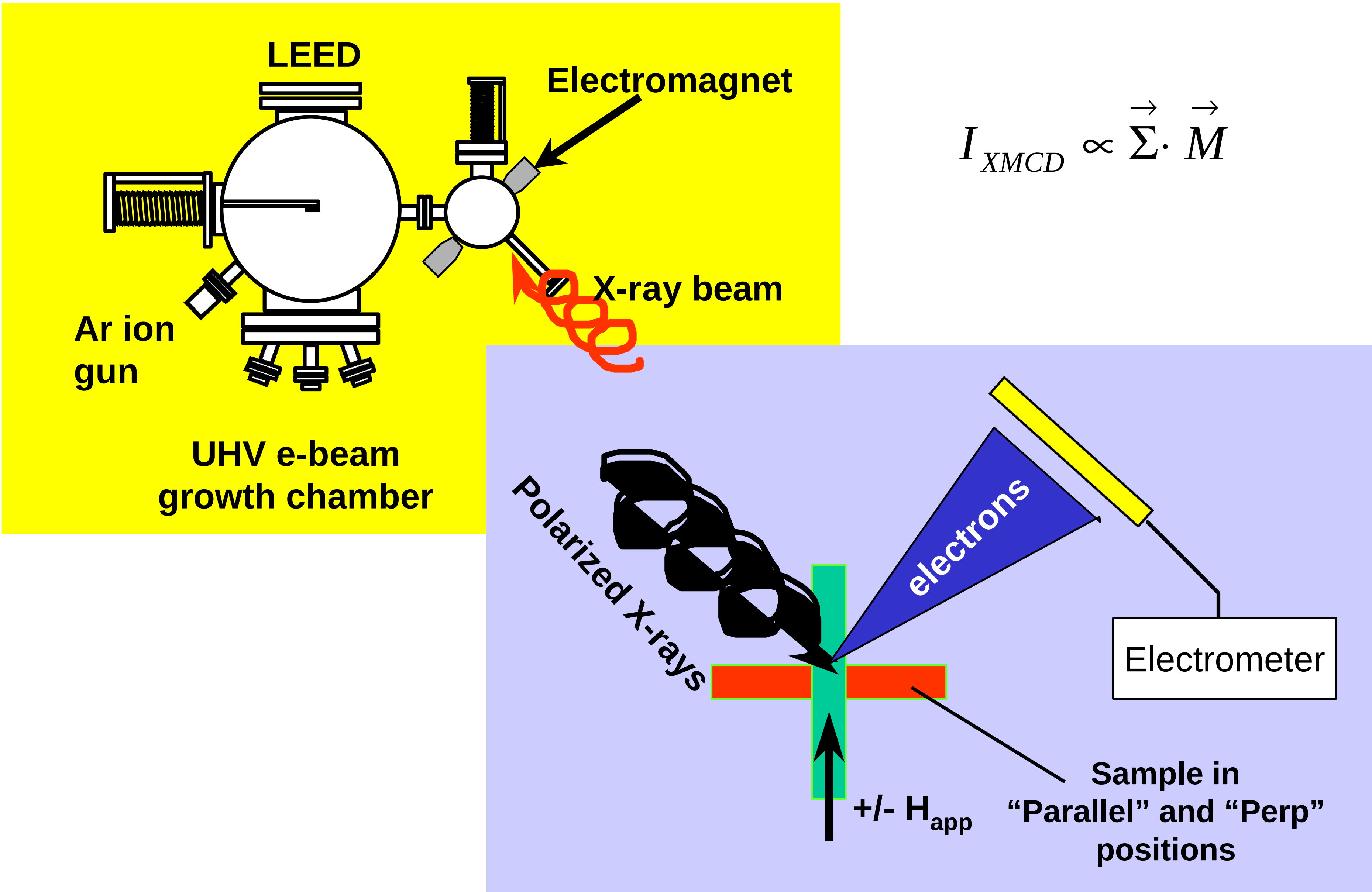
Photons carry angular momentum (spin), which is parallel or anti-parallel to the direction of propagation for circularly polarized light.

$$I_{XMCD} \propto \vec{\Sigma} \cdot \vec{M}$$

The effect is an atomic physics effect: Spin-orbit splitting of d-shell electrons.

