Recovery of Text from Archimedes Palimpsest

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Outline

➔ **Discovery of X-rays**

➔ **What are X-rays?**

➔ **Who was Archimedes?**

➔ **What is the Palimpsest?**

➔ **The Challenge?**

➔ **Instrumentation**

➔ **Preliminary results**

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Wilhelm Conrad Röntgen (1845-1923) -Discoverer of "X-rays"

Wilhelm Conrad Röntgen was born in Lennep in March 1845. He was just 3 years old when the family Röntgen emigrated to the Netherlands. After his teenage years and his schooling, Wilhelm Conrad attended a technical private school in Utrecht. At the age of 20, he began to study at the newly established "Eidgenössische Polytechnikum" (Swiss Polytechnic) in Zurich. In 1868 he concluded his studies with a degree in mechanical engineering. Initially, Röntgen was not quite sure as to what sort of career he should pursue.

Prof August Kundt (Ph. D.) an experimental physicist in Zurich, ended the period of uncertainty by saying, "First try it out with physics." Röntgen accepted the advice and gained his Ph. D. at the university of Zurich one year later, on account of a thesis based on purely physical phenomenon. He remained loyal to

Who was Archimedes?

➔ Born: About 287 BC in Syracuse, Sicily. At the time Syracuse was an independent Greek city-state with a 500-year history.

➔ Died 212 or 211 BC in Syracuse when it was being attacked by a Roman army. He was killed by a Roman soldier who did not know who he was.

➔ Education: Probably studied in Alexandria, Egypt, under the followers of Euclid.

➔ Family: His father was an astronomer named Phidias and he was probably related to Hieron II, the king of Syracuse. It is not known whether he was married or had any children.

➔ Inventions: Many war machines used in the defense of Syracuse, compound pulley systems, planetarium, water screw (possibly), water organ (possibly), burning mirrors.

Archimedes

➔ **Fields of Science**
Initiated Hydrostatics, static mechanics, pycnometry (the measurement of the volume or density of an object). He is called the "father of integral calculus."

➔ **Major Writings**

On plane equilibriums, Quadrature of the parabola, On the sphere and cylinder, On spirals, On conoids and spheroids, On floating bodies, Measurement of a circle, The Sandreckoner, On the method of mechanical problems.

➔ **Place in History**

Generally regarded as the greatest mathematician and scientist of antiquity and one of the three greatest mathematicians of all time (together with Isaac Newton (English 1643-1727) and Carl Friedrich Gauss (German 1777-1855)).

Palimpsest

➔ A palimpsest, from the Greek words $\pi\alpha\lambda\iota\upsilon$ = "again", and $\pi\sigma\epsilon\sigma\tau\sigma\zeta$ = "rubbed" is a manuscript written on parchment that has another text written over it, leaving two (or more) layers of visible writing. Palimpsests were common in antiquity because parchment for writing was scarce and costly. As certain kinds of texts went in and out of literary fashion, manuscripts were recycled and reused, their original content rubbed away and overwritten.

Archimedes palimpsest

➔ **Circa 287-212 B.C.**
Before his death at Syracuse in 212 B.C., Archimedes pens some of his most important treatises and equations onto a collection of papyrus scrolls in Greek. These include *On the Method of Mechanical Theorems, On Floating Bodies, On the Measurement of the Circle, On the Sphere and the Cylinder, On Spiral Lines,* and *On the Equilibrium of Planes.*

➔ **212 B.C.- A.D. 1000**
The original Archimedes scrolls are lost, but fortunately unknown persons copy them down at least once beforehand onto other papyrus scrolls.

➔ **Circa 1000**
A scribe working in Constantinople handwrites a copy of the Archimedes treatises, including their accompanying diagrams and calculations, onto parchment, which is assembled into a book.

Archimedes palimpsest

➔ **circa** 1200
A Christian monk handwrites prayers in Greek over the Archimedes text, turning the old mathematical text into a new prayer book. The book is now a palimpsest, a manuscript with a layer of text written over an earlier scraped- or washed-off text.

➔ circa 1200-1906
For centuries the monk's prayer book is used in religious study, but eventually it is stored within the Mar Saba monastery in Constantinople. There it survives numerous abuses, including the Fourth Crusade in 1204, during which Constantinople is sacked and many of its books burned.

➔ 1906
Danish philologist Johan Ludvig Heiberg discovers the lost manuscript in the library of The Church of the Holy Sepulchre in Istanbul, identifies the underlying layer of text as the work of Archimedes, and photographs every page. Heiberg transcribes what he can make out of the palimpsest's shadowy bottom layer, using a magnifying glass as his only aid. He publishes his transcription with the accompanying images.

Archimedes palimpsest

➔ **1907-1930**

The palimpsest goes missing and is believed stolen. At some point during this period, probably after 1929, a forger paints copies of medieval evangelical portraits in gold leaf onto four pages in the book, presumably in an attempt to increase its value and perhaps unaware of the Archimedes text beneath.

Recovery of text from Au overlay

Close up of ink on palimpsest

Archimedes palimpsest

➔ circa 1930
A member of a French family who is an amateur collector of antiques travels to Istanbul and purchases the manuscript from a local dealer. Unbeknownst to the outside world, it is kept in the family's Paris home for the next seven decades.

➔ 1971
Nigel Wilson, a classics professor at Oxford, examines a leaf from an old manuscript housed in a Cambridge University library. He identifies it as a page from the missing Archimedes palimpsest Heiberg had photographed and transcribed 65 years earlier. Wilson surmises that Constantine Tischendorf, a German scholar who described a palimpsest he saw in a Greek monastic library in 1846, tore out the page for further examination.

History of X-rays

➔ X-rays were first discovered by Wilhelm K. Roentgen (German physicist, 1845-1923) who won the Nobel Prize in 1901, for the discovery of x-rays. X-rays have been used for commercial elemental analysis since the 1950's. X-ray spectroscopy is much older than that, dating back to 1909 when Charles G. Barkla found a connection between x-rays radiating from a sample and the atomic weight of the sample.

➔ In 1913, Henry Gwyn Jeffreys Moseley helped number the elements with the use of x-rays, by observing that the K lines in an x-ray spectrum moved the same amount each time the atomic number increased by one. He is credited for changing the periodic tables which were based on increasing atomic weight, to periodic tables based on atomic number. He later laid the foundation for identifying elements in x-ray spectroscopy by establishing a relationship between frequency and the atomic number.

What are X-rays?

➡ **They can be either a wave i.e. described by wavelengths from 0.01 - 2.5 nm.**

➡ **They can also be described as a particle i.e. they will have energies that are from 0.2 keV to 100 keV.**

➡ **Dual nature of X-rays means that we can use two techniques to measure them.**

History XRF

➔ **Secondary excitation or fluorescence technique was first visualized by de Broglie in 1914 but developed by Glocker and Schreiber in 1928. A major inconvenience persists in the application of electron excitation in non-metallic materials: the sample must be made electrically conductive by mixing it with a conducting material.**

Bohr Diagram

Left diagram labels: N, M, L, K, Nucleus, e⁻, E_0, E

Photoelectron
$\Delta E = E - E_0$
e^-

Incoming
radiation from
x-ray tube or
radioisotope.

