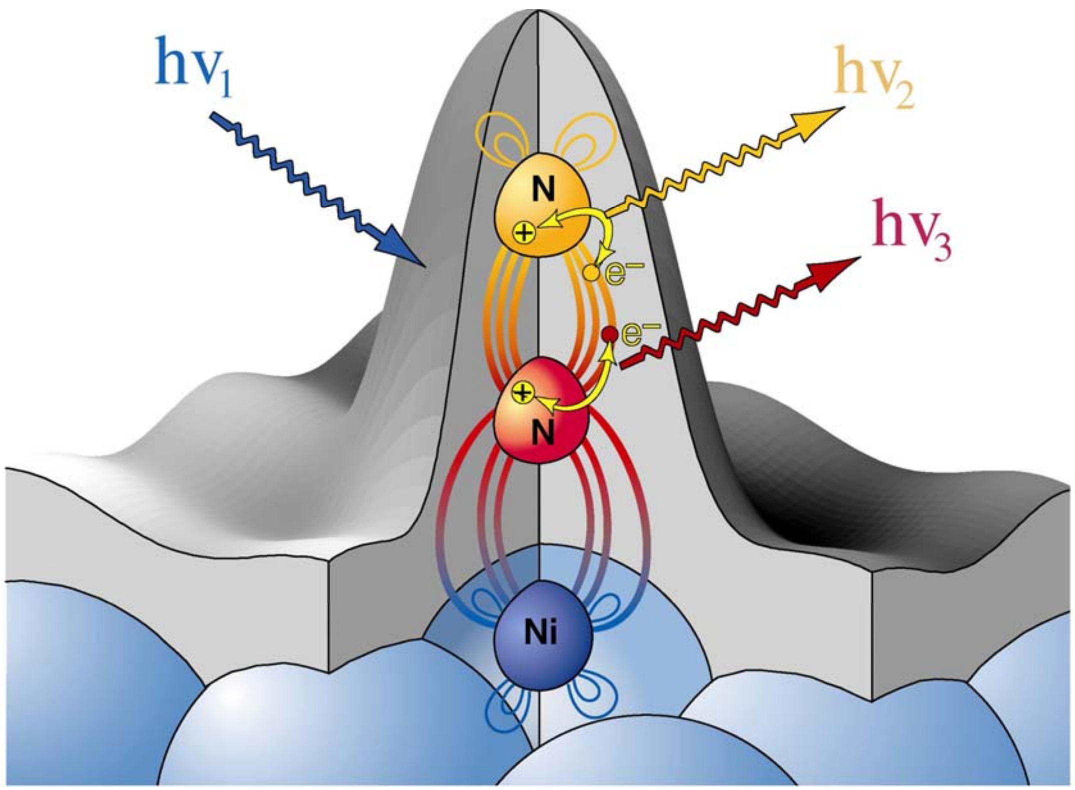
Synchrotron Radiation Interaction with Matter; Different Techniques

Anders Nilsson
Stanford Synchrotron Radiation Laboratory

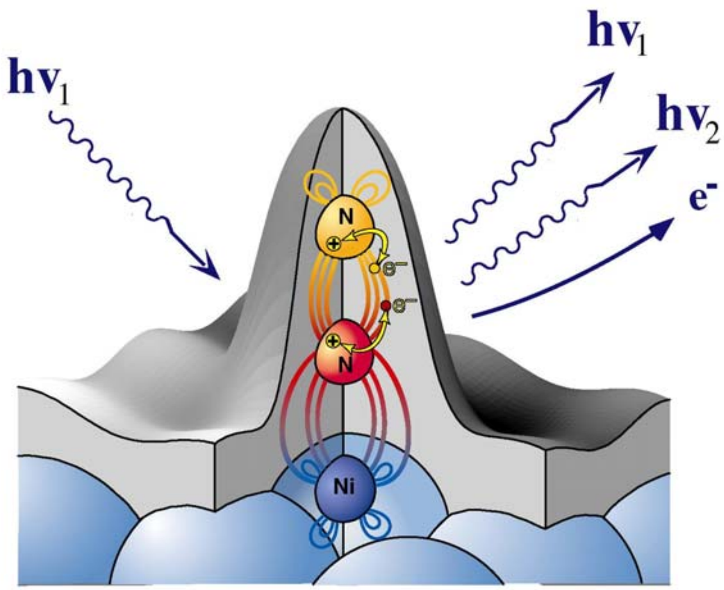


Why X-rays?
VUV?

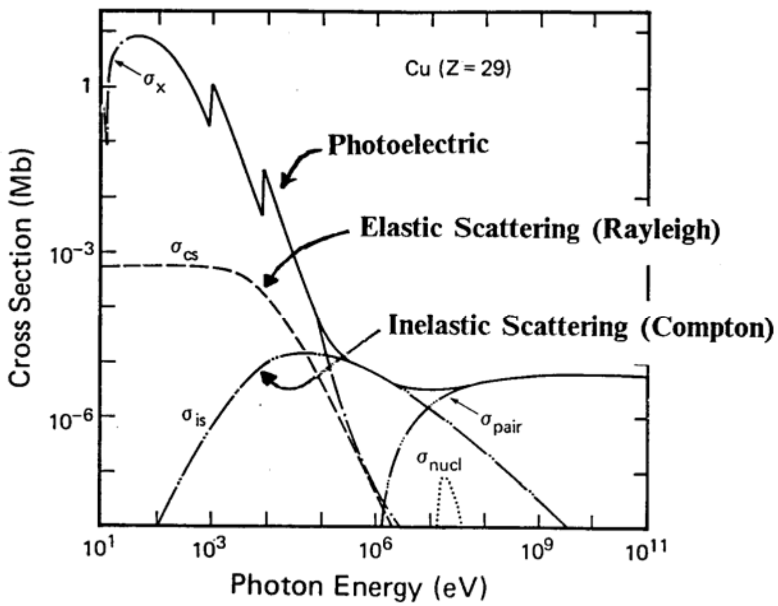
What can we hope to learn?

Photon Interaction

Incident photon interacts with electrons
Core and Valence



Cross Sections



Stöhr, NEXAFS spectroscopy

•Photon is

•Adsorbed

•Elastic Scattered

•Inelastic Scattered

•Electron is

•Emitted

•Excitated

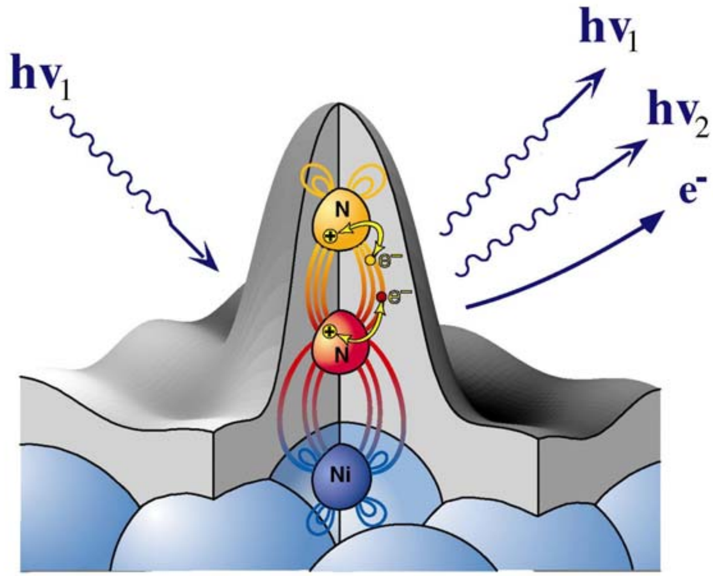
•Dexcitated

Below 100 keV

Photoelectric and elastic cross section dominates

Spectroscopy-Scattering

Detected Particles



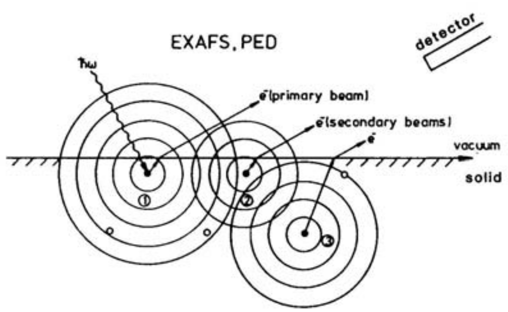
EMITTED PARTICLE

- *Elastic Scattering* X-Diffraction, Speckle
- *Inelastic Scattering* X-ray Emission Spectroscopy
- *Electron Emission* Photoelectron Spectroscopy