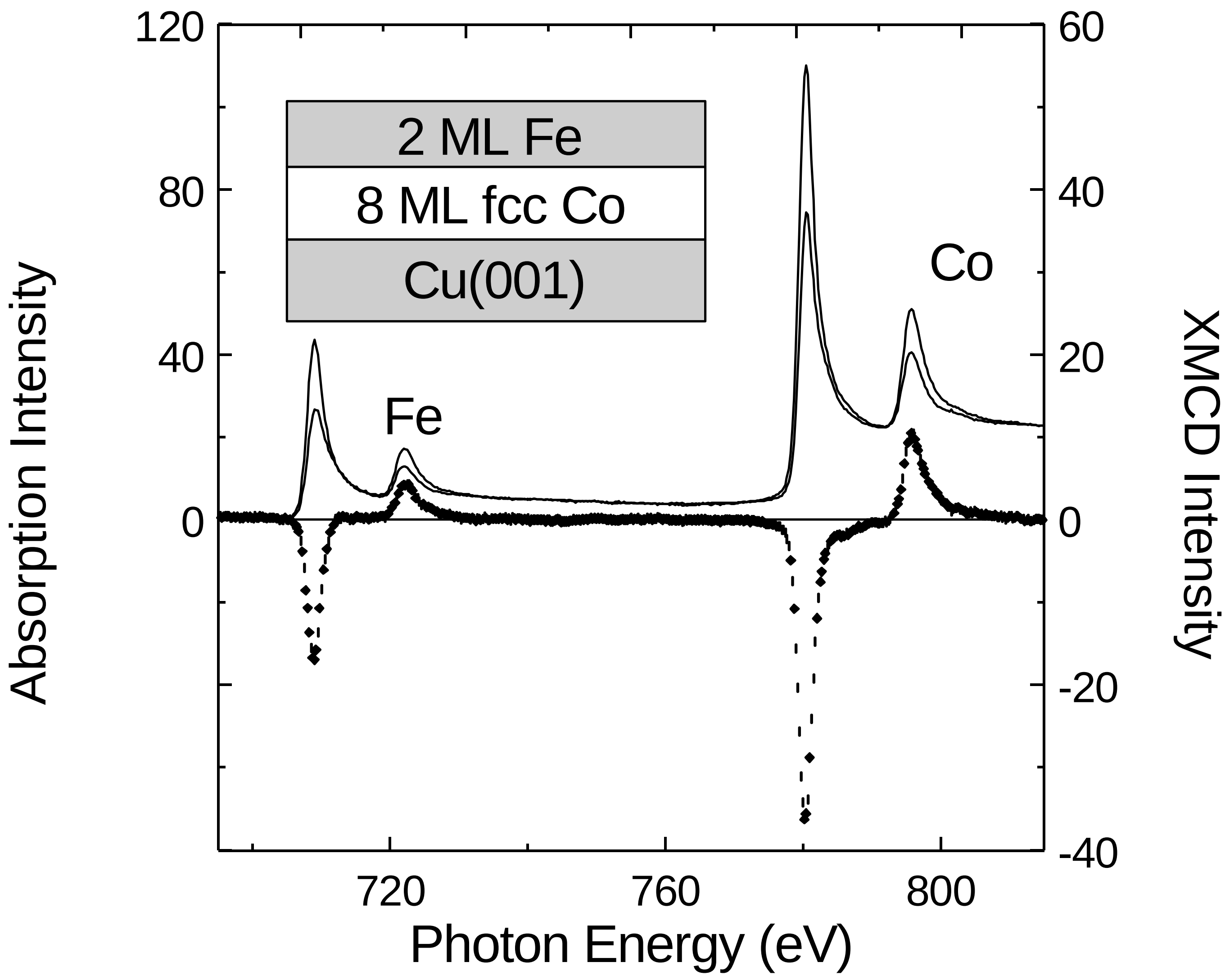


The technique of X-ray Magnetic Circular Dichroism (XMCD)