Right diagram labels: N, M, L, K, Nucleus, E_1, e^-, E_0, e^-, E_2

x-ray
$\Delta E = E_1 - E_0 = K_\alpha$

or

$\Delta E = E_2 - E_0 = K_\beta$
x-ray
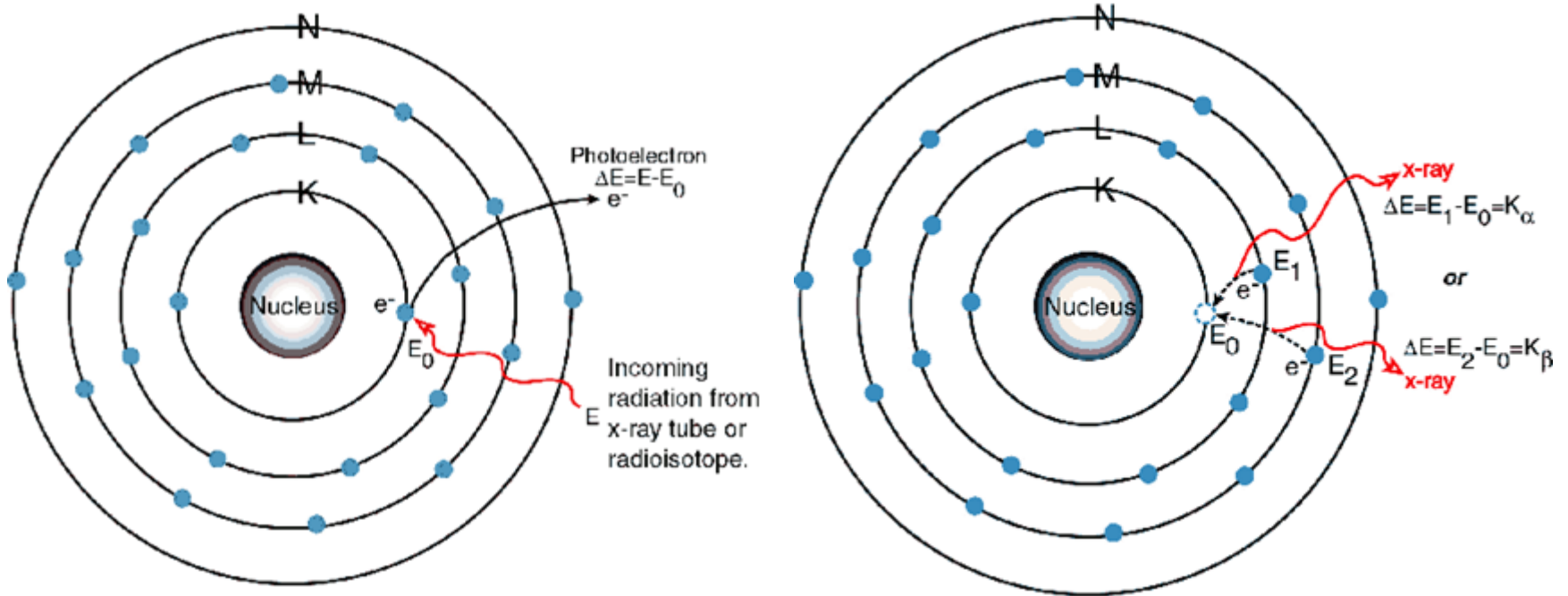
K-alpha K-beta lines
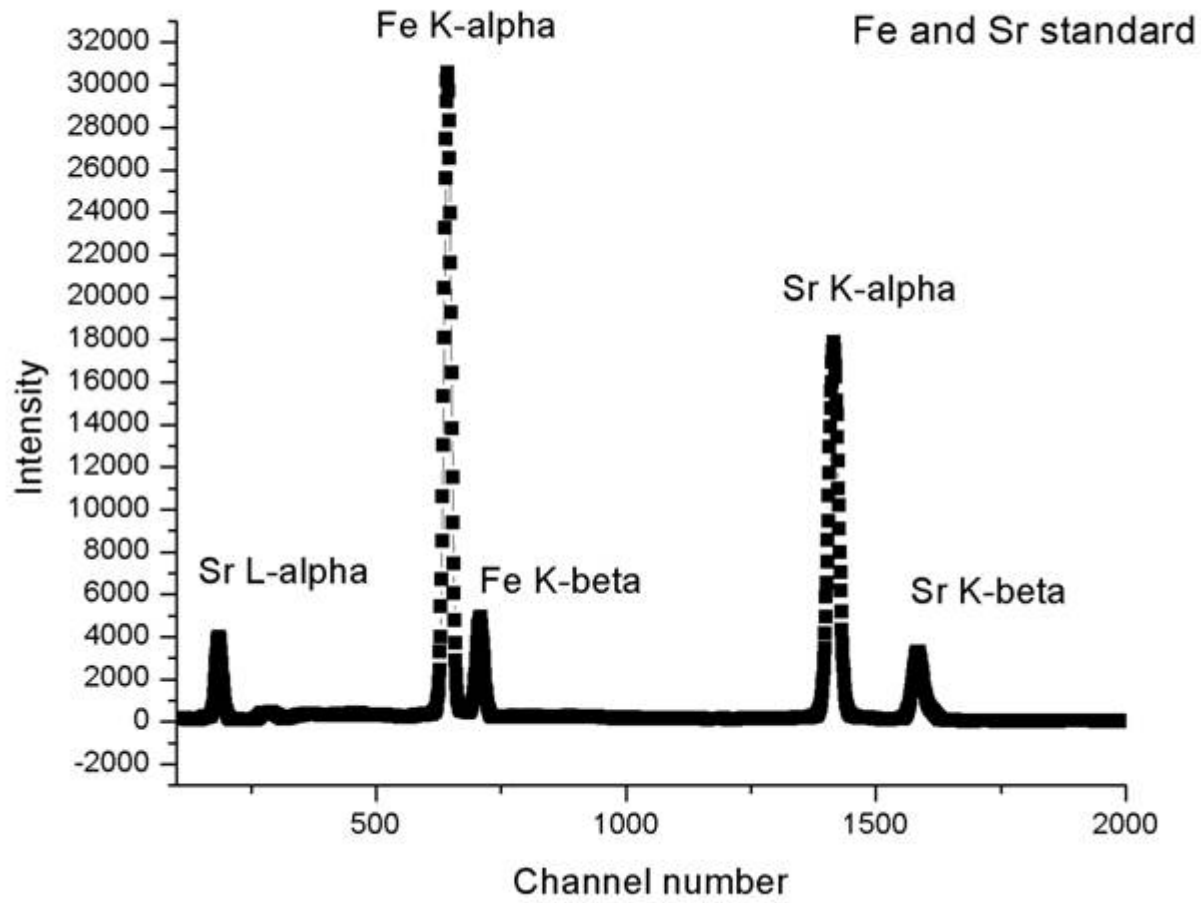
L lines (for Au)
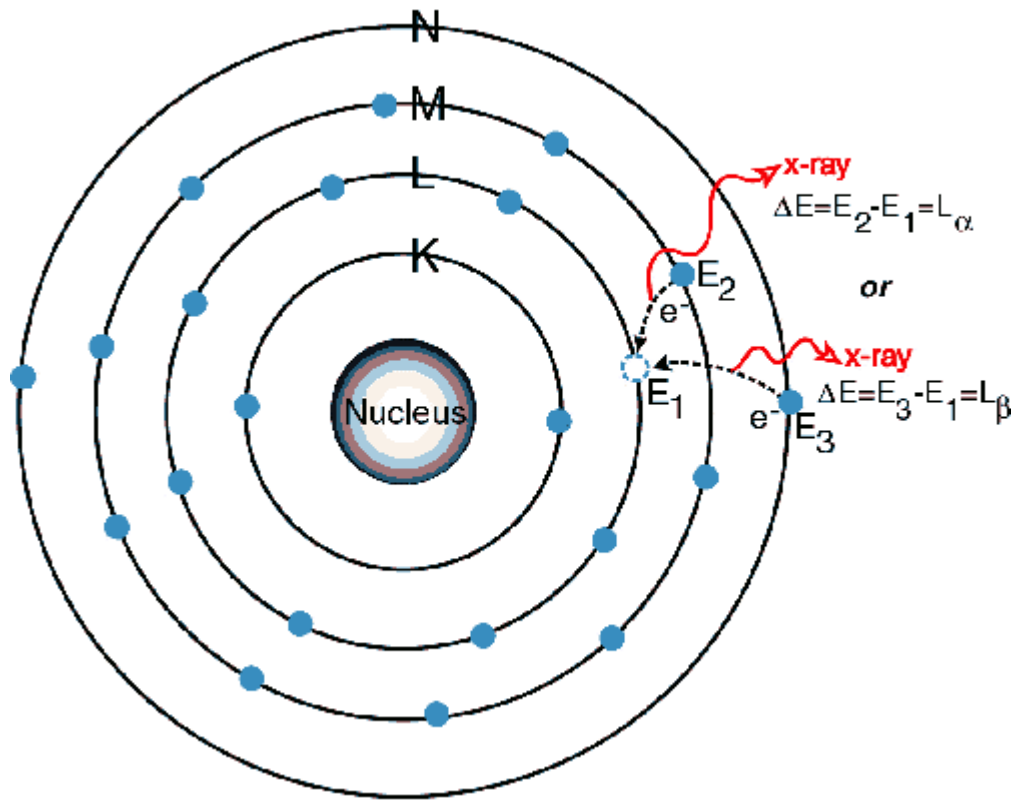
What is ink?

