Electron Energy Loss spectroscopy

Electron scattering to study excitations on surfaces and interfaces

Energy exchange: kinetic energy of the electron ⇒ excitation in the materials
Vibrations: localized for molecules delocalized = phonons
Electronic excitaitons: electron-hole pairs, plasmons
Experimental techiniques with different probes: electromagnetic radiation, atoms

Electromagnetic radiation: infrared (IR) spectroscopy, Raman spectroscopy

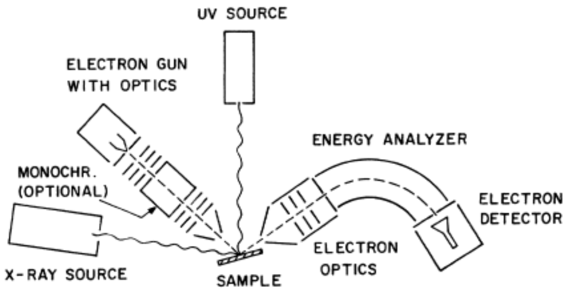
Helium atom scattering.

Electron energy loss

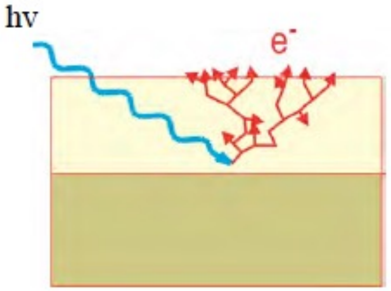
Incident beam energy E_1, anelastic scattering energy $E_2 = E_1 - \hbar\omega_0$

ω_0 vibrational frequency

High energy resolution
Vibration line width less than 1 meV, ideal resolution of our experimental apparatus



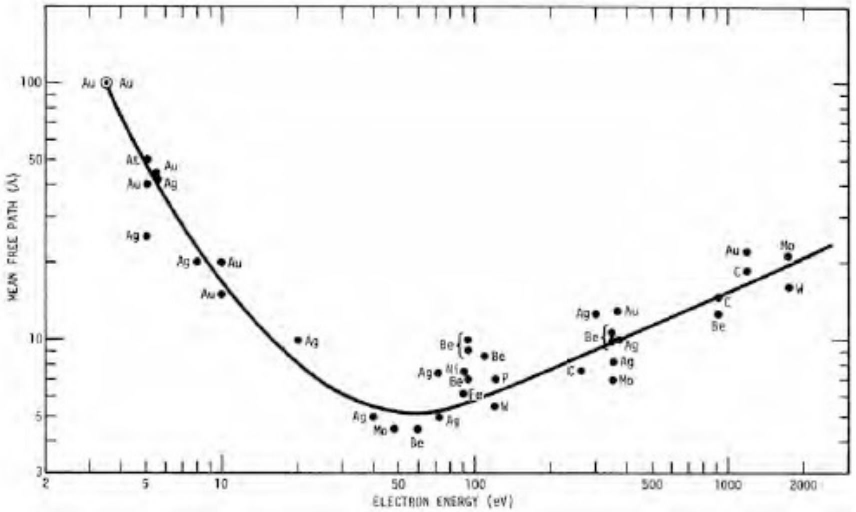
Electron mean free path:



Electrons interact strongly

Surface Sensitivity

5-20 Å



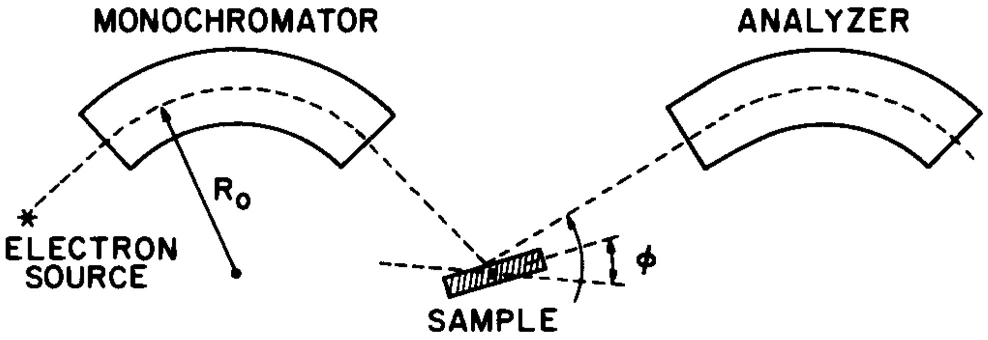
Dependent on electron kinetic energy

UHV to keep the probe in well defined status
Necessita’ di ultra alto vuoto per mantenere il sistema in condizioni controllate.
At 10^{-6} mbar 1 scattering event per second per surface atom
Mean free path of electron in gases