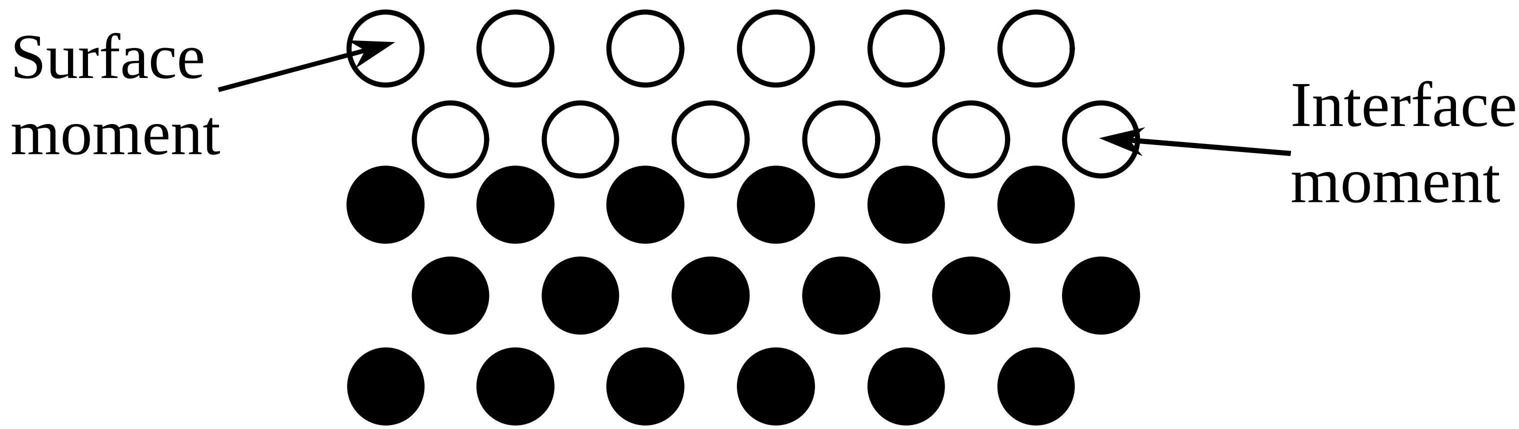
$$I_{XMCD} \propto \vec{\Sigma} \cdot \vec{M}$$

XMCD: Element specific magnetometry



Spin and Orbital Contributions to Magnetic moment

- Total moment is $\mathbf{M}=(\mathbf{L} + 2\mathbf{S})\mu_B$.
- For (Fe, Co, Ni), L/2S is about 1/10, so the orbital moment is small, but….
- Orbital moments contribute signficantly to the magnetic anisotropy (spin-orbit)



Orbital moments may be enhanced at surfaces or interfaces.

