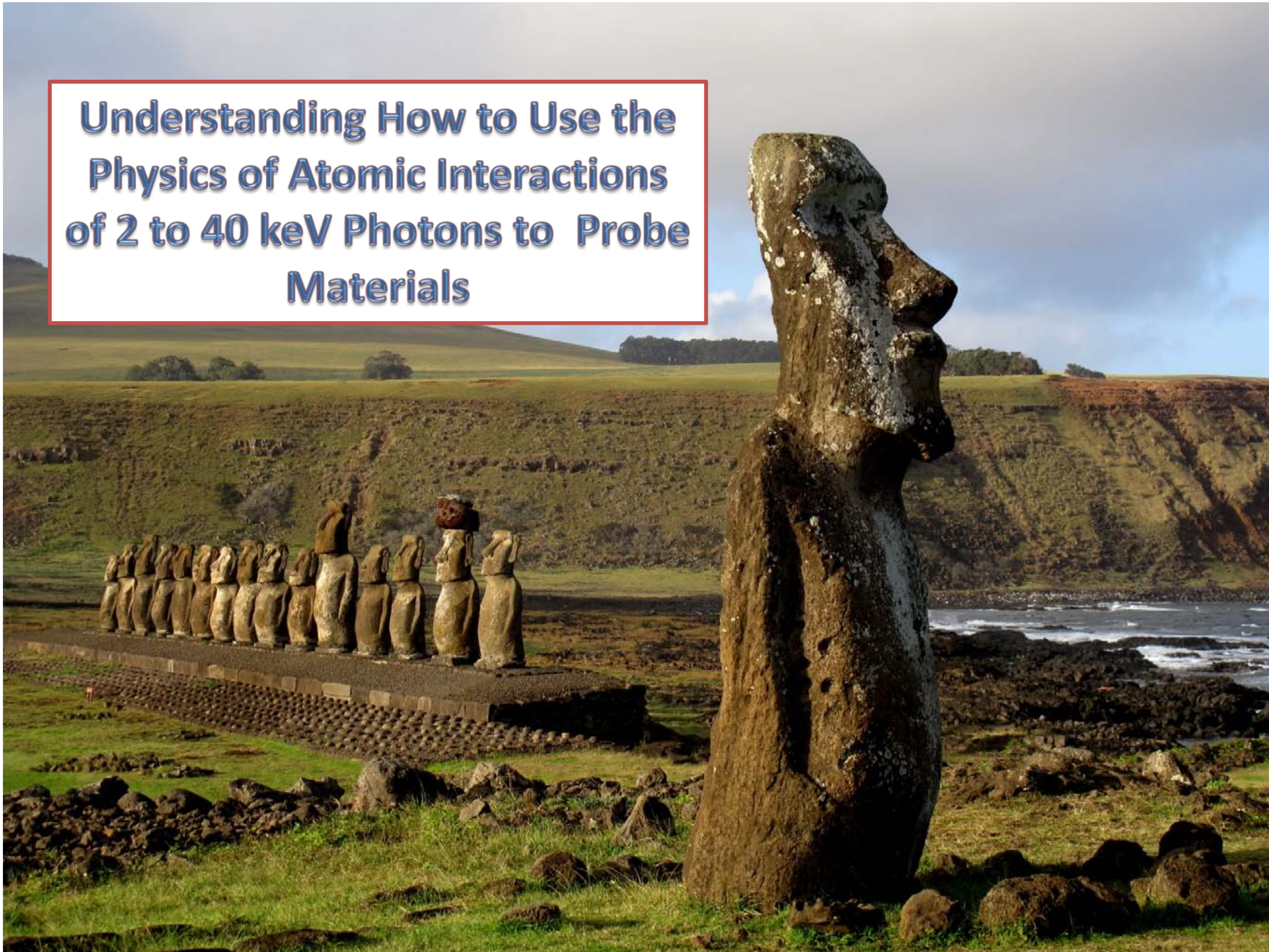
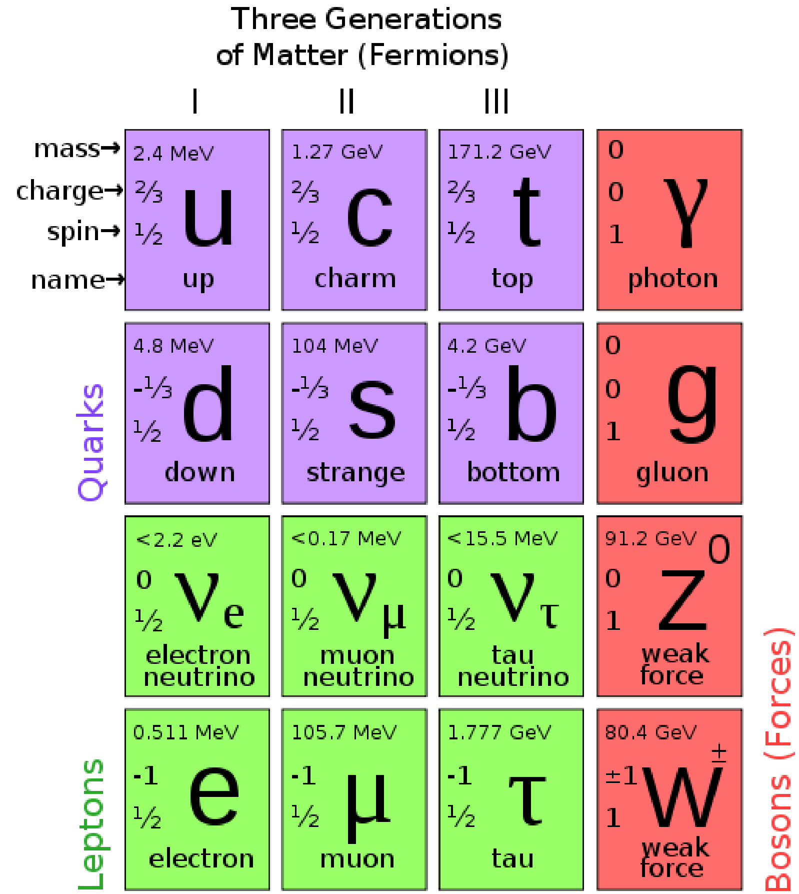
Understanding How to Use the Physics of Atomic Interactions of 2 to 40 keV Photons to Probe Materials