NO EMITTED PARTICLE

- *Photon Adsorbed* X-ray Absorption Spectroscopy

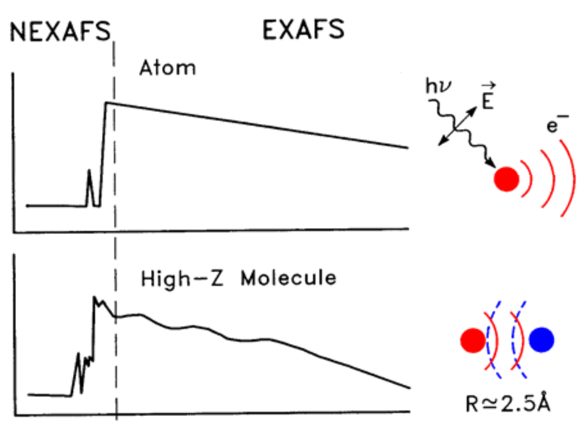
Diffraction



•X-ray diffraction

•Photoelectron diffraction (PhD)

•Extended X-ray Absorption Fine Structure (EXAFS)



Long range *X-ray diffraction*

Interference of many scattered photons

Short range *PhD and EXAFS*

Local scattering of electrons to nearest neighbor

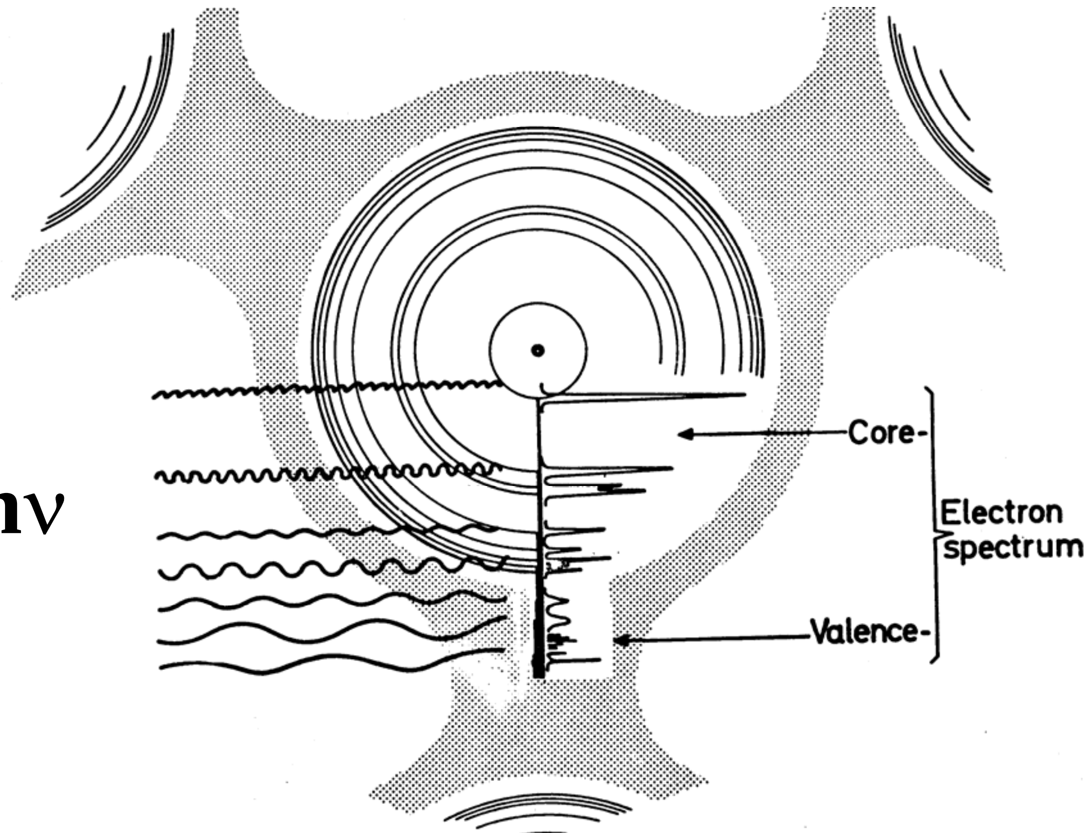
Spectroscopy

Valence electrons ⟶ Chemical Bonding

Core electrons ⟶ Non interacting

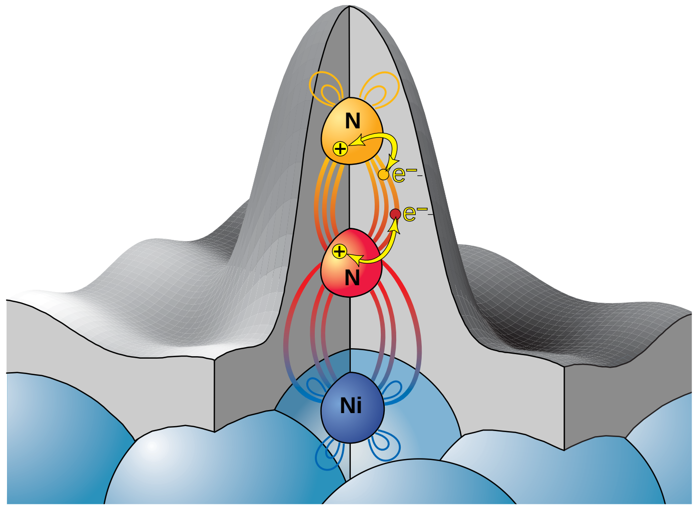