Dichroism sum rules

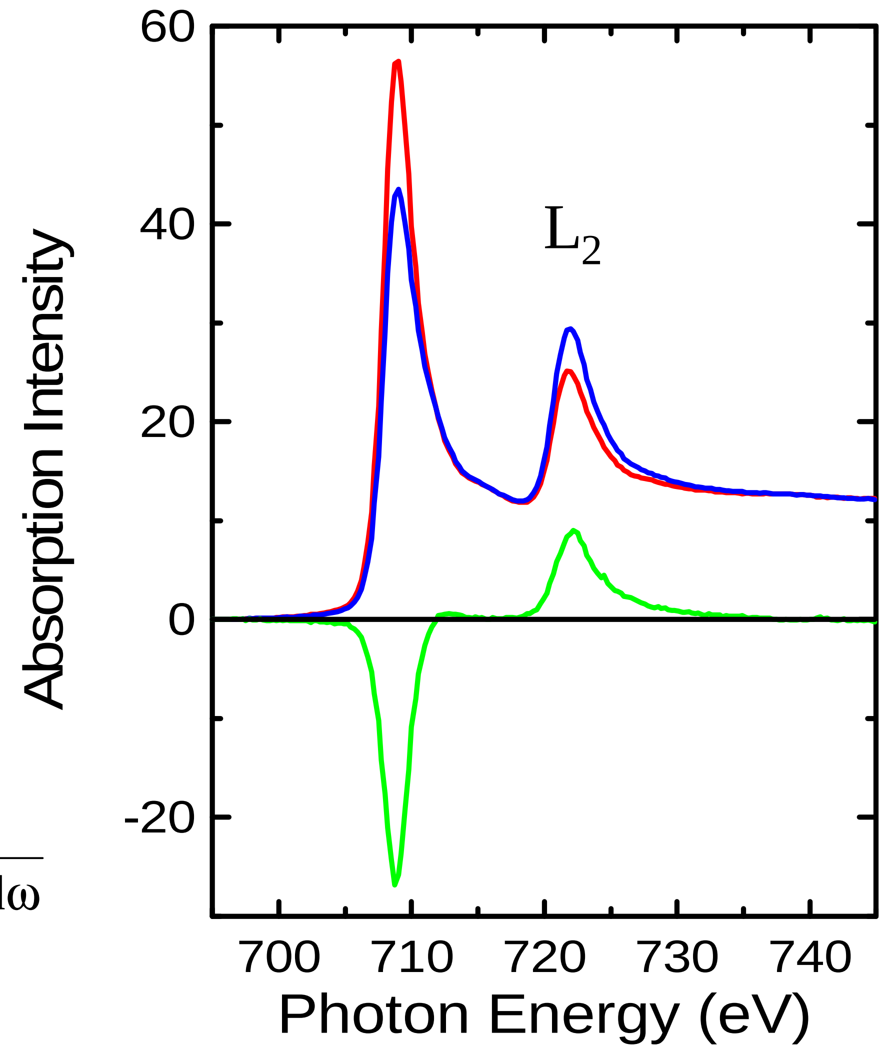
$$M_{orbit} = L_3 + L_2$$

$$M_{spin} = |L_3| + 2|L_2|$$

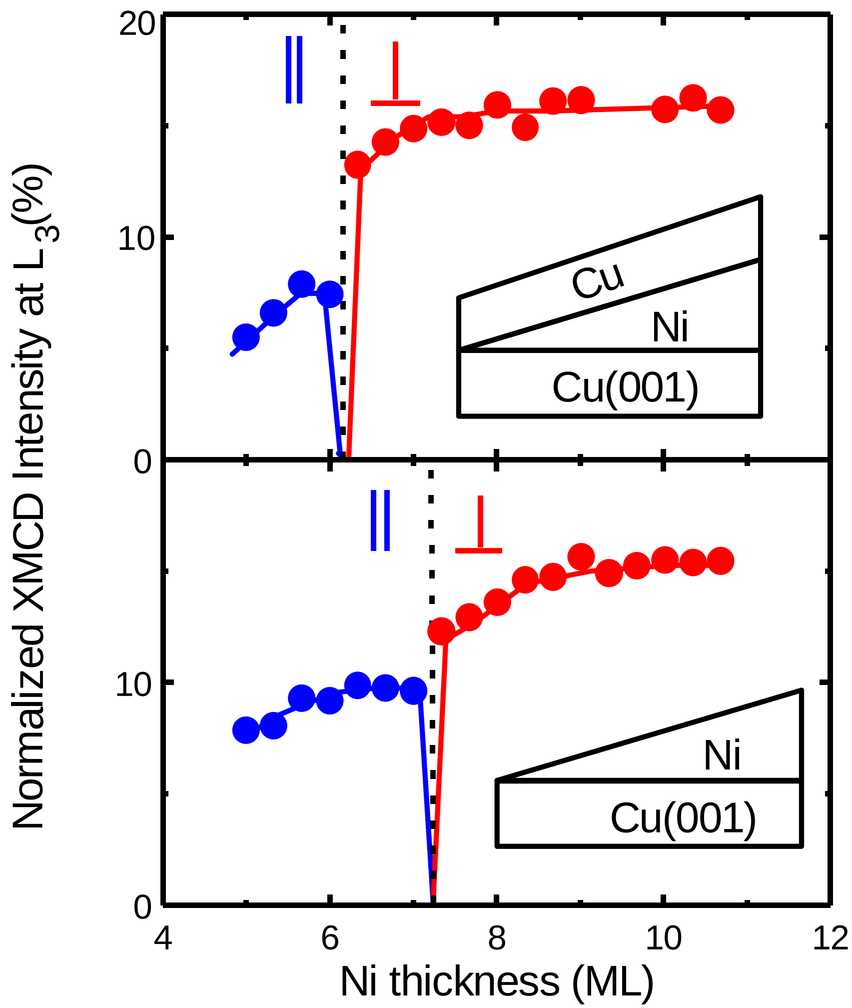
$$M_o = \frac{4}{3} h \frac{\int_{L_{2,3}} \sigma_M d\omega}{\int_{L_{2,3}} (\sigma_+ + \sigma_-) d\omega}$$