Clean surface preparation:
Sputtering (ion gun), annealing

Thin film deposition

Characterization of the order of the surface LEED Low Energy Electron Diffraction

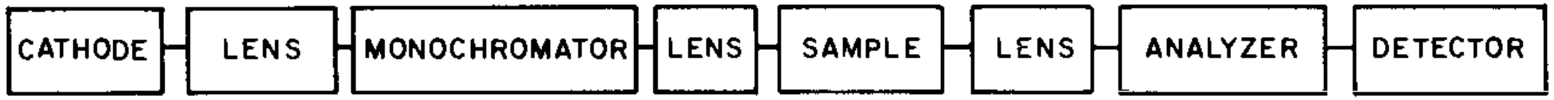


Cathode
Heated filament → Electron emission
WF and Fermi Dirac distribution energy distributio widht kT
Electron acceleration with electric fields

High resolution spectrometer → monocromator
Analyzer with matching resolution after scattering
Analyzer and monochromators based on deflection of electron trajectories in electric fields

Detector after the electron analyzer counting few electrons per second (max 10^6)
Detect single electron.
Electron multiplier(channeltron)
Amplifier, single channel analyzer (discriminator with lower (and upper threshold))
Measurement: number of scattered electrons as afunction of the kinetic energy → energy loss spectrum

High energy resolution for vibrational spectroscopy
Ideally 1 mev energy resolution