Ionization ⟶ Photoelectron Spectroscopy

hν

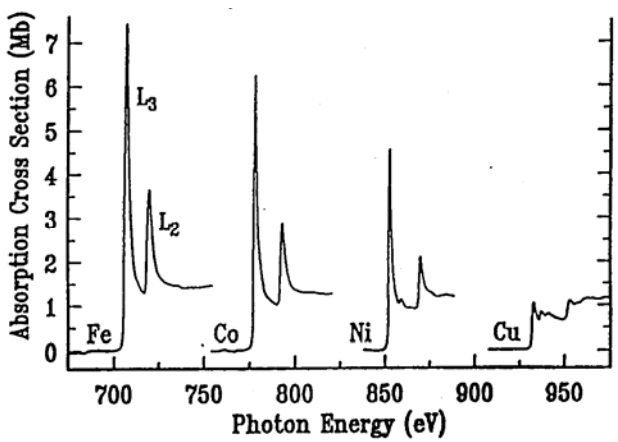


Core Levels-Atom Specific Information

X-rays probes core levels

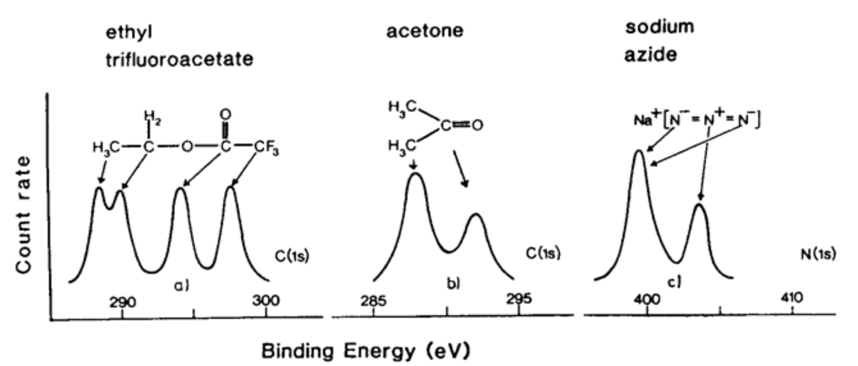


Element Sensitive



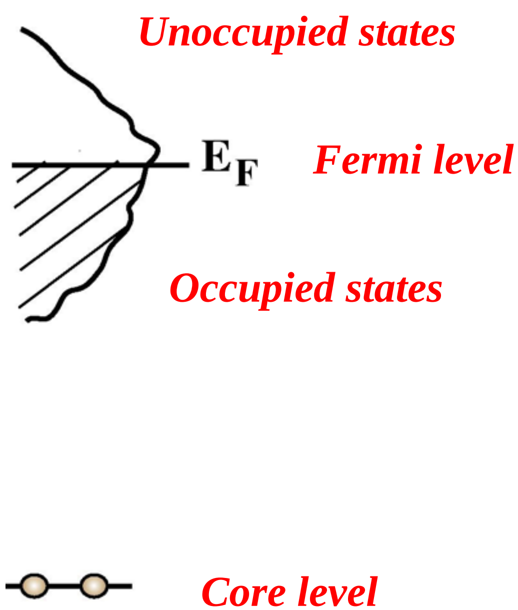
Stöhr et.al

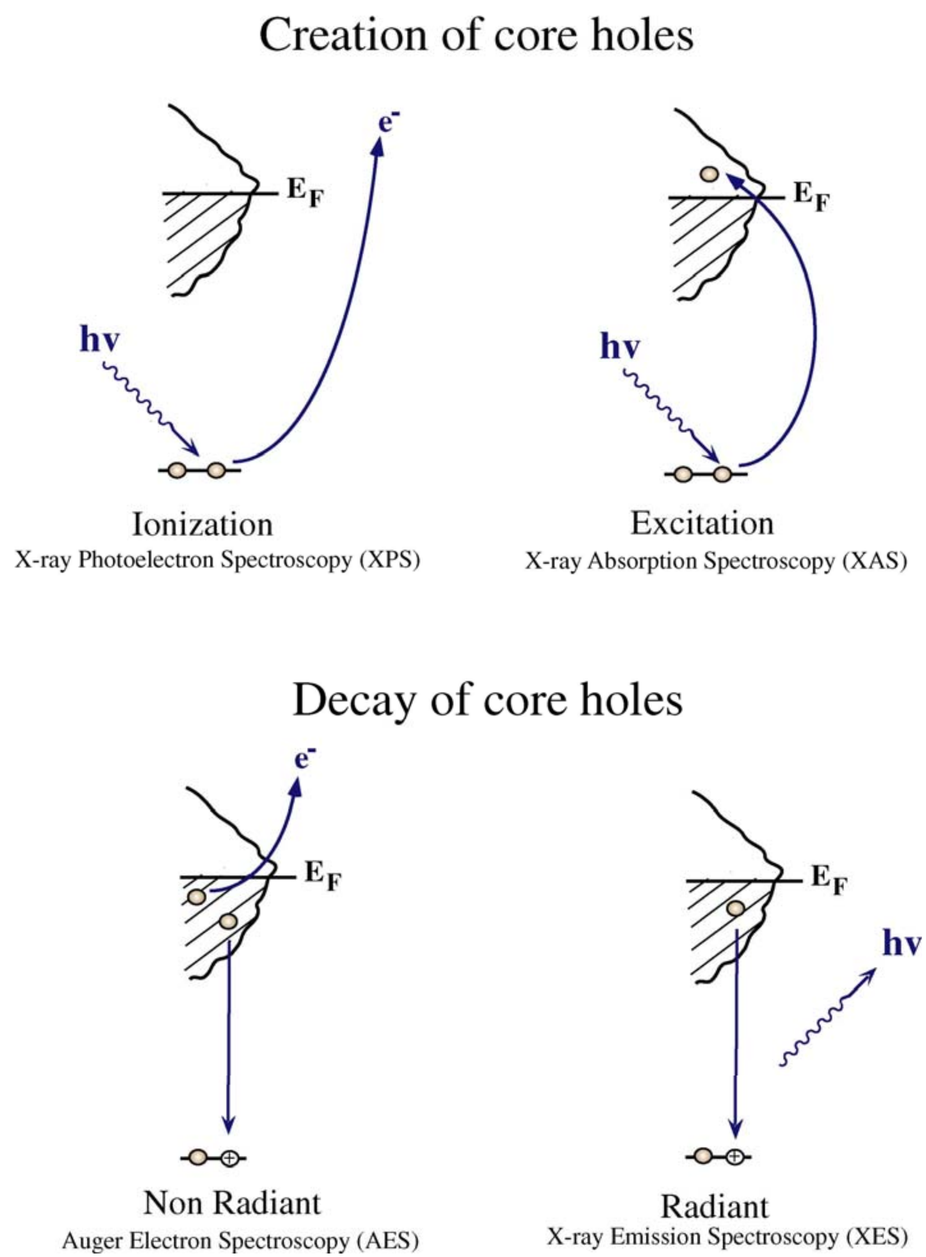
Chemical Shifts



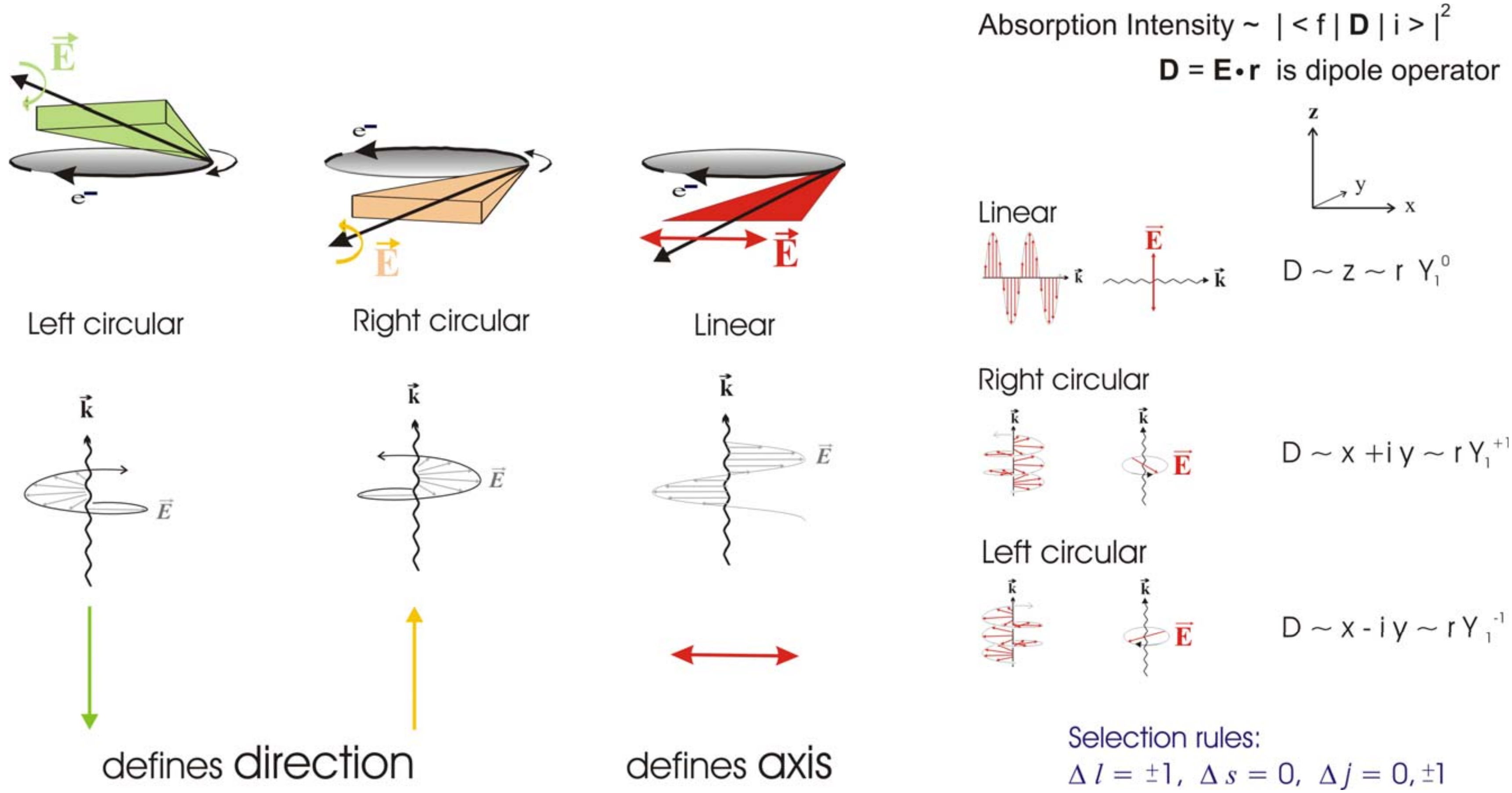
Hufner, Photoelectron Spectroscopy

Core Level Spectroscopy





Polarized X-rays Orientations and Directions

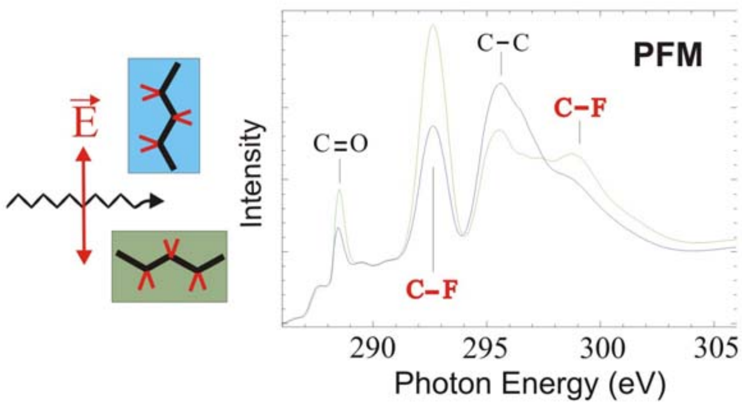