The standard model of particle physics



The standard model of particle physics is a theory concerning the electromagnetic, weak, and strong nuclear interactions, which mediate the dynamics of the known subatomic particles.

Because of its success in explaining a wide variety of experimental results, the standard model is sometimes regarded as a theory of almost everything.

What is a Photon?

the **electron volt** (symbol **eV**; also written **electronvolt**[1][2]) is a unit of energy equal to approximately 1.602×10^{-19} J.

Photons, like all quantum objects, exhibit both wave-like and particle-like properties. Their dual wave–particle nature can be difficult to visualize. The photon displays clearly wave-like phenomena such as diffraction and interference on the length scale of its wavelength. For example, a single photon passing through a double-slit experiment lands on the screen exhibiting interference phenomena but only if no measure was made on the actual slit being run across. To account for the particle interpretation that phenomena is called probability distribution but behaves according to the Maxwell's equations.[46] However, experiments confirm that the photon is *not* a short pulse of electromagnetic radiation; it does not spread out as it propagates, nor does it divide when it encounters a beam splitter".[47]

Rather, the photon seems to be a point-like particle since it is absorbed or emitted *as a whole* by arbitrarily small systems, systems much smaller than its wavelength, such as an atomic nucleus (≈10^{-15} m across) or even the point-like electron.

Values of h	Units
$6.62606896(33) \times 10^{-34}$	J·s
$4.13566733(10) \times 10^{-15}$	eV·s
$6.62606896(33) \times 10^{-27}$	erg·s

Speed of light c	
metres per second	299,792,458

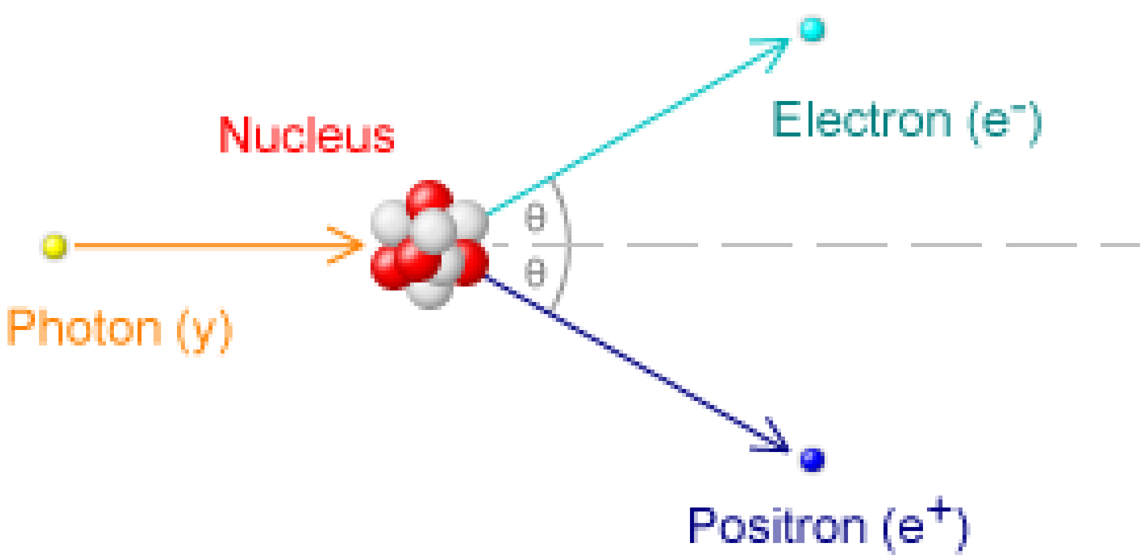
$$E = \hbar\omega = h\nu = \frac{hc}{\lambda}$$

What is an Electron?