➔ **Vehicle**
- ★ linseed oil

➔ **Insoluble Pigments**
- ★ inorganic
  - • red lead, etc
- ★ organic
  - • coal tar
    - – alizarin, aniline, etc.

➔ **Binders**
- ★ gum

➔ **Handwriting inks**
- ★ iron-gall
- ★ aniline

Chemistry of ink

➔ **Bone black: Calcium phosphate + C.**

★ $Ca_3(PO_4)_2$
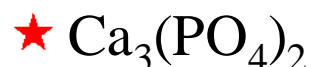
➔ **Prussian blue: Ferric ferrous cyanide**

★ $Fe_4[Fe(CN)_6]$

➔ **Vermilion: mercury sulfide (HgS)**

★ most red serial numbers on stocks and bonds printed before 1900.

➔ **Brunswick green: compound pigment of Prussian blue and lead chromate precipitated on barium sulfate.**

★ $PbSO_4 \bullet PbCrO_4, Fe_4[Fe(CN)_6], BaSO_4$

➔ **Gas or carbon black: C**

➔ **Iron-gall: contains iron, originally black then oxidizes to brown. Used in ink pens of the 1800s.**

★ Fe + gallic acid
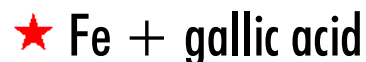
Supporting Analytical Methods
(Non-destructive)

➔ **Micro X-ray fluorescence (XRF)**
  - ★ For elemental analyses, Na – U.
  - ★ Penetration Depth: 5-200 μ

➔ **Micro attenuated total reflectance Fourier transform infrared (ATR-FT-IR)**
  - ★ Chemical compound determination
  - ★ Penetration Depth: 1-15 μ

➔ **Micro Raman**
  - ★ Chemical compound determination and polymorphs (crystal structure)
  - ★ Penetration Depth: 1-5 μ

Instrumentation

Micro XRF Geometry poly cap
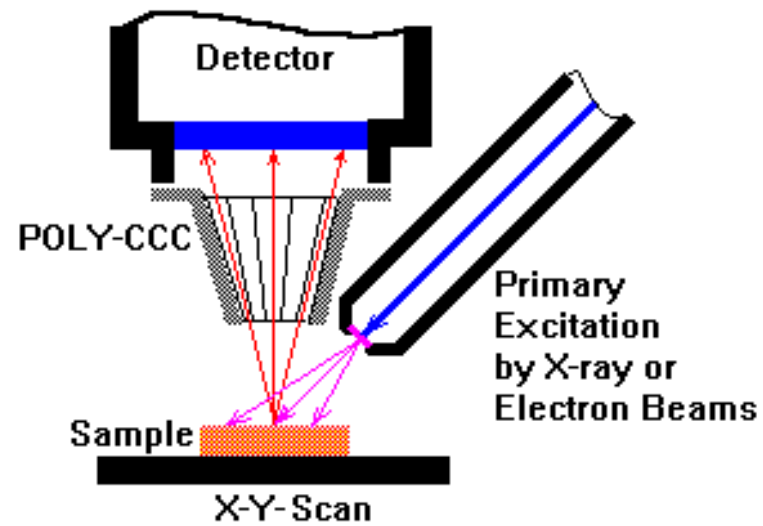
Polycap lens details
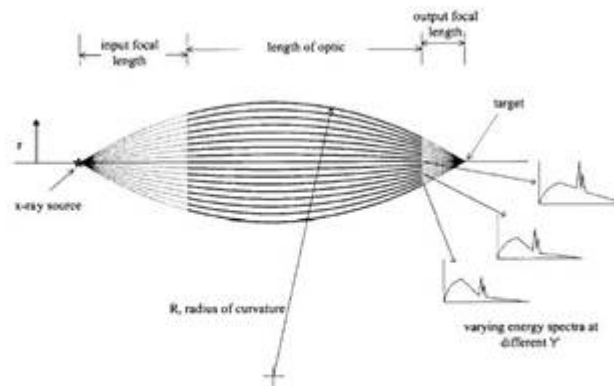
Figure 1. Geometry of polycapillary construction. The optic is radially symmetric and the distance from the optic axis is defined as r. The individual capillaries are arcs from a circle connecting the foci, and the radius of curvature, R, changes with r such that they are inversely related (R_{min} occurs at r_{edge}). Because capillaries further from the axis present a smaller acceptance angle to the source, and the critical angle becomes smaller with increasing energy, the transmitted energy spectrum will change with r.

Hall   24
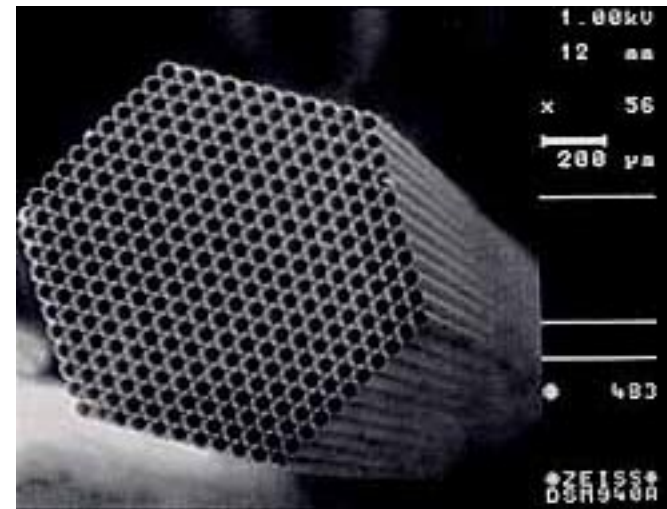
Tube Detector geometry

40 micron beam area with Rh tube

Elemental Image Analysis

➔ Micro XRF is used to analyze the sample at computer controlled locations on the document. Elements are selected and a false color image is generated based on the X-ray intensity of the element in question. Since Fe is a major component in the iron gall ink, all the writings can be imaged based on Fe. In addition, other elements not in the ink can be imaged based on the element content in the parchment such as Ca and K. These elements can be imaged based on absorption going thru the Fe gall ink or thru the gold layer.

Interactions of X-rays with matter

Det.