Probing Charge orientations and Spin directions

Polarization Effects in X-ray Absorption

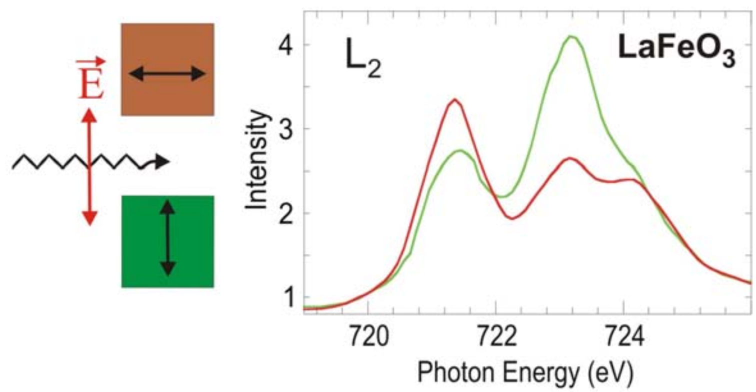
X-ray Linear Dichroism

Stöhr *et al.,* Phys. Rev. Lett. **47**, 381 (1981)



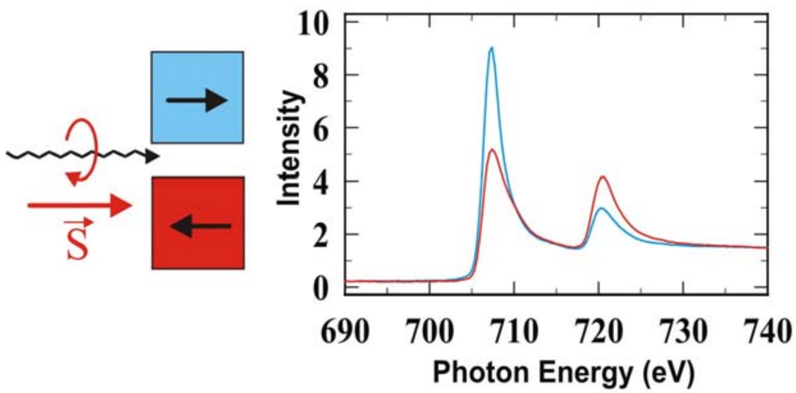
X-ray Magnetic Linear Dichroism

Van der Laan *et al.*, Phys. Rev. B **34**, 6529 (1986)



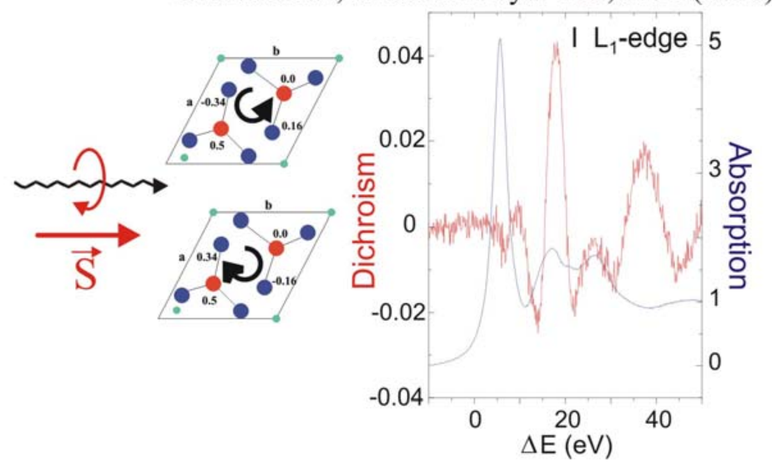
X-ray Magnetic Circular Dichroism

Schütz *et al.,* Phys. Rev. Lett. **58**, 737 (1987)



X-ray Natural Circular Dichroism

Goulon *et al.*, J. Chem. Phys. **108**, 6394 (1998)