The **electron** is a subatomic particle carrying a negative electric charge. It has no known components or substructure. **Therefore the electron is generally-believed to be an elementary particle.**[2] An electron has a mass that is approximately 1/1836 that of the proton.[9] The intrinsic angular momentum (spin) of the electron is a half integer value in units of *ħ*, which means that it is a fermion. The antiparticle of the electron is called the positron, which is identical to the electron except that it carries electrical and other charges of the opposite sign. **When an electron collides with a positron, both particles may either scatter off each other or be totally annihilated, producing a pair (or more) of gamma ray photons.** Electrons, which belong to the first generation of the lepton particle family,[10] participate in gravitational, electromagnetic and weak interactions.[11] Electrons, like all matter, have quantum mechanical properties of both a particle and a wave, so they can collide with other particles and be diffracted like light

What is a Pair production?

Pair production refers to the creation of an elementary particle and its antiparticle, usually from a photon . This is allowed, provided there is enough energy available to create the pair – at least the total rest mass energy of the two particles – and that the situation allows both energy and momentum to be conserved . All other conserved quantum numbers (angular momentum, electric charge) of the produced particles must sum to zero — thus the created particles shall have opposite values of each (for instance, if one particle has strangeness +1 then another one must have strangeness −1).



What is wrong with these pictures?

What does ppm mean?

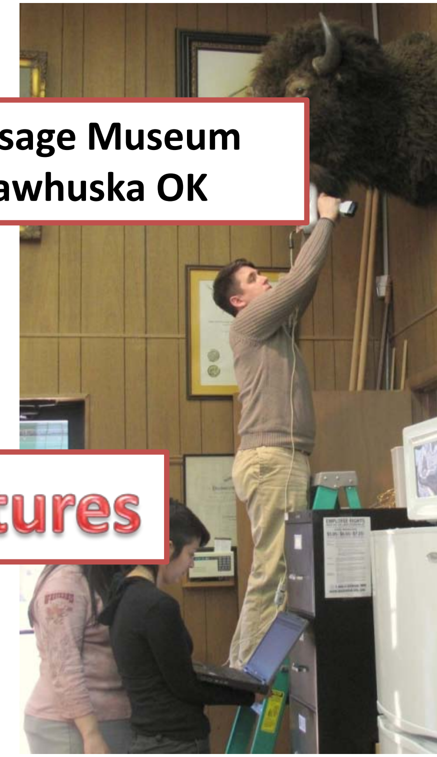
PPM, is an abbreviation that has many meanings. In computers it can mean pulse position modulation, portable pixmap, probabilistic packet marketing, prediction by partial matching, or pearl package manager

It means Parts Per Million. It is generally used to measure and denote the concentration of chemical in very low quantity. e.g we say the sea water contains 0.5 ppm of pure gold. Or human blood contains 20 ppm of iron oxide.