Charged particle energy analysis

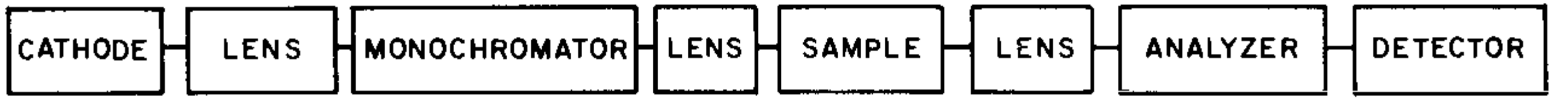
4 methods

Scattering/collision with resonances

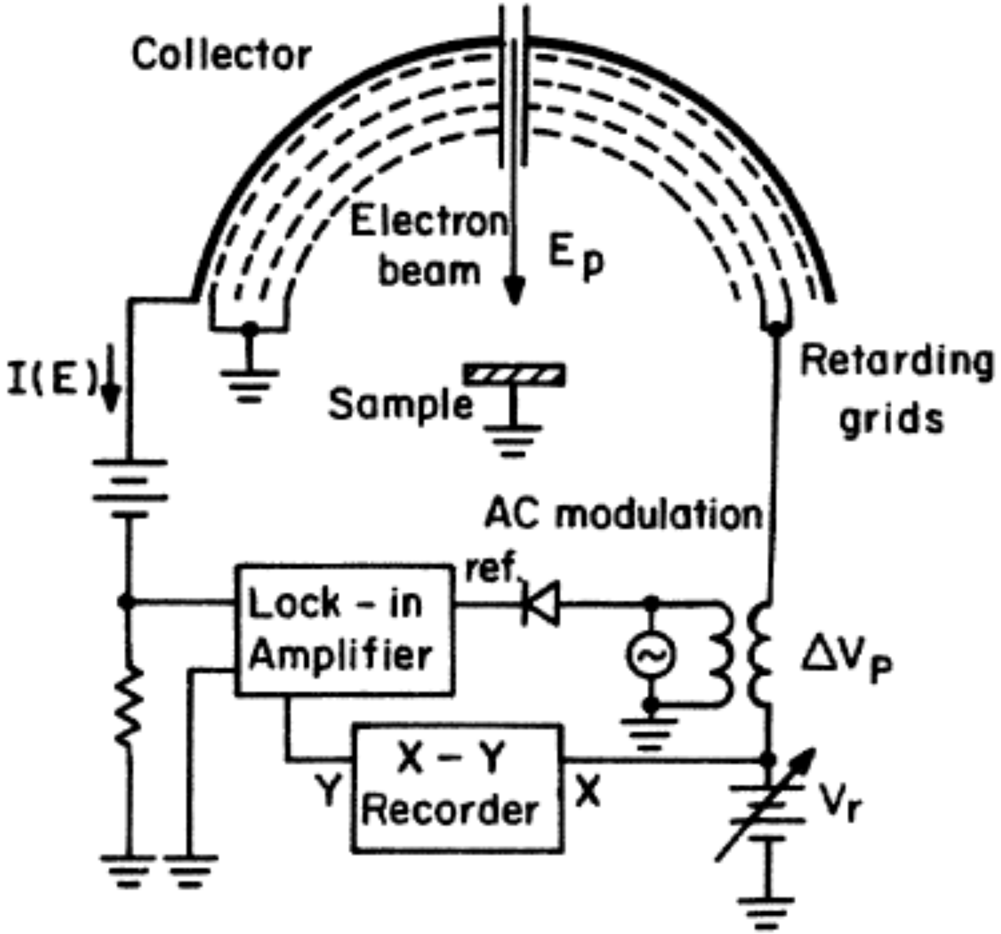
Time of flight measurement

Retarding potential → high pass filter (LEED optics)

Deflection in magnetic or electrostatic fields (or combinations) band pass filter



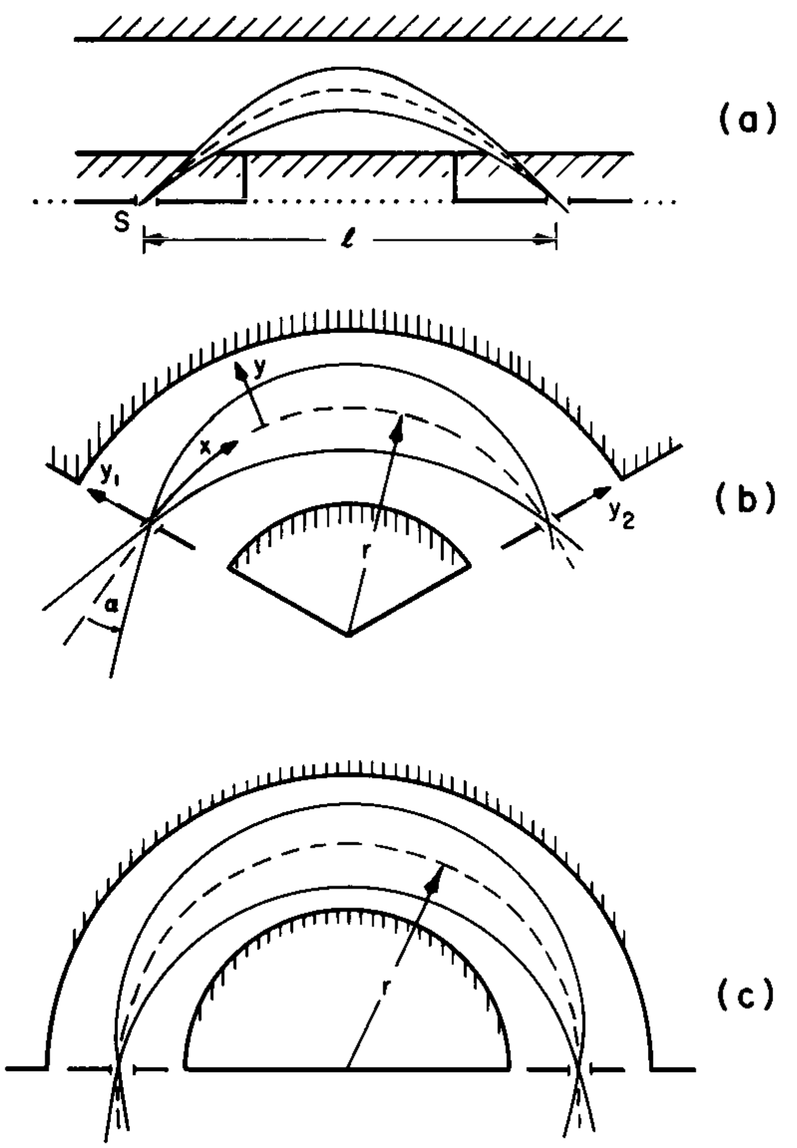
Retarding potential analyzer (LEED optics)