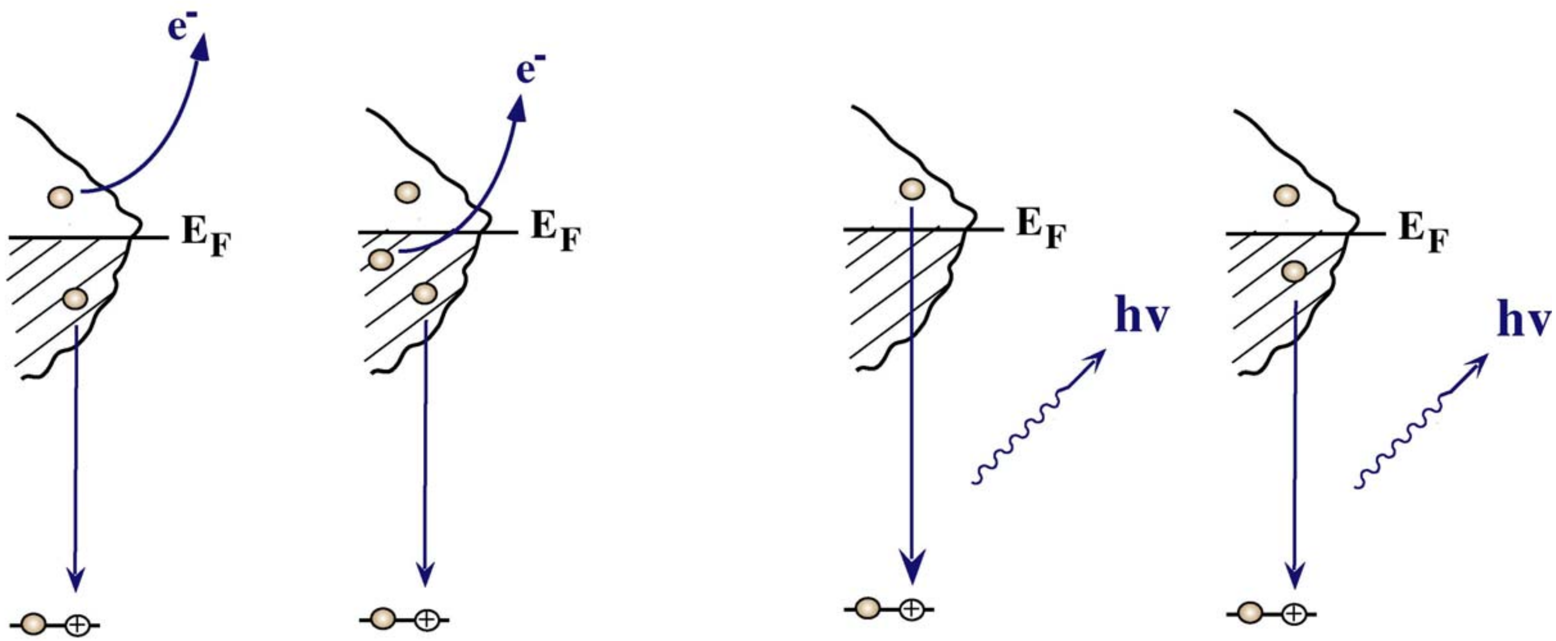
Resonant Processes

Non Radiant

Resonant Photo-Electron Spectroscopy (RPES)
Resonant Auger Spectroscopy (RAES)
Autoionization Spectroscopy (AIS)

Radiant

Resonant Inelastic X-ray Scattering (RIXS)
Resonant X-ray Emission Spectroscopy (RXES)



Participator decay
one hole final state

Spectator decay
two hole-one particle final state

Participator decay
Recombination process
ground state

Spectator decay
one hole-one particle final state

Methods

- X-ray Diffraction
- Photoelectron Spectroscopy (PES)

Core level electron spectroscopy

Valence band photoemission

Resonant photoemission

Photoelectron Diffraction

- X-ray Absorption Spectroscopy (XAS)

Near Edge X-ray Absorption Spectroscopy (NEXAFS)

Extended X-ray Absorption Fine Structure (EXAFS)

X-ray Magnetic Circular Dichroism (XMCD)

- X-ray Emission Spectroscopy (XES)

Resonant Inelastic X-ray Scattering (RIXS)

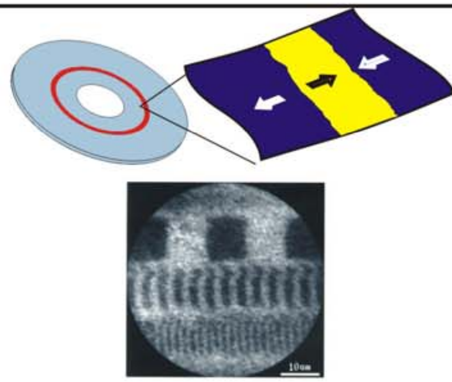
- Soft X-ray Scattering

Speckle

Why are X-Rays so Useful ?

