EE 213, Microscopic Nanocharacterization of Materials
Lecture 8.
other micro-characterization using charged particle beams
Class website: https://ee213-winter16-01.courses.soe.ucsc.edu

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Crystal Spectrometer geometry

Bent to radius 2R
**Henry Augustus Rowland**

| Born          | November 27, 1848  
|              | Honesdale, Pennsylvania, U.S. |
| Died         | April 16, 1901 (aged 52)  
|              | Baltimore, Maryland, U.S. |
| Nationality  | American |
| Fields       | Physicist |
| Institutions | University of Wooster  
|             | Rensselaer Polytechnic Institute |
|             | Johns Hopkins University |

1st chair of physics at Johns Hopkins University
Figure A.2: Rowland circle geometry
Rowland Circle Arrangement
Generic EMPA/SEM WDS

- Electron gun
- Column/ Electron optics
- Optical microscope
- Scanning coils
- EDS detector
- SE, BSE detectors
- Vacuum pumps
- Faraday current measurement
- WDS spectrometers
WDS Spectrometers

An electron microprobe generally has 3-5 spectrometers, with 1-4 crystals in each. Here, SP4 (spectro #4, LF) with its cover off.

Crystals (2 pairs)

Proportional Counting Tube (note tubing for gas)

\[ n\lambda = 2d \sin \theta \]

where, \( n \) = an integer (1, 2, 3...),
\( \lambda \) = wavelength,
\( d \) = d-spacing of the crystal,
and \( \theta \) = incident angle (measured from crystal surface)
Over the course of the first 30 years of EPMA, ~50 crystals and pseudocrystals have been used.

\[ N\lambda = 2d \sin \theta \]
P10 gas (90% Ar - 10% CH₄) is commonly used as an ionization medium. The X-ray enters through the thin window and 3 things can occur: (1) the X-ray may pass thru the gas unabsorbed (esp for high keV X-rays); (2) it may produce a trail of ion pairs (Ar⁺ + e⁺), with number of pairs proportional to the X-ray energy; and (3) if the X-ray is >3206 eV it can knock out an Ar K electron, with L shell electron falling in its place. There are also 3 possibilities that can result from this new photon:

(3a) internal conversion of the excess energy with emission of Auger electron (which can produce Ar⁺ + e pairs); (3b) Ar Ka X-ray itself can knock out electron of another Ar molecule, producing Ar⁺ + e pair; or (3c) the Ar Ka X-ray can escape out thru a window, reducing the number of Ar⁺ + e pairs by that amount of energy (2958 eV)
2. Li Drifted Si, energy detector

Li acts as donor to compensate for impurity acceptor levels (B)
- results intrinsic region
- e⁻-h⁺ can only be created by external ionizing radiation
- bias the detector to drag e⁻ to 1 side

x-ray absorbed in intrinsic layer, Ex
\[ \text{#e⁻-h⁺ pairs produced} = \frac{E_x}{e} = 3.7 \text{eV in Si} \]

\[ Q = \left( \frac{E_x}{e} \right) e \]

detector has capacitance, so we actually get

\[ V = \frac{Q}{C} = \frac{e}{C} \left( \frac{E_x}{e} \right) \]

pulse hit \( \propto \) x-ray energy \( \rightarrow \) energy detector

we count pulses (one at a time)

assuming Poisson statistics for \( Q \) then

\[ \text{stand. dev. of voltage pulse is } \sqrt{\frac{E_x}{G}} \]

\[ \Delta V = \frac{e \sqrt{E_x}}{C \sqrt{G}} \]

\[ \frac{\Delta E_x}{E_x} = \frac{\sqrt{E_x}}{E_x} \rightarrow \Delta E_x = \frac{\sqrt{E_x}}{E_x} E_x \]

\[ \frac{\Delta E_x}{E_x} = 2.36 \Delta E_x \]

\[ \text{for a Gaussian dist}: \ FWHM = 2.36 \Delta E_x \]
X-Ray Analysis

\[ \text{call } \frac{\text{std.dev}}{N} = F \implies \text{fit Poisson, } F = 1 \]