$I_o(E)$

$I(E) = I_o \exp(-\mu\rho x)$

Coherent

Incoherent

x

Hall   27
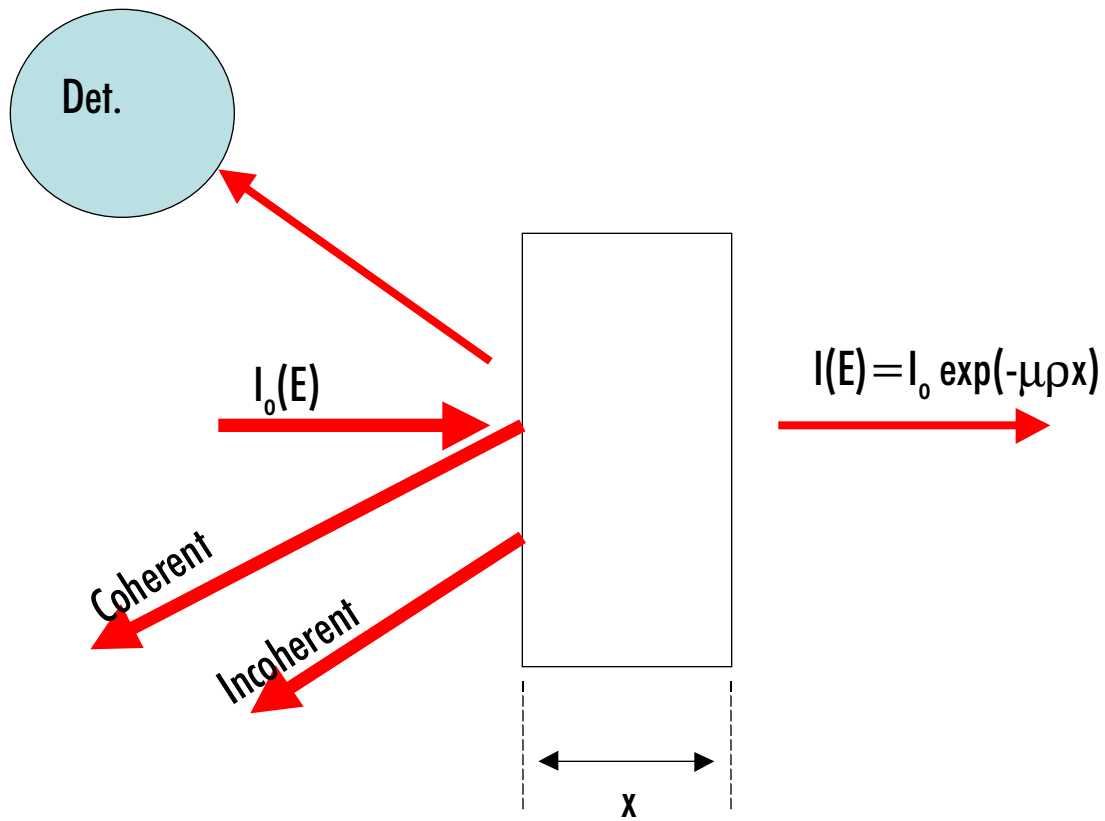
Polycap lens focus
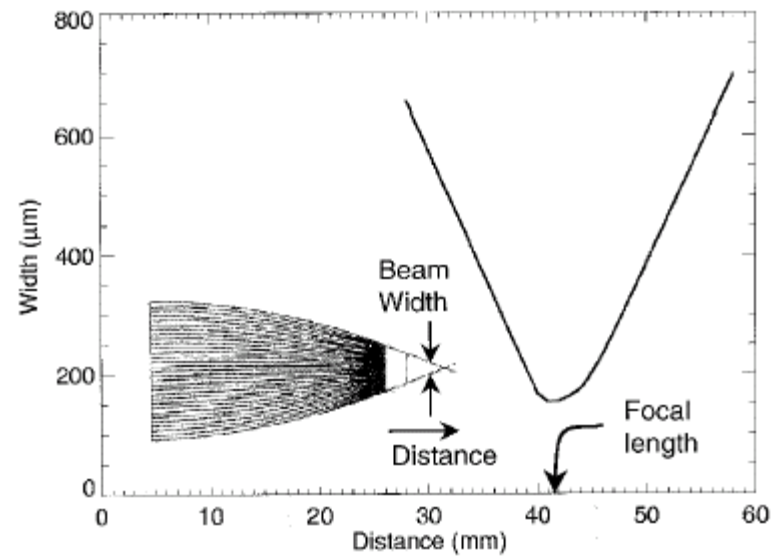
Poly cap setup

X-ray penetration

tube

detector

To detector

$$I(z) = I_o \exp(-\mu\rho t \, \mathrm{cosec}\, \theta_2)$$

θ_1

θ_2

t

Au layer

Text

parchment

From tube

$$I(z) = I_o \exp(-\mu\rho t \, \mathrm{cosec}\, \theta_1)$$
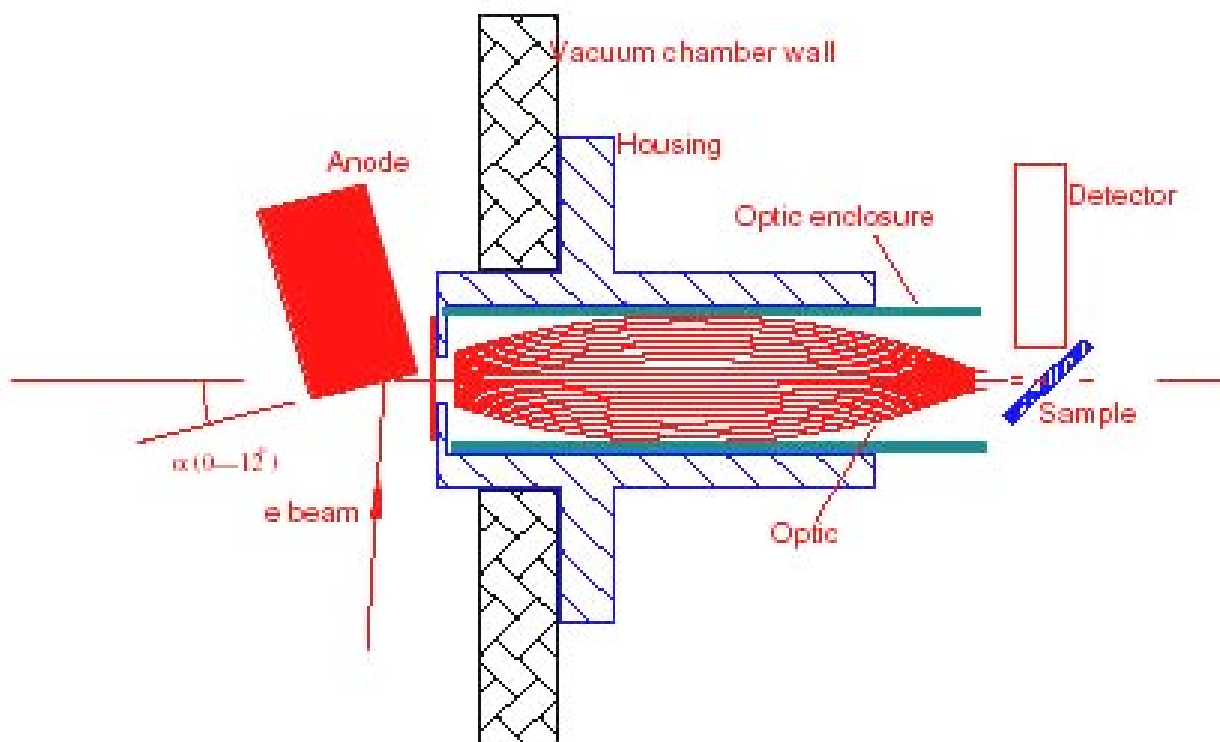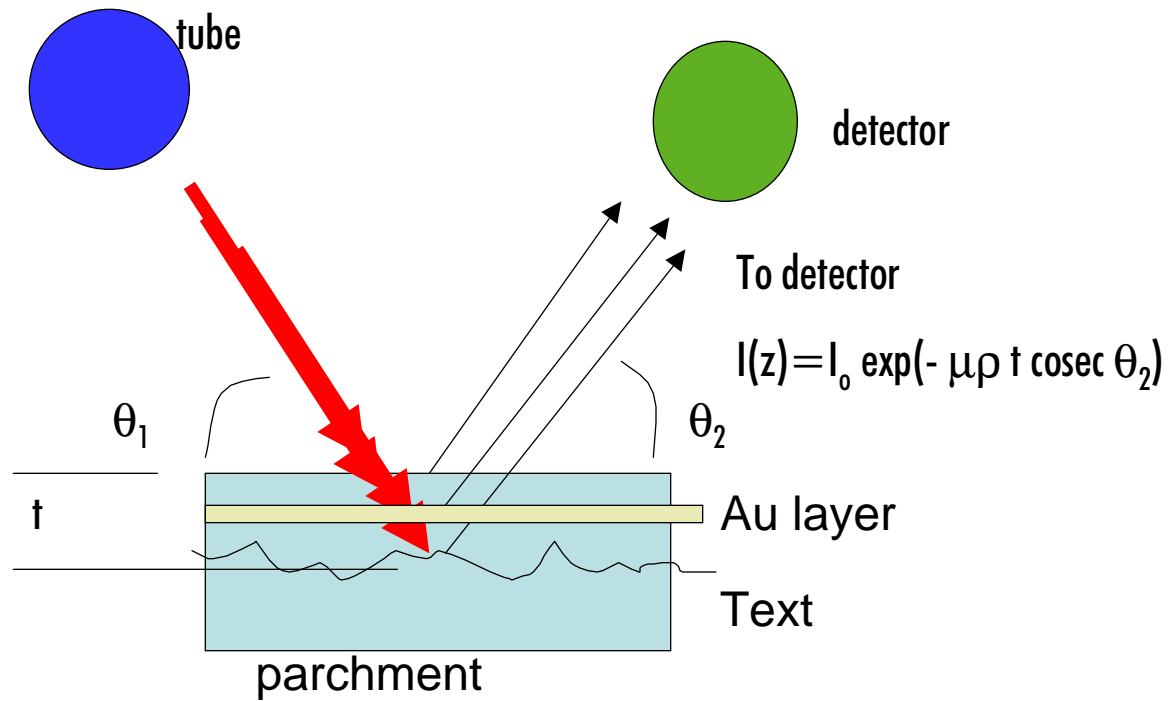
Note: μ is function of energy