$$M_S + 7M_D = 2h \frac{\int_{L_3} \sigma_M d\omega - 2 \int_{L_2} \sigma_M d\omega}{\int_{L_{2,3}} (\sigma_+ + \sigma_-) d\omega}$$

$$\frac{M_o}{M_S + 7M_D} = \frac{2}{3} \cdot \frac{\int_{L_{2,3}} \sigma_M d\omega}{\int_{L_3} \sigma_M d\omega - 2 \int_{L_2} \sigma_M d\omega}$$



XMCD of Magnetic properties of ultrathin films



Schulz and Baberschke* have already determined K_I+K_S (Interface plus surface anisotropy) to be -0.38 ergs/cm^2

Note this favor *in-plane* M

Using this value and the results presented here we determine that

K_I=-0.16 ergs/cm^2

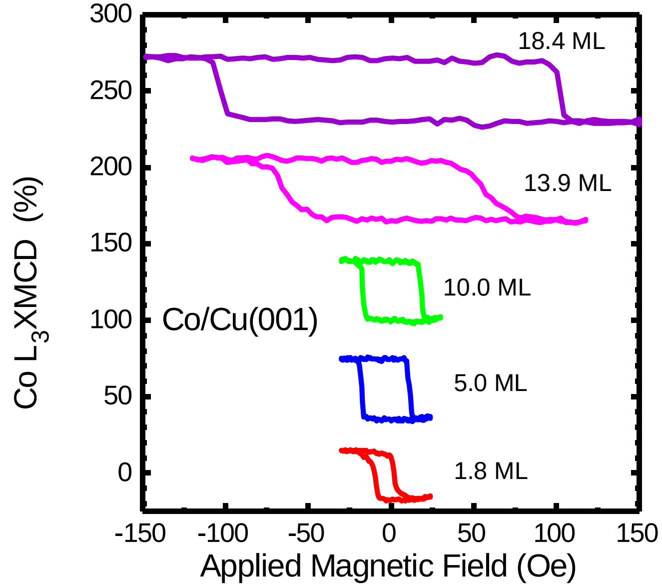
K_S=-0.22 ergs/cm^2

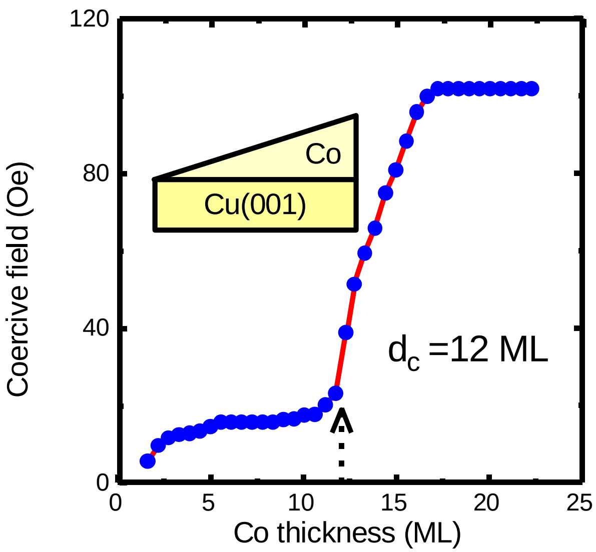
This means: both interface and surface anisotropy are negative.

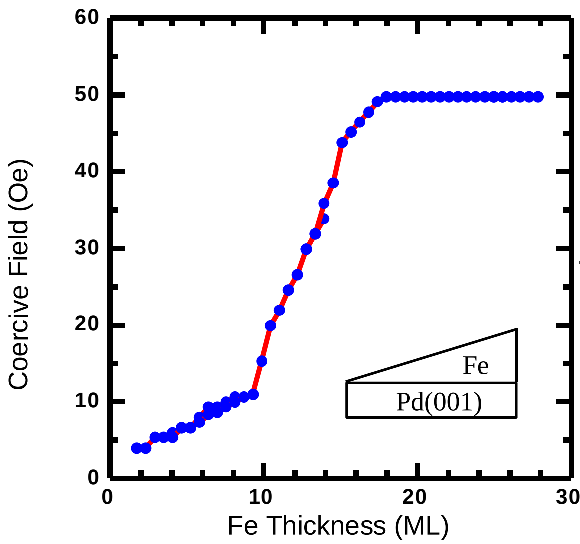
*PRB **50** 13468 (1994).