\[ F = \text{Fano factor} - \text{for Si(Li)} = 0.12 \]

\[ \Delta E_{\text{Si(Li)}} = 1.61 E_{\text{ex}} \text{ in eV} \]

\[ \text{intrinsic energy resolution} \]

but pulses are small, need amplification
-- extra elec. noise

\[ \Delta E_{\text{FWHM}} = \sqrt{(1.61 E_{\text{ex}})^2 + E_{\text{elec}}^2} \]

\[ \text{Exl = 50-100 eV} \]
\[ \text{need to cool to 100 K} \]
\[ \text{to reduce thermal noise} \]

efficiency of detector:

1) solid X

2) windows, metalization layers, dead layer etc.

all of these depend upon the X-ray energy

Z effects:

1) X-ray absorption in these layers resulting in fewer e-h+ produced

2) X-rays of high enough energy can get absorbed in the intrinsic layer

this is similar for all EDX type detectors --
X-Ray Analysis (int)

Consider the efficiency resulting from these various layers

\[ f_{\text{DET}} = \left[ \prod_{\text{ABS,trans}} e^{-\left(\frac{\mu Nt_{\text{det}}}{\mu_{\text{det}}}ight)} \right] \left[ 1 - e^{-\left(\frac{\mu Nt_{\text{det}}}{\mu_{\text{det}}}ight)} \right] \]

product of probability
absorption that a x-ray
in each layer in intrinsic region

NOTE: If we call for a layer of given thickness t, we can do any thickness \( t' \) as

\[ t' = Nt \quad \Rightarrow \quad e^{-Nt} = (e^{-t})^N \]

it is clear that to manage absorption in front layers, want to make them as thin as possible.

best is "window-less" detectors - no vacuum window frame, / probs.

pt. to note / light element detection is poor since x-ray energies are so low - any kind of physical window cuts down on transmission.
Xray Energy (in KeV)

Transmission

Si
0.1 μm

Au
200 A

Be
7.5 μm

0.2
0.5
1
2

Xray Energy (in KeV)
\[ I(E) \propto E \left( \frac{E_0}{E_X} - 1 \right) \times \frac{d\sigma}{d\Omega} \propto z^2 \ln \left[ \frac{1}{E_X} \left( \frac{E_0}{E} + \sqrt{\frac{E_0}{E} E_X} \right)^2 \right] / E_X \]

results normalized at 15 keV

\[ I(E) \rightarrow \text{solid target emission (Kramers, 1923)} \]

\[ \frac{d\sigma}{d\Omega} \rightarrow \text{semi-classical electron slowing down (Jackson, 1962)} \]

--- Figure 2. ---
Continuum Radiation from charged particles

\[
\frac{d\sigma}{dE}_{Br} = \frac{3.2 \times 10^{-27} Z^2 z^4}{\beta^2} \left(\frac{M_E}{M}\right)^2 \frac{\ln\left[\frac{1}{E_x} \left(\sqrt{E_0} + \sqrt{E_0 - E_x}\right)^2\right]}{E_x} \quad \text{in cm}^2/\text{eV}
\]  

(1)

where \(\beta = v/c\), \(M_E\) is the electron mass, \(Z\) is the atomic number of the target atom, \(z\) is the atomic number of the incident particle. For electrons as the colliding particle, this reduces to:

\[
\frac{d\sigma}{dE}_{Br} = \frac{3.2 \times 10^{-11} Z^2}{\beta^2} \frac{\ln\left[\frac{1}{E_x} \left(\sqrt{E_0} + \sqrt{E_0 - E_x}\right)^2\right]}{E_x} \quad \text{in Å}^2/\text{eV}
\]  

(2)

The point to be noted here is that this cross-section (per atom) is orders of magnitude smaller than that of the cross-section for characteristic x-ray production [for the incident electron energies that we will generally be using for microanalysis]. However, if the number concentration of the atoms giving the characteristic x-ray signal is small, then this cross-section can be of comparable magnitude to the characteristic cross-section, thus affecting the detectability.
considerations on fundamental bkg. in ebeam-induced xray spectra