Imaging - Seeing the Invisible

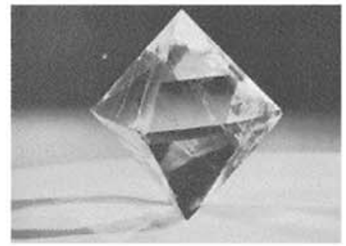
1895

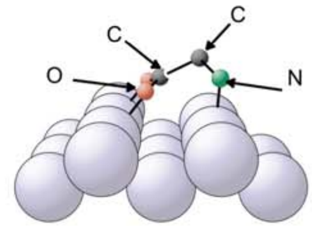


1993

Atomic and Molecular Structure

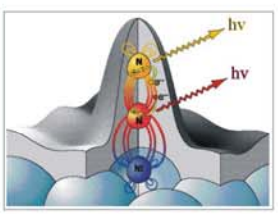
- where are the atoms -

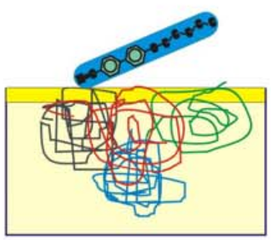


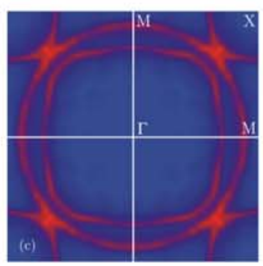


Electronic Structure and Bonding

- where are the electrons -

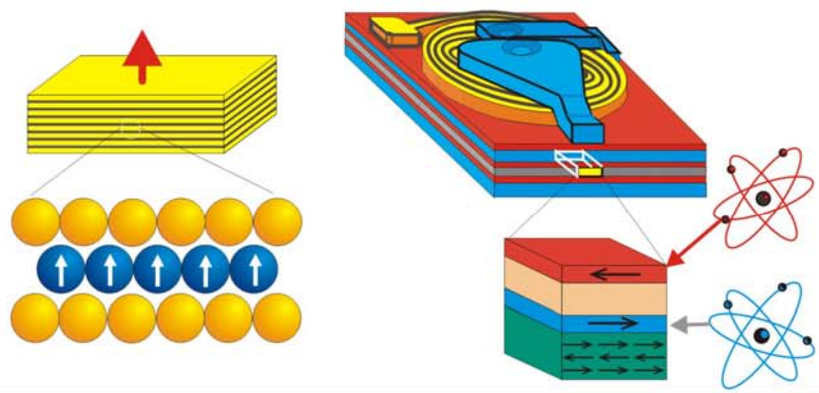




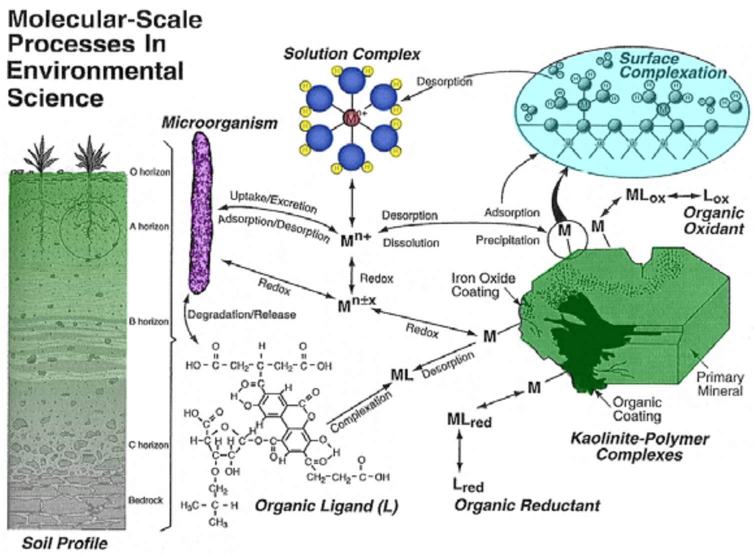


Magnetic Structure and Properties

- where are the spins-

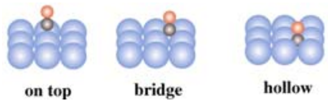


Chemical Analysis

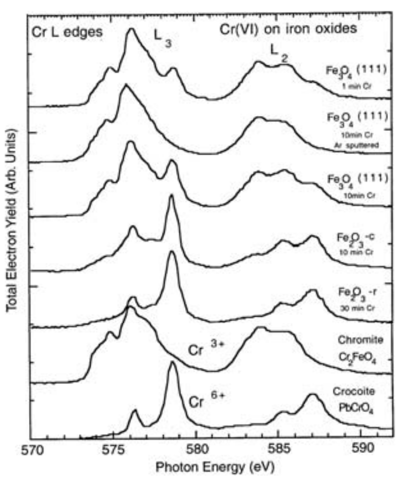


- Chemical Identifications
- Speciation
- Quantitative analysis

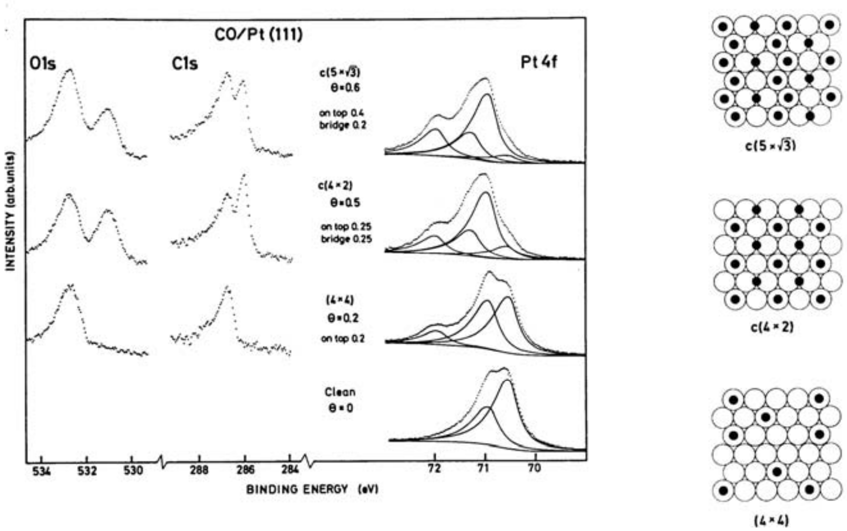
CO adsorption



Cr(VI) on Iron oxides

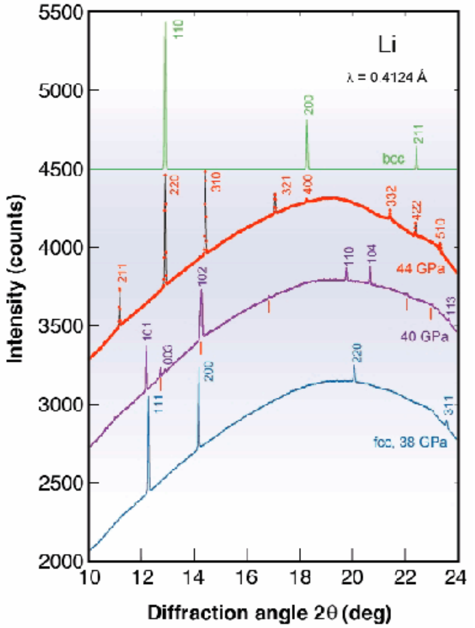


Cr L XAS

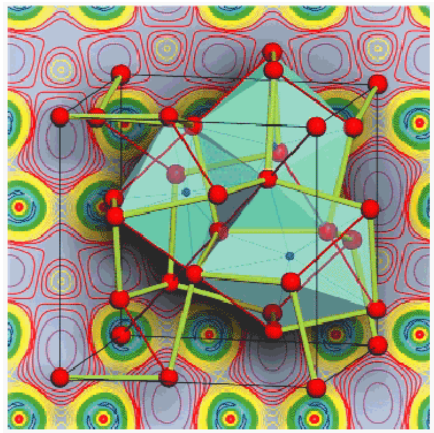


C1s, O1s and Pt4f XPS

Geometric Structure

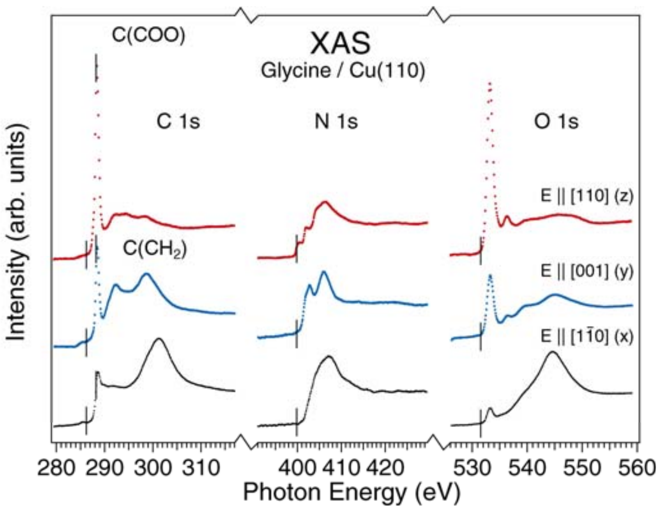


Diffraction pattern of of Li metal

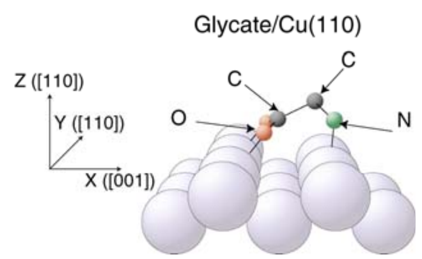


Representation of Li structure at 44 Gpa pressure

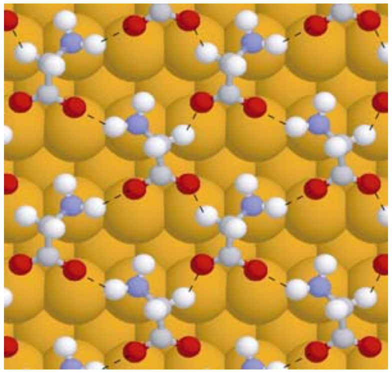
- Lattice parameters
- Bond length
- Molecular orientation



XAS spectra of glycine adsorbed on Cu(110)

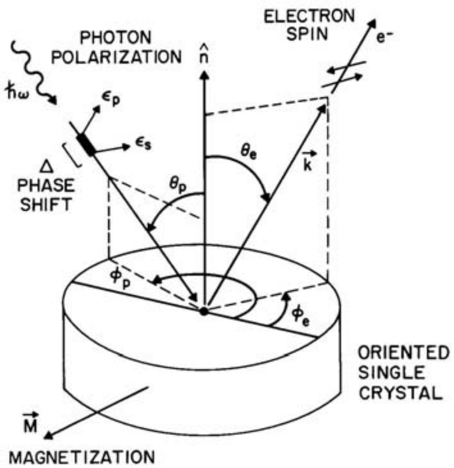


Local orientation of glycine on Cu(110)



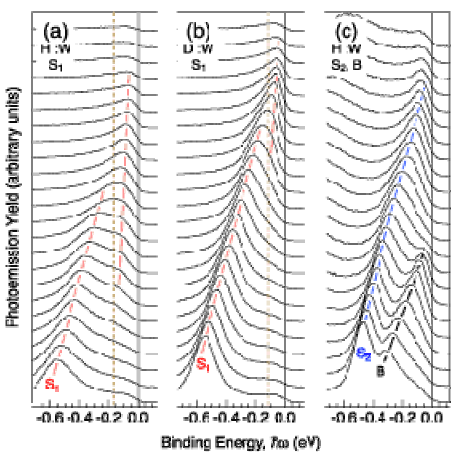
Two dimensional structure of glycine adsorbed on Cu(110)

Electronic Structure

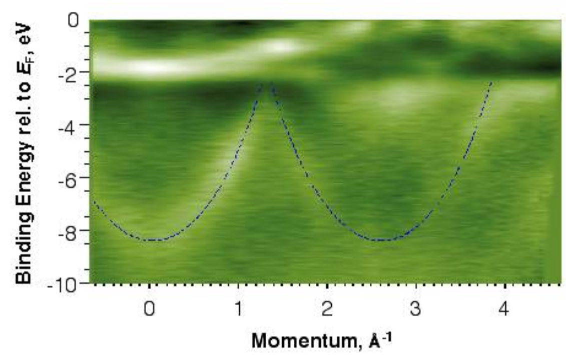


Angular resolved PES

- •Electronic Structure
- •Band structure
- •Electronic properties in complex materials
- •Magnetism