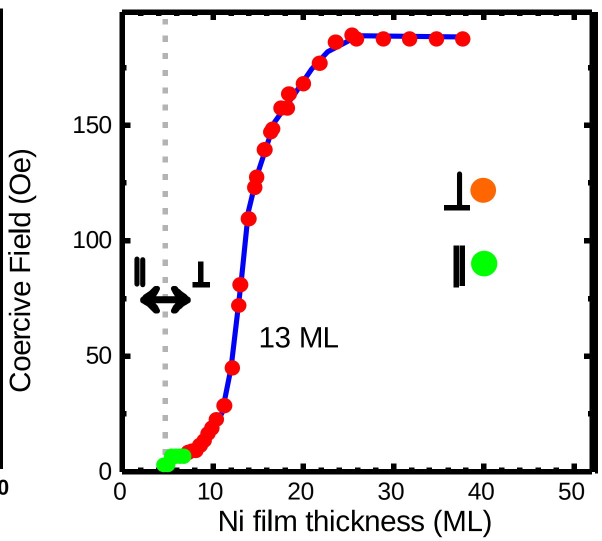
XMCD Magnetometry of Ultrathin films

- Main features are film independent
- Coercivities rise sharply near the critical thickness

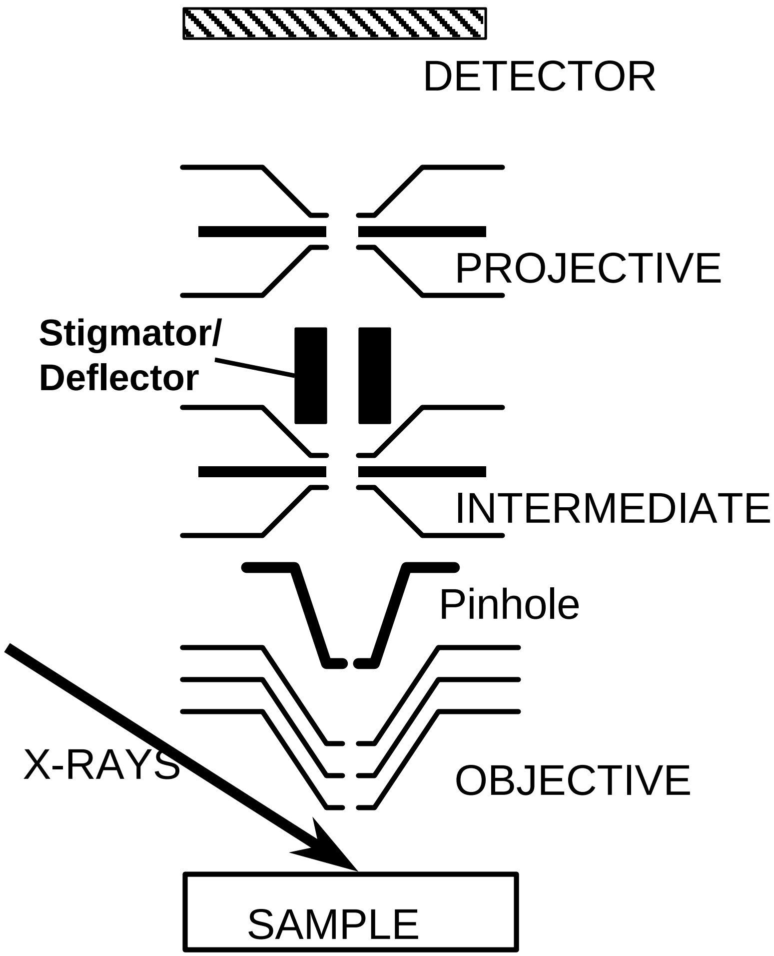


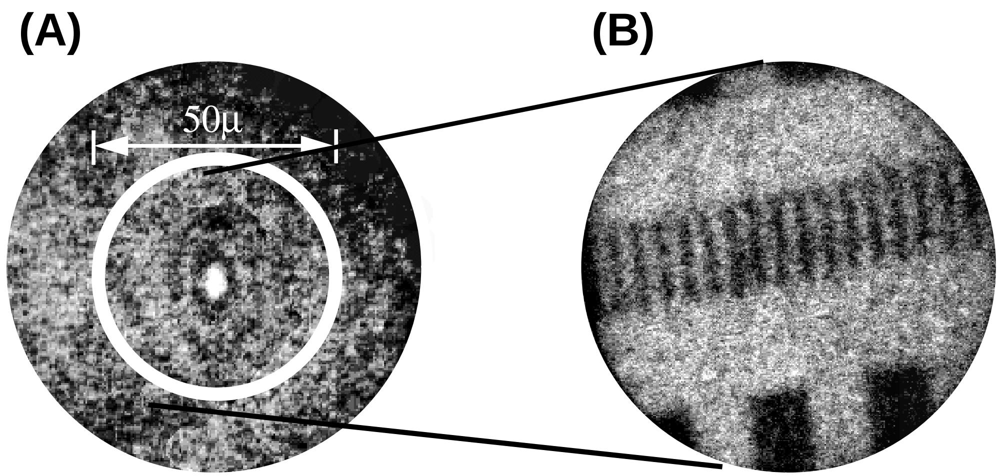






XMCD Microscopy





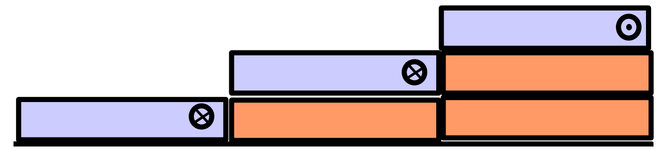
Linear polarization:
Topographical information