-QM taken into account by taking the particle velocity to be any before and after collision

\[ \Delta E_{\text{avg}} = \frac{[\Delta E_0 + \Delta E_0 - \Delta E_x]}{2m} \]

Note: for electrons

\[ \frac{d\sigma}{dE_{\text{br}}} = \frac{3.2 \times 10^{-11} Z_t^2 Z_i^2}{E_x} \ln \left[ \frac{1}{E_x} \left( \frac{\sqrt{E_0 + \Delta E_x}}{E_x} \right) \right] \text{ in } \text{cm}^2/\text{ev} \]

the "background" for electrons

for any charged particle

\[ \frac{d\sigma}{dE_{\text{br}}} = \frac{3.2 \times 10^{-11} Z_t^2 Z_i^2}{E_x} \left( \frac{M_e}{M} \right)^2 \ln \left[ \frac{1}{E_x} \left( \frac{\sqrt{E_0 + \Delta E_x}}{E_x} \right) \right] \]

\[ Z_t = Z \text{ of target atoms} \]
\[ Z_i = Z \text{ of incident particle} \]
\[ M_e = \text{ele. mass} \]
\[ M = \text{mass of the incident charged particle} \]

Note: we reduce by going to higher energies or by using incident particles of higher mass than Melec.
What is the min unc. we can detect with Xrays \( / \) charged particle induced Xrays

\[
\text{peak signal (cts)} = S_p \tau = N_A J_{\text{tot}} Y_A F_A \tau
\]

\[
S_p \tau = \frac{M_A}{A_{\text{tot}} \mu_p} J_{\text{tot}} Y_A F_A \tau = P_A
\]

\[
\text{logg signal (cts)} = S_{\text{bg}} \tau = \frac{M_T}{A_{\text{tot}} \mu_p} \int \left[ \frac{d\phi}{dE} \right]_{\text{bg}} dE = P_{\text{back}}
\]

\[
y = 1
\]

\[
P_A \geq \sqrt{P_{\text{back}}} \quad \text{if } \frac{S}{N} = \sqrt{N} \quad \text{Poisson stats}
\]

\[
\text{contrast factor - from Rose}
\]

\[
\text{take the two eqns. 1ST for } M_A, 2\text{nd for } M_T
\]

\[
\text{detected} \quad \text{mass fraction} = MF = \frac{M_A}{M_T} = \frac{A_A}{A_{\text{tot}}} \left[ \frac{M_T}{M_A} \int \left( \frac{d\phi}{dE} \right)_{\text{bg}} dE \right]^{1/2}
\]

\[
2 \text{ pts } / \text{ to decrease } MF/
1. \text{ increase } Y_A, F
2. \text{ decrease } \frac{d\phi}{dE} \text{ bg}
3. \text{ increase } \tau
4. \text{ decrease } \Delta E
\]
Detectable Mass Fraction

Xray detection, EDX

Detectable mass fraction, MF

Atomic number, Z

$E_0 = 100$ keV, $\Delta E = 150$ ev, $t = 100$ sec, $k = 3$

1. $d_e = 1$ nm, 2. $d_e = 10$ nm

$T_{substance} = 100$ nm
so what strategy to reduce min. det. conc.

- Note: $M_t J = \left[ \frac{\pi I d^2}{4} \right] \left[ \frac{I_p}{\pi d_b^2} \right]$

  \[= \frac{C_t I_p}{\pi} \quad \text{decreasing beam size doesn't reduce MF} \]

  but increasing $I_p$ does reduce MF.

- Increasing the counting time, $T$, reduces MF.

- $\frac{\Delta E}{E}$ reduction helps — depends on detector

- Increasing $\gamma_0$ helps — depends on process we choose

- $\frac{\partial E}{\partial E} \propto \frac{1}{\beta^2 (\text{Minc})^2}$ so increasing the velocity

  of the particle or

  increasing its Minc helps also!