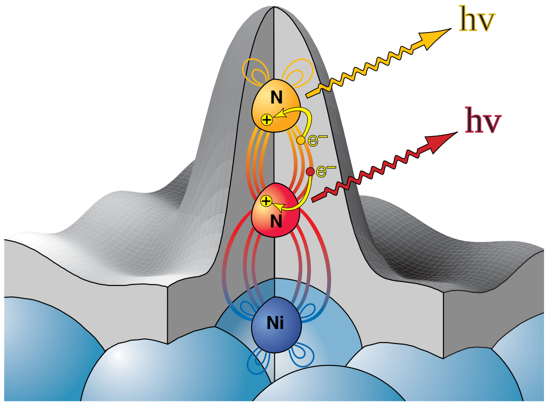


Photoemission spectra of W



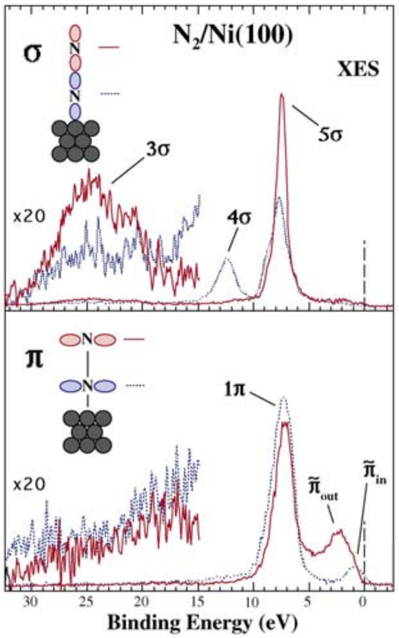
Measured band structure of quasicrystals

Chemical Bonding

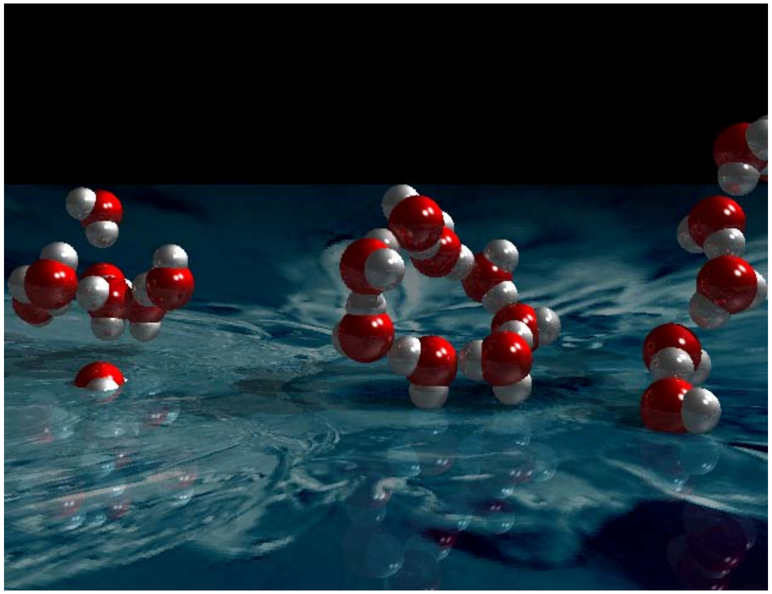


X-ray emission process

- Electronic structure
- Chemical Bonding
- Molecular orbitals
- Local Probing

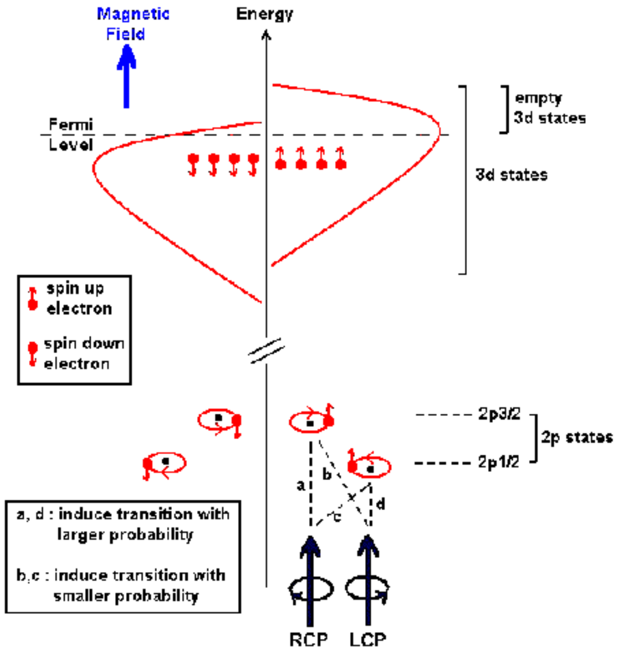


XES spectra of N_2 on Ni(100)

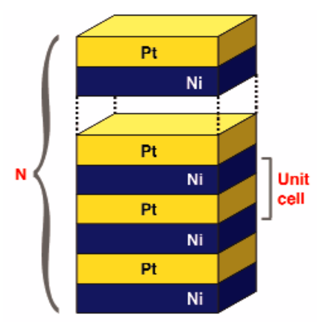


Hydrogen bonding in water

Magnetism

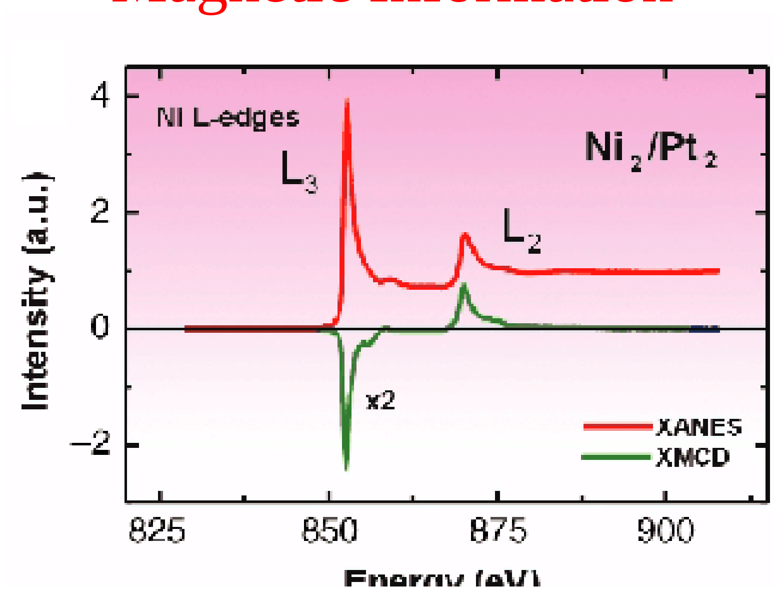


XMCD principle



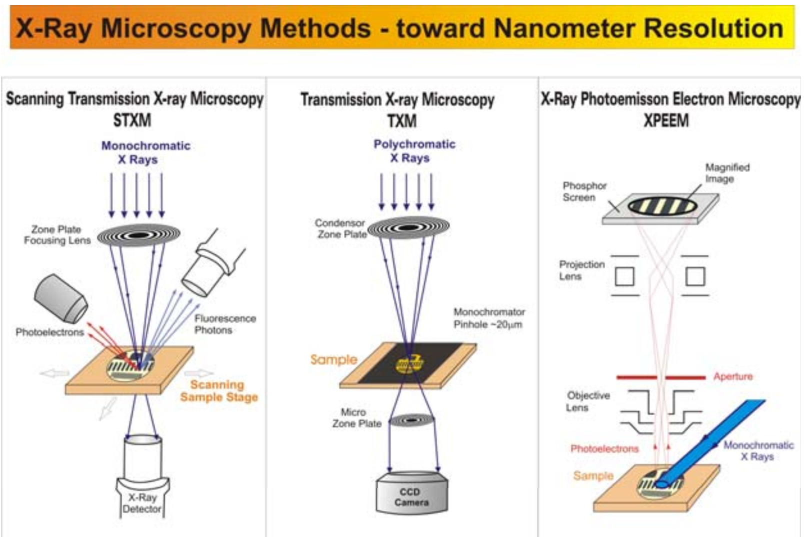
Pt-Ni Multilayer

- X-ray magnetic circular dichroism (XCMD)
- Element specific
- Spin and orbital moments
- Magnetic Information