Micro XRF Imaging
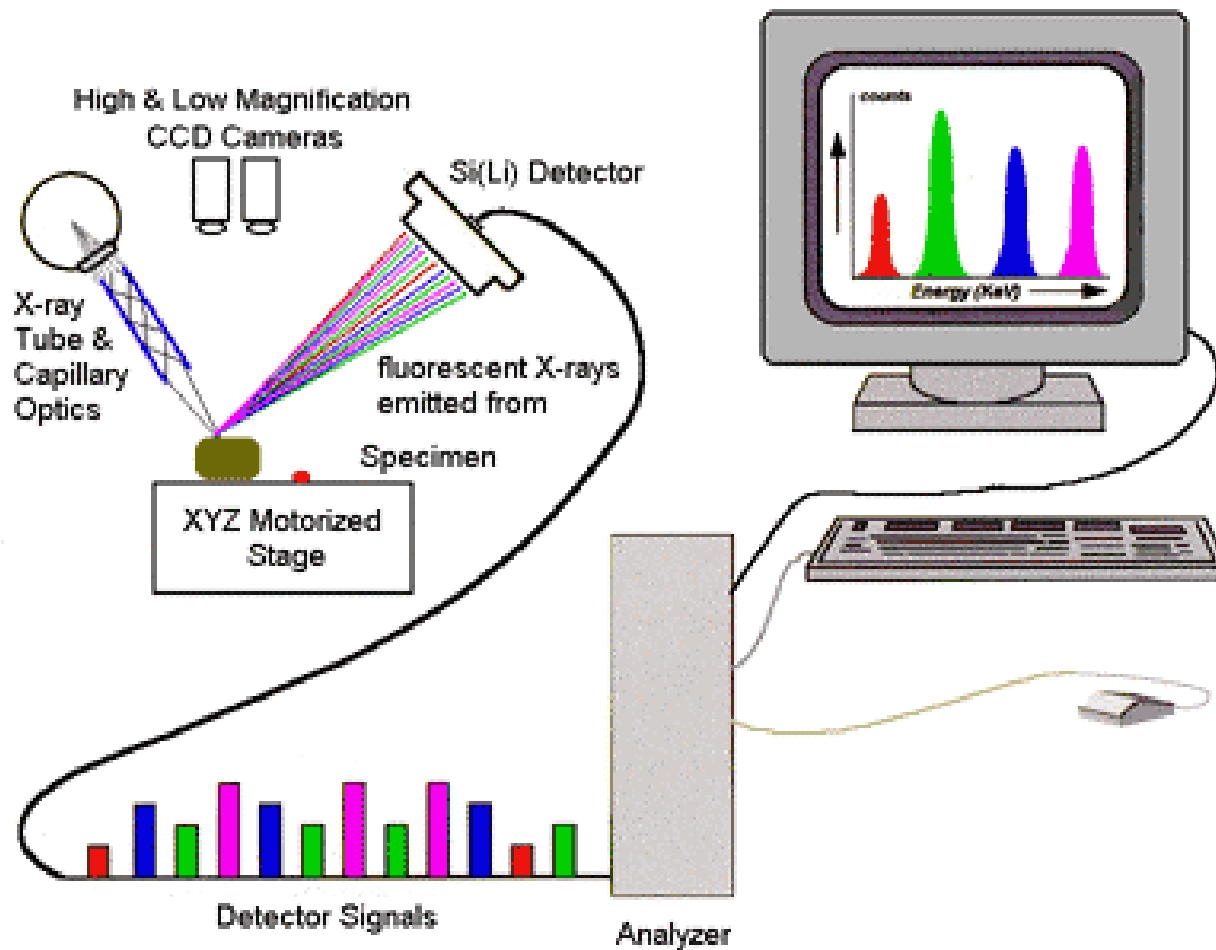
Eagle II Micro XRF

Leaf in Micro XRF

Leaf attached to xyz computer controlled stage

Wire grid for reference
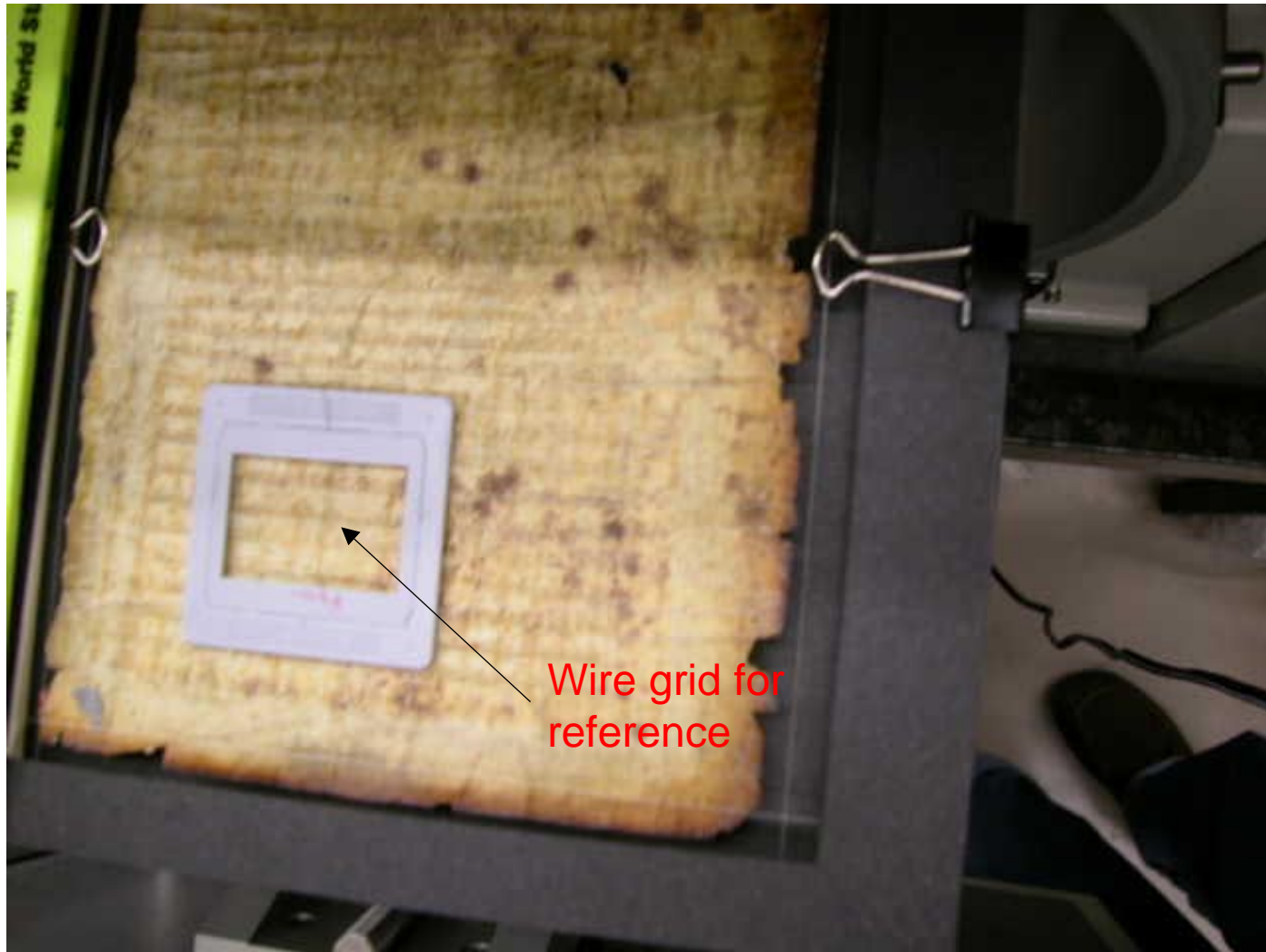