As we will discuss all of these:

1. Detectors

2. $\gamma_0 \rightarrow$ if you detect energy for electrons

   rather than x-rays, $\gamma_0 = 1 > W_0$

3. If you use positron irons Minc $\gamma$ so MF $\gamma$

4. Higher energies help somewhat since $\frac{\partial E}{\partial E} \propto \frac{1}{\beta^2}$ but

   $\gamma$ does $\frac{\partial E}{\partial E}$ so not so by an effect
SCATTERING MECHANISMS FOR CHARACTERIZATION

1. UNSCATTERTED
\[ \Delta E = 0, \Delta P = 0 \]
\[ I_{\text{UN}} \]
\[ 0 \leq \theta \leq \theta_0 \]

2. ELASTICALLY SCATTERED
\[ \Delta E \approx 0 \]
\[ \sigma_{\text{EL}} \approx Z^{3/2} \]
\[ \theta_0 \approx \lambda / 2 \pi a \leq \theta_B \]
\[ I_{\text{EL}} \]
\[ [\theta^2 + \theta_0^2]^{-2} \]

3. INELASTICALLY SCATTERED
\[ \theta_E \approx \frac{\Delta E}{P_0 V_0} \]
\[ \sigma_{\text{IN}} \approx Z^{1/2} \]
\[ \frac{d\sigma_{\text{IN}}}{d\Delta E} \text{ material specific} \]
\[ I_{\text{IN}} \]
\[ [\theta^2 + \theta_E^2]^{-1} \]
\[ \Delta E \text{ large, small} \]

EE 213, Nanocharacterization/M.Isaacson
EELS of Nucleic Acid Bases obtained Using 25keV Incident Electrons


Energy Loss Spectra of Metal Fluorides

How to Measure Energy of Energy Loss Electrons?

In X Rays, solid state detector

energy deposited \( \Rightarrow \) e^- h pairs

creates micrope pulse

\[ \Delta E \approx 1.6 \sqrt{E_x} \] resolution

resolution \( \approx \) 100 eV//

If we used same tin electrons,
incident energy \( \approx \) 10^2 keV (in an EM)

If energy lost is 1 keV, then
99 keV electron hits detector.

\[ \Delta E \approx 1.6 \sqrt{99 \times 10^3 \text{ eV}} \approx 500 \text{ eV} \]

so we resort to \( \vec{E}, \vec{B} \) fields which
deflect the electrons – and separate different
energies in space.

\[ \vec{F} = q(\vec{v} \times \vec{B} + \vec{E}) \]

more on this later, but can get \( \Delta E/E \approx 10^{-6} \)!
Rutherford Scattering (Coulomb scatt)

\[ \frac{d\sigma}{d\Omega} \propto \frac{(eZ_0)^2(eZ)^2}{E_0^2} \left[ \frac{4 \left( \cos \theta + \sqrt{1-x^2 \sin^2 \theta} \right)^2}{\sin^4 \theta \sqrt{1-x^2 \sin^2 \theta}} \right] \]

where \( x = \frac{M_0}{M} \) \hspace{1cm} \text{same for RBS}

for electrons \( x \ll 1 \) and \( Z_0 = 1 \)

\[ \frac{d\sigma}{d\Omega} \propto \frac{e^4 Z^2}{E_0^2} \frac{1}{\sin^4(\theta/2)} \]

\[ \text{OK for larger } \theta \]

for electrons/ Ruth Scatt \( \sim \) elastic

\( \text{ie, virtually no energy loss} \)

\[ \Delta E_{\text{max}} \approx \frac{4 Me^2}{M} E_0 \]

\( \text{max. energy that can be transferred} \)

in collision

\[ \frac{Me}{M_0} = 5.46 \times 10^4 \]

\( \text{eg, 100keV electrons} \)

\( \text{Iron, } A = 55.8 \text{amu} \)

\[ \therefore \Delta E_{\text{max}} \approx 3.9 \text{eV} \]
\[
\frac{\sigma_{\text{crit}}}{\sigma_{\text{EL}}} \approx \left( \frac{\lambda}{4 \text{pA}} \right)^2 \left[ \frac{E_m}{E_D} - 1 \right]
\]

Minimum Detectable Concentration, EELS

\[ MF = K A_c \left( \frac{m_B}{M} \right)^{1/2} \frac{e^{nT/2}}{\sigma_p F_p} \]

We assume 100 keV incident electrons. Sample is 1000 Å thick.