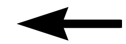
Circular polarization
difference image:
Magnetic bit information

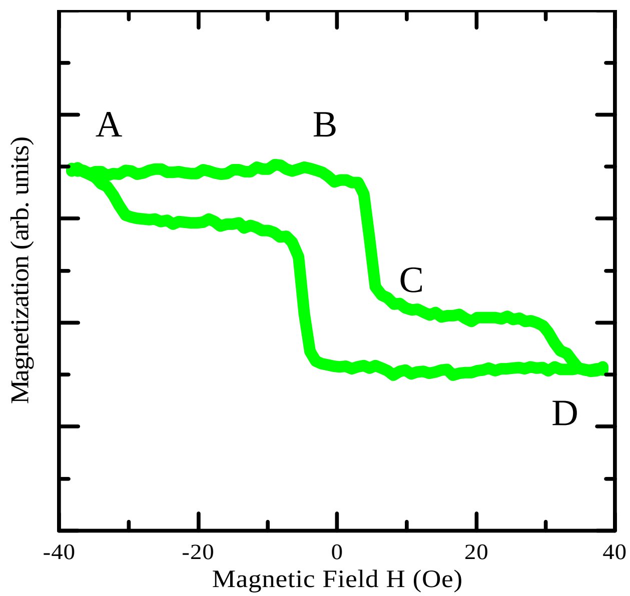
Step bunches can explain anomalous uniaxial anisotropy

Two different sites for atoms

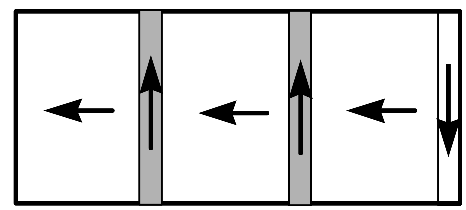
- •near steps - strong uniaxial anisotropy
- •terrace - weaker uniaxial anisotropy (non-zero)