Imaging analysis
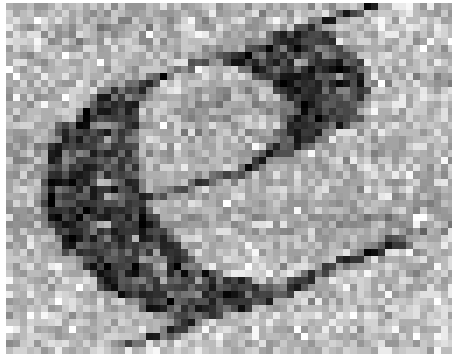
White light image
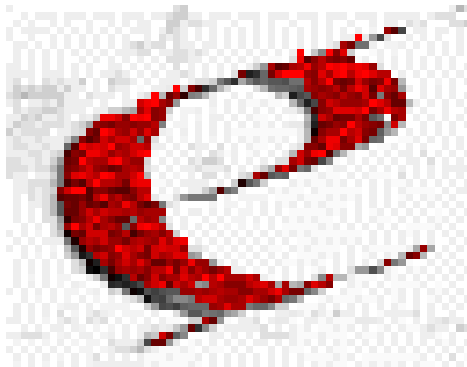
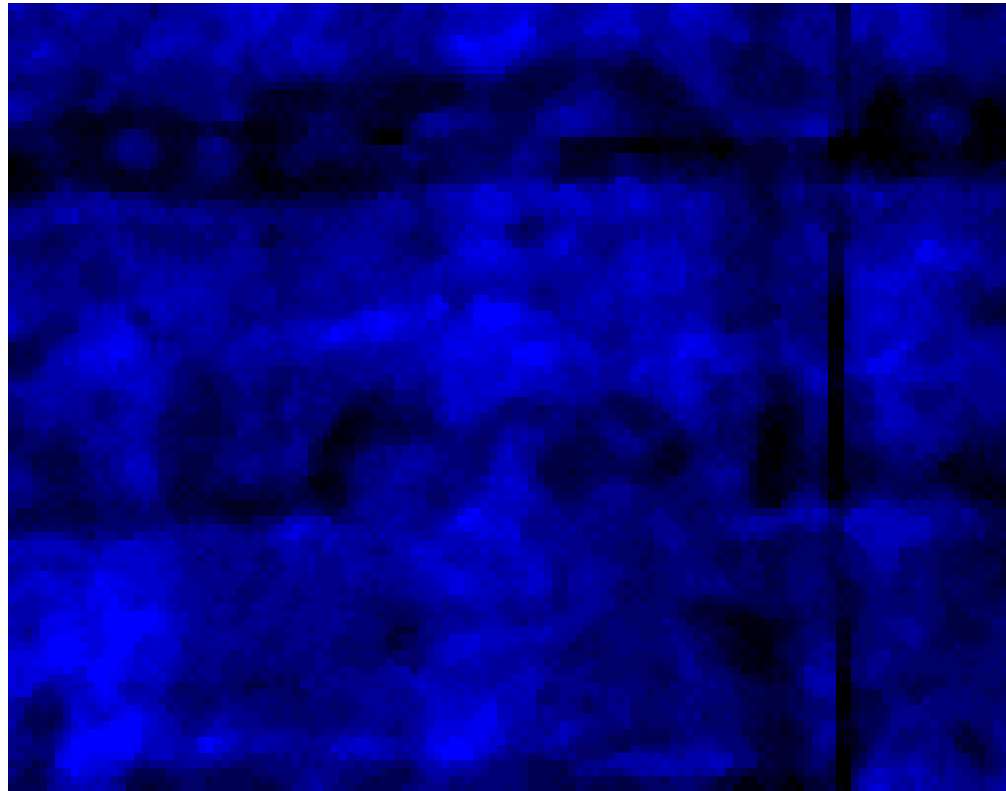Fe map of e in British counterfeit banknote