All curves assume \( K = 3 \), \( I_e = 1.27 \times 10^5 \) A/m^2 (\( I_e = 10^{-7} \) A/m^2, \( d_e = 10^5 \) Å) and \( T = 100 \) sec.
Single Atom Identification in STEM

STEM Imaging/EELS of individual atoms/defects
From Krivanek, et.al. Ultramicroscopy. (2102) In press
Single Atom Detection by EELS

Senga & Suenaga. Nature Communications. 6.7943 (1915)
so what strategy to reduce min. det. conc.

- Note/Notation: $M_r J = \left[ \frac{\pi d_0^2 \rho T}{4} \right] \left[ \frac{I_P}{\rho d_0^2} \right]$

  $= \rho T I_P \quad \text{decreasing beam size}
  \quad \text{doesn't reduce MF}$

  but increasing $I_P$ does reduce MF.

  - Increasing the counting time, $T$, reduces MF
  - $\Delta E/F$ reduction helps — depends on detector
  - Increasing $Y_\alpha$ helps — depends on process we choose
    - $(dE/d\rho) \propto \frac{1}{\beta^2 (\text{Minc})^2} \quad \text{so increasing the velocity}
    \quad \text{of the particle or}
    \quad \text{increasing its Minc helps also}$

  as we will discuss all of these —

  1. detectors
  2. $Y_\alpha \rightarrow$ if you detect energy for electrons
     rather than x-rays, $Y_\alpha = 1 > W_\alpha$
  3. If you use positrons n.m.o. Minc $\beta$ so MF $\beta$
  4. Higher energies help somewhat since $\frac{dE}{d\rho} \propto \frac{1}{\rho^2}$ but
     so does resistance — so not so big an effect
For ebeam induced Xrays, Concentrations about 0.1-1%

Figure 8.

Minimum detectable concentration for proton induced Xray fluorescence each solid line corresponds to the proton energy in MeV.

The detectable weight concentration of a trace element of atomic number Z in a 0.1mg/cm² carbon matrix.

The concentration calculated assumes peak counts = \(2 \times \sqrt{2 \times \text{background count}}\).

The solid angle that the Si(Li) detector subtends is \(\Omega = 0.003 \times 4\pi\) ster. We assume 100% detector efficiency.

The incident proton charge is 10 mequiv and the signal detailed to Xrays.

Most of the experimental facilities of our laboratory are based on a 5 MV Van de Graaff (VdG) electrostatic accelerator. VdG provides energetic ions (H+, D+, He+, etc.) for ion beam analysis, physical experiments, as well as for the modification and testing of materials.

http://iba.atomki.hu/facilities.html
PIXE Applications and Theory

Elemental Analysis Incorporated, utilizing Proton Induced X-ray Emission (PIXE), provides a non-destructive, simultaneous analysis for the 72 inorganic elements from Sodium through Uranium on the Periodic Table for solid, liquid, and thin film (i.e. aerosol filter) samples. The PIXE technique offers the advantage of analysis, without the necessity for time consuming digestion, thereby minimizing the potential for error resulting from sample preparation.

Sample Types

Solids – such as plastics, papers or metals, are analyzed “as received,” while powdered materials, such as fly ash, activated carbon, catalysts, and corrosion products, are ground to 200 mesh or finer and pressed into pellets for analysis.