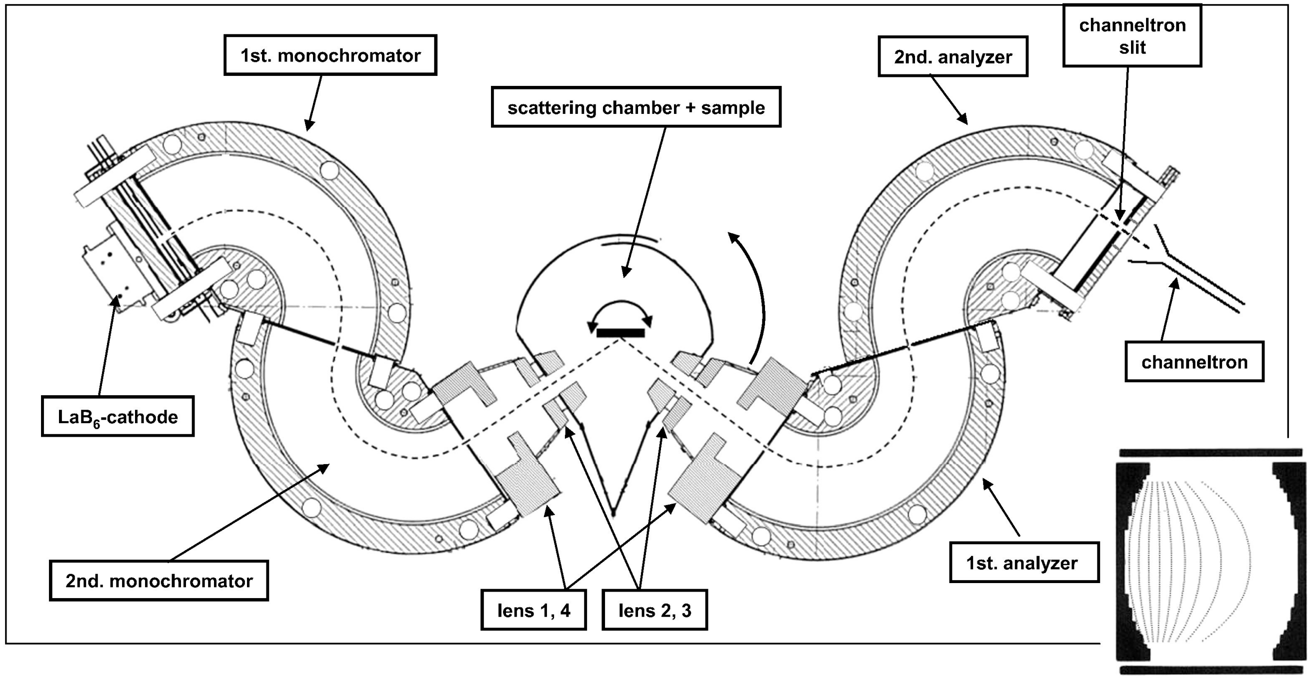


Analyzers based on trajectory deflection in static electric fields

Analyzers:
a) Plane mirror o cilindrica mirror (CMA)
b) Cylindrical deflector
c) Spherical deflector

$$\Delta E_{\mathrm{B}}/E_0 = As + B\alpha^n + C\beta^n,$$




1st. monochromator
scattering chamber + sample
2nd. analyzer
channeltron slit
LaB$_6$-cathode
channeltron
2nd. monochromator
1st. analyzer
lens 1, 4
lens 2, 3

How a deflection analyzer works?