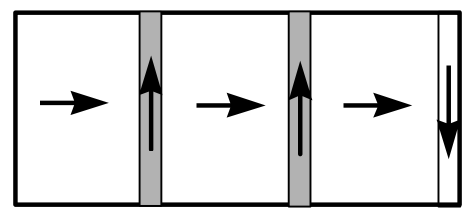
A - fully magnetized 



B



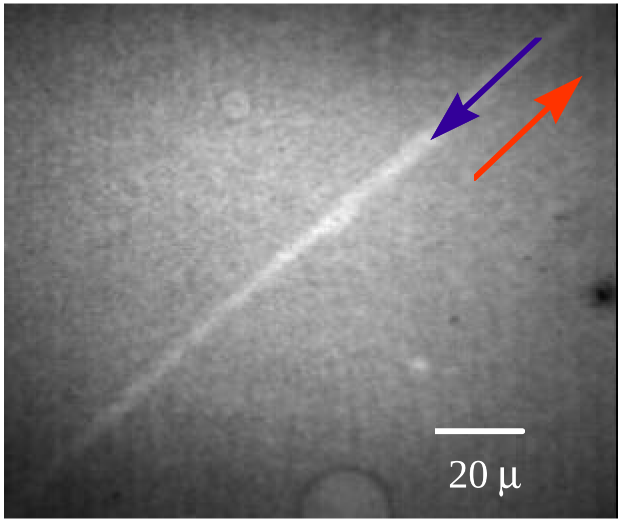
C



D - rotate the step moments full magnetization

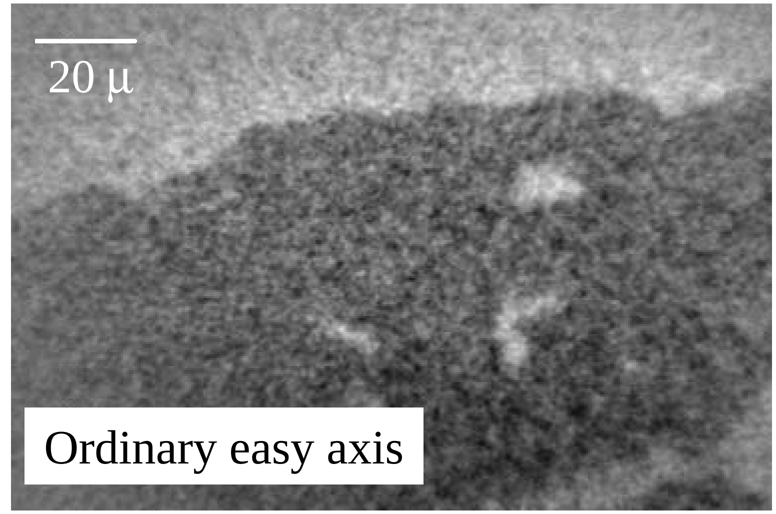
Magnetization Reversal along anomalous axis: Schematic explaining the magnetization reversal along the anomalous "easy" axis of magnetization for miscut fcc Co films. There are two spin sites, a terrace site which has a weak uniaxial anisotropy which may or may not be zero and a step site which has a strong uniaxial anisotropy.

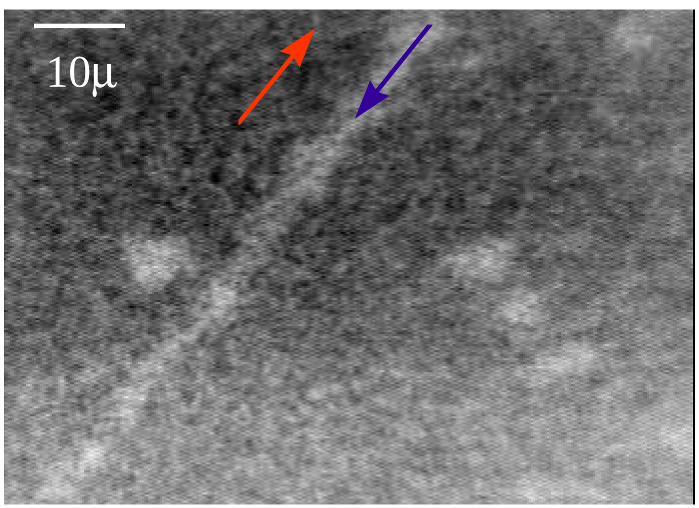
XMCD microscopy of step bunch domains
Co/Cu ultrathin films



Spontaneous domain formation

110 Easy axis





Hard-axis magnetization