Preliminary results

Palimpsest folio 81r gold paint

Text underneath

Black ink
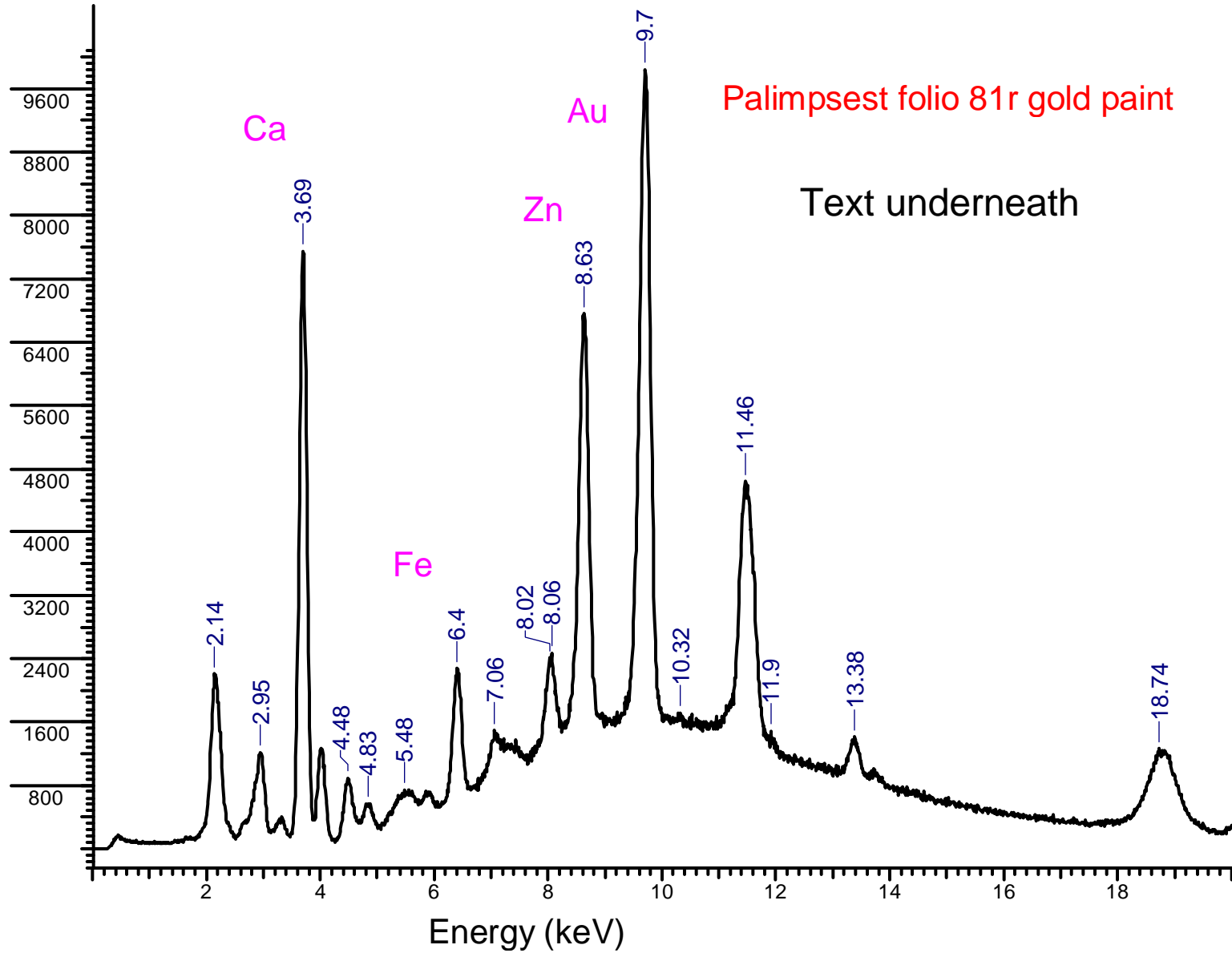
Palimpsest folio 28r black ink
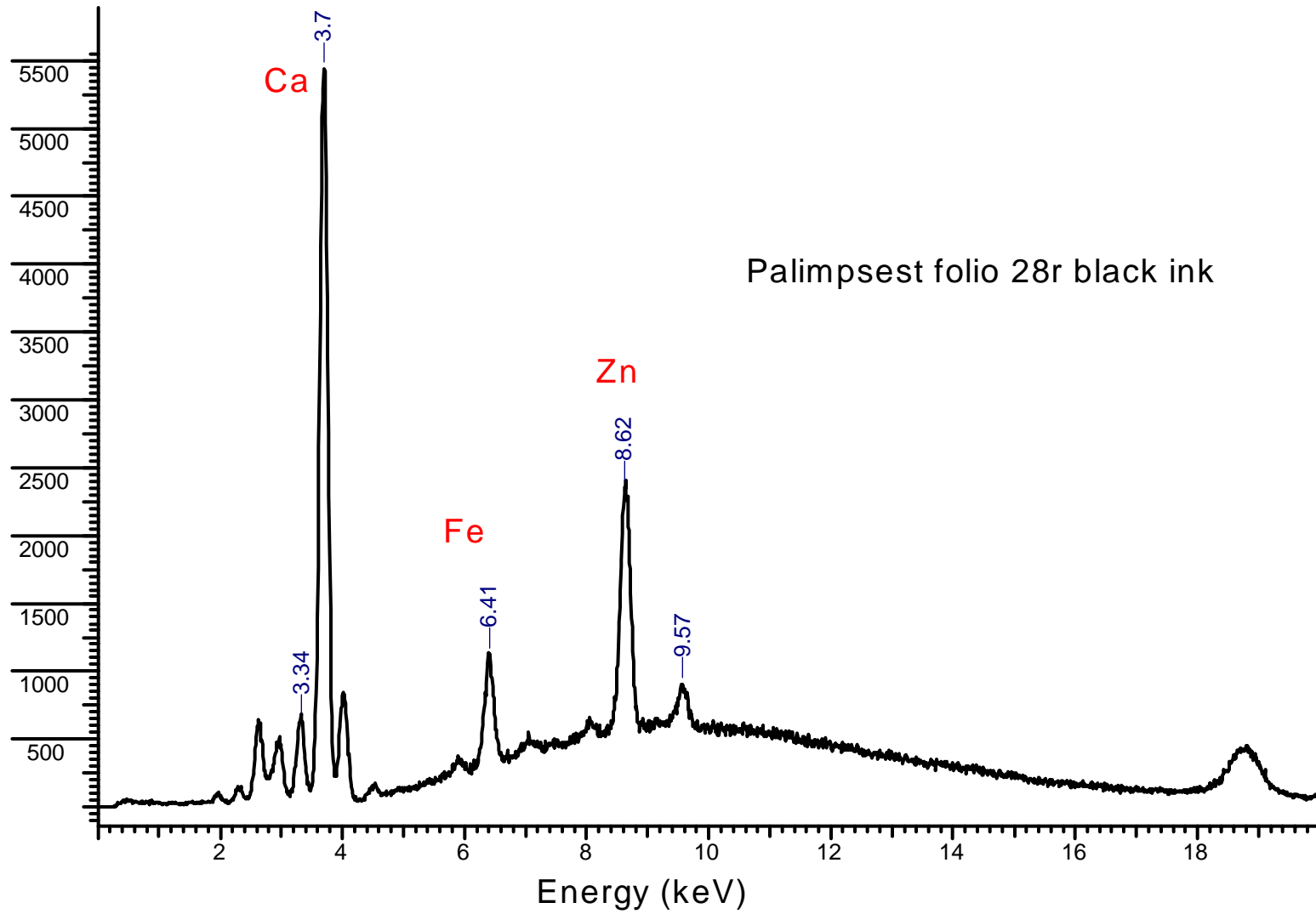
Strategy