Spherical or cilindrical analyzer

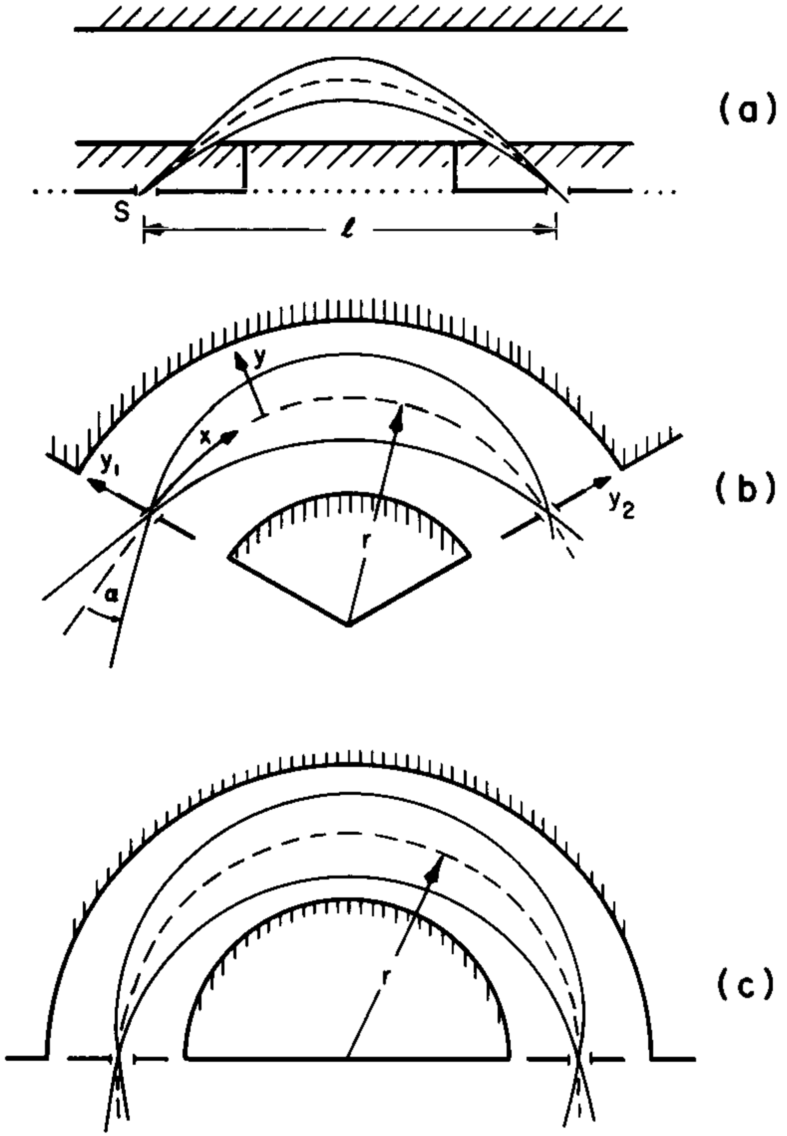
Circular trajectory electrostatic force equal to m x centripetal acceleration

$$mv^2/r = 2E_0/r = e\mathscr{E}_r,$$

For a deflection cilindrical analyzer:

$$\mathscr{E}_r = \frac{\Delta V}{\ln(r_o/r_i)}\frac{1}{r}.$$

$$E_0 = \tfrac{1}{2}e\,\Delta V/\ln(r_o/r_i).$$



First order focalization

$$mv^2/r = 2E_0/r = e\mathscr{E}_r, \qquad \mathscr{E}_r = \frac{\Delta V}{\ln(r_o/r_i)}\frac{1}{r}. \qquad E_0 = \tfrac{1}{2}e\,\Delta V/\ln(r_o/r_i).$$

$$y = y_1\cos\left(\sqrt{2}\,\frac{x}{r}\right) + r\,\frac{\delta E}{2E_0}\left(1 - \cos\left(\sqrt{2}\,\frac{x}{r}\right)\right) + \frac{r\alpha}{\sqrt{2}}\sin\left(\sqrt{2}\,\frac{x}{r}\right)$$

Y Radial deviation from central path

$$+\, r\alpha^2\left(\frac{2}{3}\cos\left(\sqrt{2}\,\frac{x}{r}\right) - \frac{7}{24}\cos\left(2\sqrt{2}\,\frac{x}{r}\right) - \frac{3}{8}\right).$$

$$x_f = r\pi/\sqrt{2}, \qquad \phi = \pi/\sqrt{2} \cong 127^\circ$$

$$y_2 = -y_1 + r(\delta E/E) - \tfrac{4}{3}r\alpha^2$$

$$\delta E_+/E_0 = (s/r) + \tfrac{4}{3}\alpha_i^2 \qquad \delta E_-/E_0 = -s/r \qquad \Delta E_B/E_0 = 2s/r + \tfrac{4}{3}\alpha_i^2.$$