Ni L edge XAS spectrum and XMCD effect of Pt-Ni multilayer sample

Microscopy

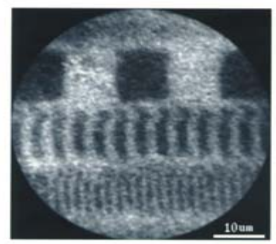


Present resolution in the 20 - 40 nm range

- •Spectroscopy with spatial resolution
- •Spatial chemical speciation
- •Magnetic domains

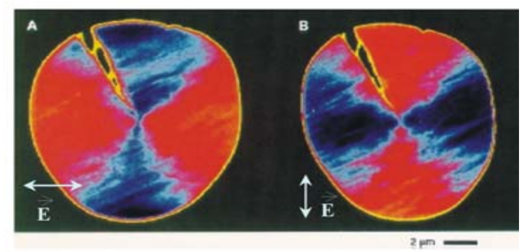
X-Ray Magnetic Circular Dichroism

Stöhr *et al.*, Science **259**, 658 (1993)



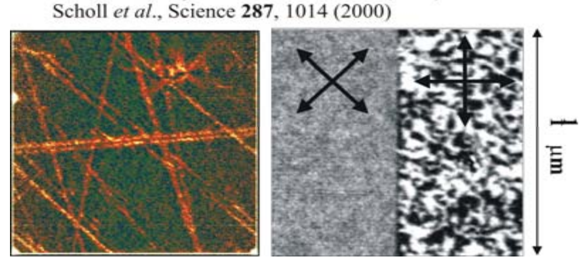
X-Ray Linear Dichroism

Ade and Hsiao., Science **262**, 1427 (1993)



X-Ray Magnetic Linear Dichroism

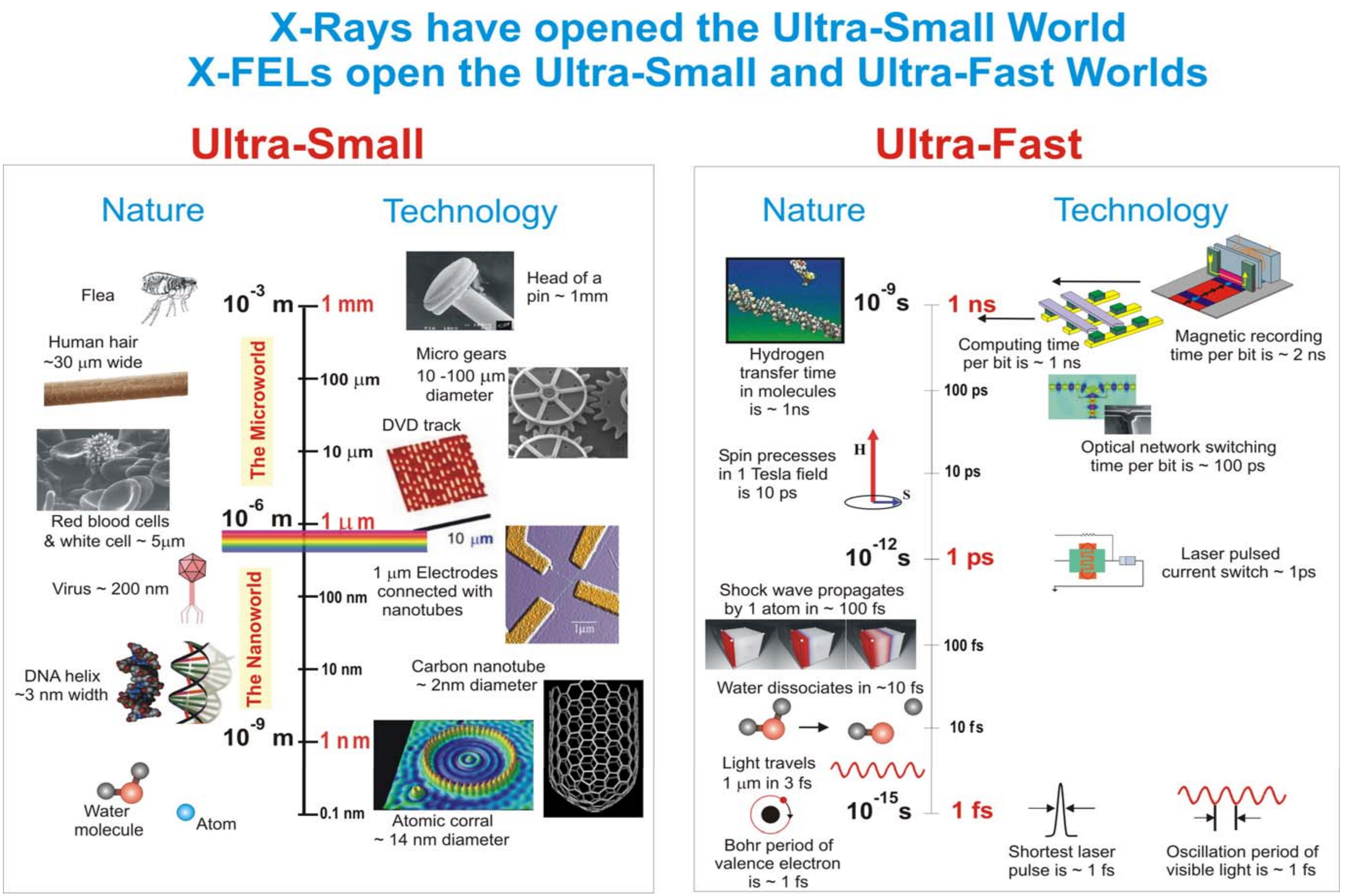
Stöhr *et al.*, Phys. Rev. Lett. **83**, 1862 (1999)
Scholl *et al.*, Science **287**, 1014 (2000)



X-Ray Circular Dichroism

?

Future



X-Rays have opened the Ultra-Small World
X-FELs open the Ultra-Small and Ultra-Fast Worlds
Ultra-Small
Nature
Technology
Flea
Human hair ~30 μm wide
Red blood cells & white cell ~ 5μm
Virus ~ 200 nm
DNA helix ~3 nm width
Water molecule
Atom
10^-3 m
1 mm
100 μm
10 μm
10^-6 m
1 μm
100 nm
10 nm
10^-9 m
1 nm
0.1 nm
The Microworld
The Nanoworld
Head of a pin ~ 1mm
Micro gears 10 -100 μm diameter
DVD track
10 μm
1 μm Electrodes connected with nanotubes
Carbon nanotube ~ 2nm diameter
Atomic corral ~ 14 nm diameter
Ultra-Fast
Nature
Technology
Hydrogen transfer time in molecules is ~ 1ns
Spin precesses in 1 Tesla field is 10 ps
H
S
Shock wave propagates by 1 atom in ~ 100 fs
Water dissociates in ~10 fs
Light travels 1 μm in 3 fs
Bohr period of valence electron is ~ 1 fs
10^-9 s
1 ns
100 ps
10 ps
10^-12 s
1 ps
100 fs
10 fs
10^-15 s
1 fs
Computing time per bit is ~ 1 ns
Magnetic recording time per bit is ~ 2 ns
Optical network switching time per bit is ~ 100 ps
Laser pulsed current switch ~ 1ps
Shortest laser pulse is ~ 1 fs
Oscillation period of visible light is ~ 1 fs