Liquid – samples, such as oils, process waters, and solutions, are analyzed using a plastic cup of either 8 mL or 3 mL in capacity with a 0.3 mil Kapton front surface window, and can be analyzed “as received” by this method without modification. However, some liquids (i.e. highly caustic or highly acidic) may require predilution or neutralization before analysis.
Tables of X-Ray Mass Attenuation Coefficients and Mass Energy-Absorption Coefficients from 1 keV to 20 MeV for Elements Z = 1 to 92 and 48 Additional Substances of Dosimetric Interest*

J. H. Hubbell and S. M. Seltzer
Radiation and Biomolecular Physics Division, PML, NIST

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Abstract
Tables and graphs of the photon mass attenuation coefficient $\mu/p$ and the mass energy-absorption coefficient $\mu_{\text{abs}}/p$ are presented for all of the elements $Z = 1$ to 92, and for 48 compounds and mixtures of radiological interest. The tables cover energies of the photon (x-ray, gamma ray, bremsstrahlung) from 1 keV to 20 MeV. The $\mu/p$ values are taken from the current photon interaction database at the National Institute of Standards and Technology, and the $\mu_{\text{abs}}/p$ values are based on the new calculations by Seltzer described in Radiation Research 136, 147 (1993). These tables of $\mu/p$ and $\mu_{\text{abs}}/p$ replace and extend the tables given by Hubbell in the International Journal of Applied Radiation and Isotopes 33, 1269 (1982).

Note on NIST X-ray Attenuation Databases

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   Table 4. [Data] compounds and mixtures.
3. The Mass Energy-Absorption Coefficient
4. Summary
5. References

*Work supported by the Standard Reference Data Program of NIST.
**Work carried out for NIST under contract 43JN001412756.

U.S. DEPARTMENT OF COMMERCE - Mickey Kantor, Secretary
Technology Administration - Mary L. Good, Under Secretary for Technology
National Institute of Standards and Technology - Arati Prabhakar, Director

Access the Data for:
Elemental Media
or
Compounds & Mixtures

NIST Standard Reference Database 126
Rate our products and services.
Online: May 1996 - Last update: July 2004

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http://www.nist.gov/pml/data/xraycoef/
Stopping-Power and Range Tables for Electrons, Protons, and Helium Ions

M.J. Berger, J.S. Coursey, M.A. Zucker and J. Chang

1 NIST, Physics Laboratory, Ionizing Radiation Division
2 NIST, Physics Laboratory, ECSED

Abstract:
The databases ESTAR, PSTAR, and ASTAR calculate stopping-power and range tables for electrons, protons, or helium ions, according to methods described in ICRU Reports 37 and 49. Stopping-power and range tables can be calculated for electrons in any user-specified material and for protons and helium ions in 74 materials.

Contents:
1. Introduction
2. ESTAR: Stopping Powers and Ranges for Electrons
3. PSTAR and ASTAR: for Protons and Helium Ions (alpha particles)

Access the Data
Electrons | Protons | Helium Ions

NIST Standard Reference Database 124
Online: October 1998 - Last update: August 2005

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This work was supported in part by the Department of Energy, Office of Health and Environmental Research, Washington, D.C. 20585; and by NIST's Systems Integration for Manufacturing Applications (SIMA) Program.
charged particles:

CSDA Range (continuous slowing down approx., Bethe Range)

depth Range or projected Range

for electrons, proj. Range < CSDA Range

for protons, proj. Range ~ CSDA Range

X-Rays: μ absorption coefficient

energies we are interested ≤ 100 keV

mainly photoeffect — all or nothing

\[ \frac{I(t)}{I(0)} = e^{-\mu t} \]

so we can think of

a projected Range as

\[ R \sim \frac{3}{\mu} \]

1e, \( \frac{I(t)}{I(0)} \sim 3 \times 10^{-2} \)
PSTAR: Stopping Power and Range Tables for Protons

\[ \rho = 2.33 \text{gm/cm}^3 \]

Range (gm/cm²)/\(\rho = \) Range (cm)
ESTAR: Stopping Power and Range Tables for Electrons

**SILICON**

\[ R_{\text{proj}} = Z^{-1/3} R_{\text{CSDA}} \]