➔ **Use multielemental mapping,**

➔ **See which elemental map gives the most information,**
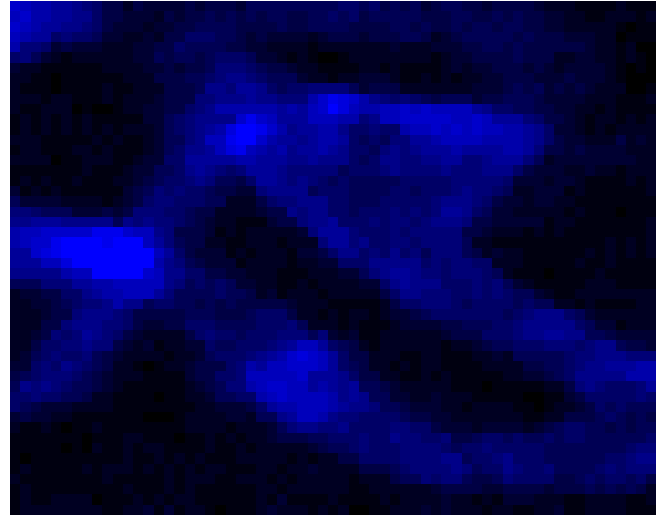
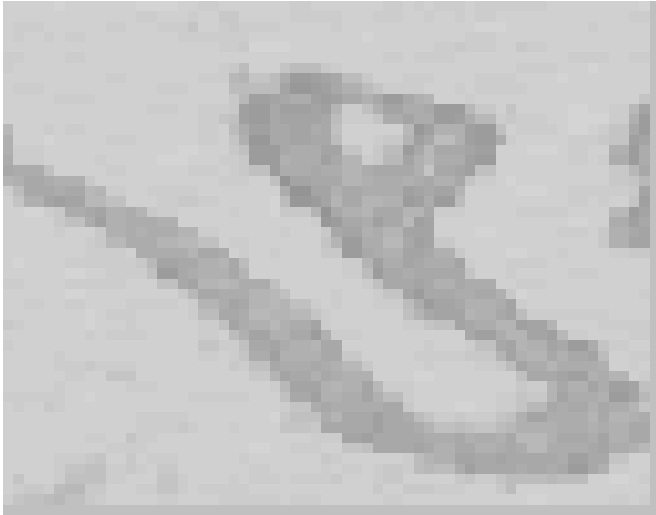➔ **Use digital imaging to enhance the elemental maps.**
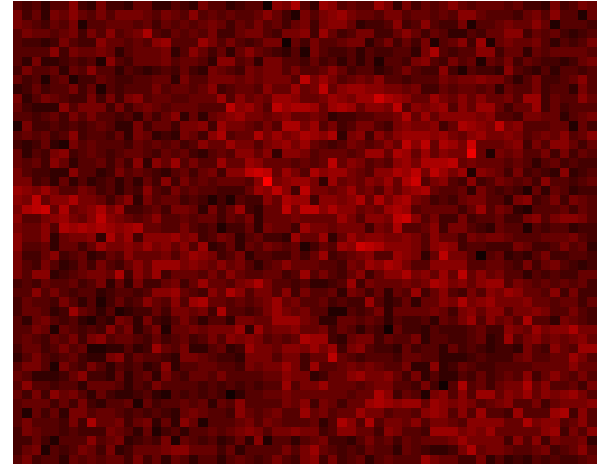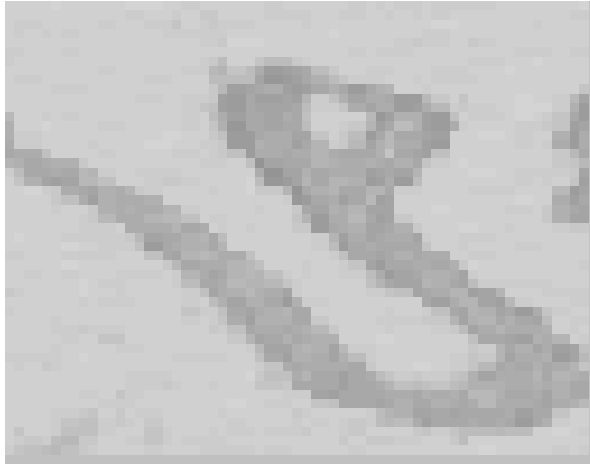
Early images thru Au
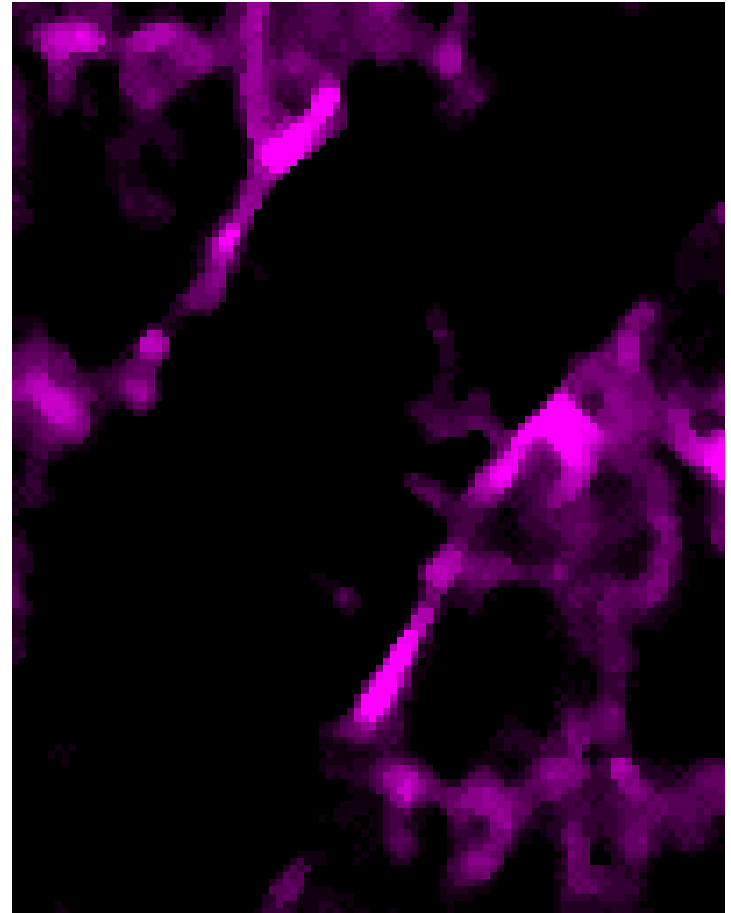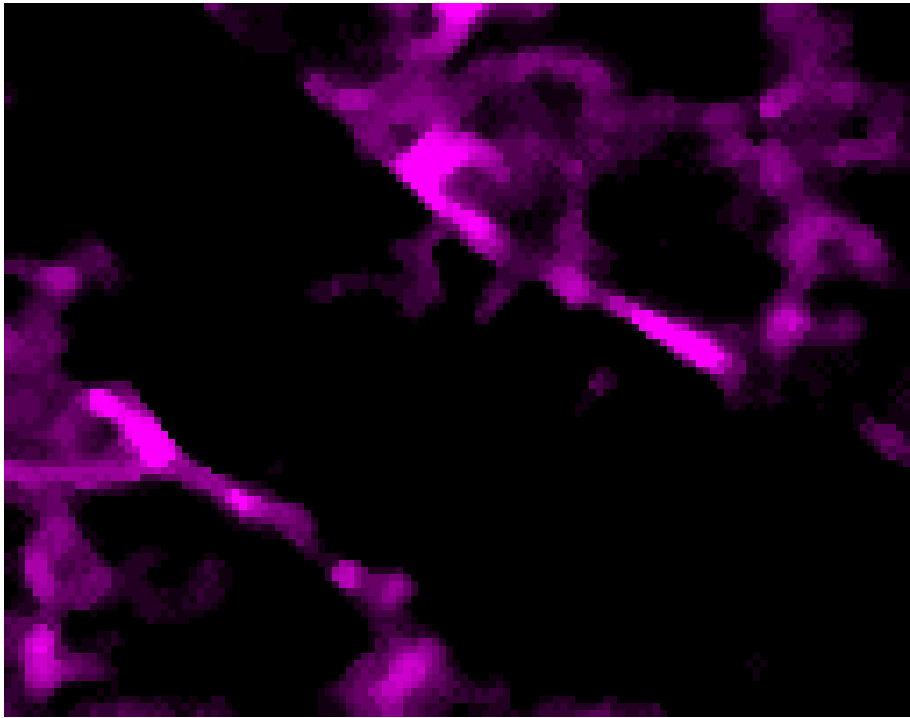
Different Fe map

Fe map of Archie text

K map

Improvements

➔ **Use a filter to diminish the Au X-ray intensity,**

➔ **Use a larger X-ray beam,**

➔ **Perform analysis in a controlled environmental X-ray chamber,**

➔ **Collaborate with image analysis scientist.**

References

➔ **The information on Archimedes and the Palimpsest were obtained from the Nova web site:**

➔ **www.nova.org**

Acknowledgements

➔ **Will Noel and Abigail Quandt allowing me to analyze two leafs of the palimpsest.**

➔ **To the owner of Archimedes Palimpsest for allowing Will and Abigail to bring the leafs to my laboratory.**