- **Energy (MeV)**
- **Range (g/cm²)**

---

**CSDA Range**

Bethe range
$Z = 14. \text{ SILICON}$

![Graph showing the linear characteristics of $\mu/\rho$ and $\mu_{en}/\rho$ as a function of photon energy. The graph indicates that $R$ is approximately $3/\mu$.](image-url)

$\mu/\rho$ or $\mu_{en}/\rho$, cm$^2$/g

Photon Energy, MeV

$R \approx 3/\mu$
Comparison of "projected" ranges

\[ \frac{1}{2} \sqrt{3} \frac{R_P}{R} \]

for 100 keV incident

\[ R_{p\text{elec}} = Z^{-1/3} R_{cs\text{pa}} \rightarrow 1.78 \times 10^{-3} \text{ cm} \]

\[ R_{p\text{protm}} = R_P \rightarrow 4.3 \times 10^{-5} \text{ cm} \]

\[ R_{p\text{xray}} = \frac{3}{\lambda} \rightarrow 6.44 \text{ cm} \]
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MicroPIXE,

Most of the experimental facilities of our laboratory are based on a 5 MV Van de Graaff (VdG) electrostatic accelerator. VdG provides energetic ions (H+, D+, He+, etc.) for ion beam analysis, physical experiments, as well as for the modification and testing of materials.
Identification of the pigments used for the "Book of the Dead"

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¹University of Göteborg, SE–405 30 Göteborg, Sweden
²Centre de recherche et de restauration des musées de France, CNRS UMR 171, Palais du Louvre Paris, France
³Chalmers University of Technology, SE–412 96 Göteborg, Sweden

View of the external microprobe set-up with the papyrus in place

The Papyrus KM 21933 consists of hieroglyphic text ended by a painted vignette. It forms the right end of a "Book of the Dead" from the Theban 19th Dynasty (c.1295–1186 B.C.). This name is given to religious funerary texts and spells for protection and guidance of the deceased entering the afterlife. Probably discovered in the 1820’s, it was acquired in Berlin in 1912 by The Kulturen Museum in Lund, Sweden.
Direct Comparison Of PIXE And EDS

From http://www.mrsec.harvard.edu/cams/PIXE.html
Particle Accelerators in Art & Archaeology

Pier Andrea Mandò

Dipartimento di Fisica and Sezione INFN, Florence, Italy

e-mail mando@fi.infn.it

www.presid.infn.it/er/er04fazio.ppt

Erice, April 17, 2004
PIXE analysis of ancient manuscripts

(INFN Firenze, Biblioteca Vaticana, Biblioteca Laurenziana)

Detecting which pigments were employed provides important art-historical information, both about general trends and specifically about the analysed work.

More or less precious materials ↔ symbolic value of the text.

Trade routes of raw material import from countries far away. Added or restored parts.
differential PIXE to discriminate the contributions of different layers

$E_1 < E_2 < E_3$

+ simultaneous use of PIGE to detect light elements
external microbeam line
Final Paper/

1. Paper due last day class
   10 page approx.
   (IEEE style references)

2. Rough outline due February 26 or earlier

3. Topic should be about a particular microcharacterization technique and comparison with at least one other method. From topics covered in course outline.

4. You must discuss the spatial resolution characteristics and limits.

5. Include the abstract of each paper you reference or a one paragraph summary of the url reference.

6. Briefly, discuss a particular application.
EE213 Paper Notes

• See IEEE.jour for formatting notes. On class web site.
• Paper should be about 10 pages long including figures.
• Paper should include a 1 paragraph abstract
• Paper should have at least 10 references.
• For each reference, either a summary or the abstract of that reference attached as an Appendix to the paper.
Possible topics for paper
SEM imaging
Quantitation in the SEM
Auger microscopy/spectroscopy
Particle beam induced Xray spectroscopy
(electrons, ions, photons, etc.)
Xray Microscopy
SIMS microscopy
RBS microanalysis
Super resolution optical microscopy
Scanned tip microscopy
Atom probe microscopy
Tomography
Other topics (upon approval)