What is right with these pictures


CSULB in Guatemala sourcing basalt

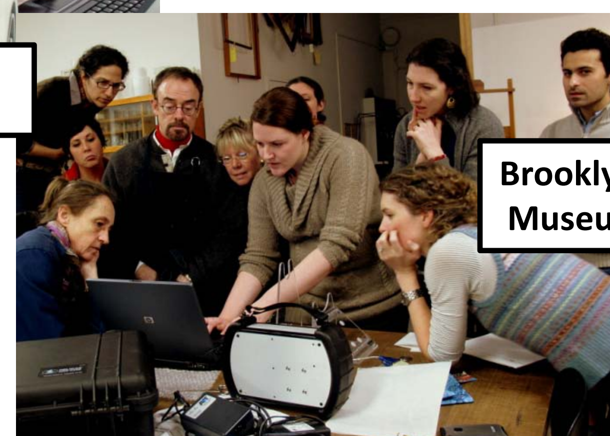

Water colors BBHC, Wyoming


Osage Museum Pawhuska OK


Indianapolis Museum


Bronze analysis Royal Ontario Museum


Rochester Museum & Science


Brooklyn Museum of Art

Most non prepared materials in museums and archeology are non uniform

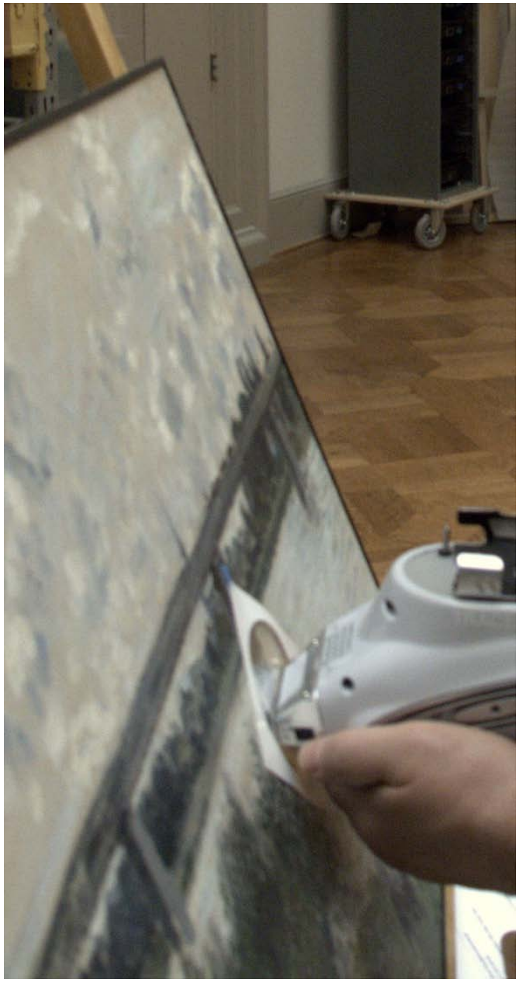
Never ever believe numbers unless you know the physics and your sample atom by atom

Answers vary as;

- the inverse square of the distance to the element
- Exponentially relative to matrix density
- Exponentially relative to elemental X ray energy emission
- Exponentially relative to element location in the sample matrix
- Exponentially relative to beam filtering and energy
- X ray beam distribution
- Orders of magnitude relative to sample uniformity

IF you can not use the numbers then you must be able to control all the x ray beam parameters and work with the raw spectra in detail to extract meaningful information from the xrf analysis.

t = thickness of material attenuating x rays



$$t = -\mathrm{Ln}(I/I_0)/(\ (\mu/\rho) * \rho\ )$$

(μ/ρ) = Mass attenuation coefficient read off the chart for a given material and a given x ray energy

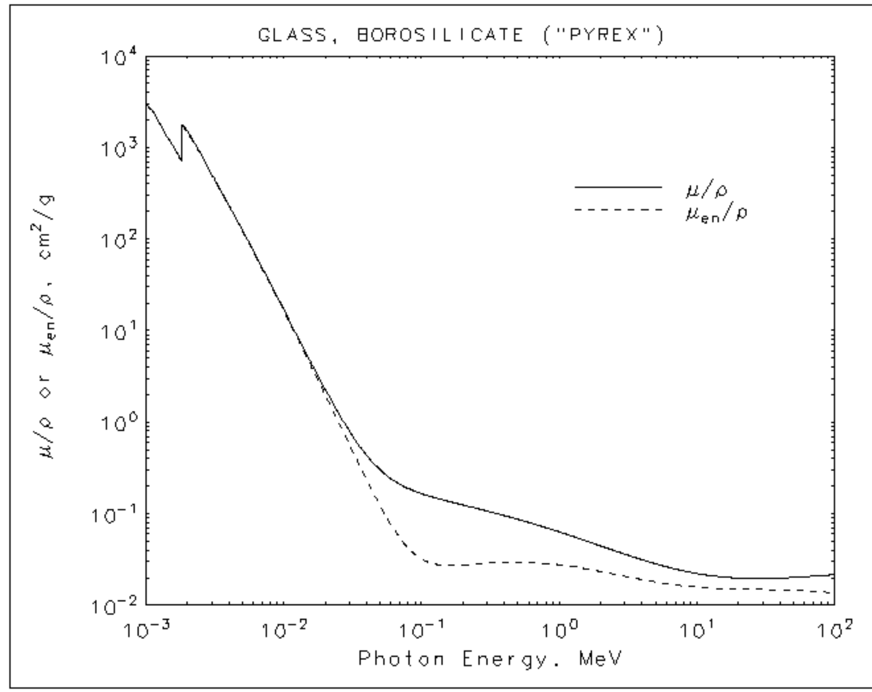
ρ = density of the material that the x ray are going through

I = Beam intensity with attenuation

I_0 = Beam intensity without attenuation

Use a value of .01 for the ratio I/I_0 to assume that all but 1.0% of x rays have been stopped

"The Hands-On Application of XRF Physics



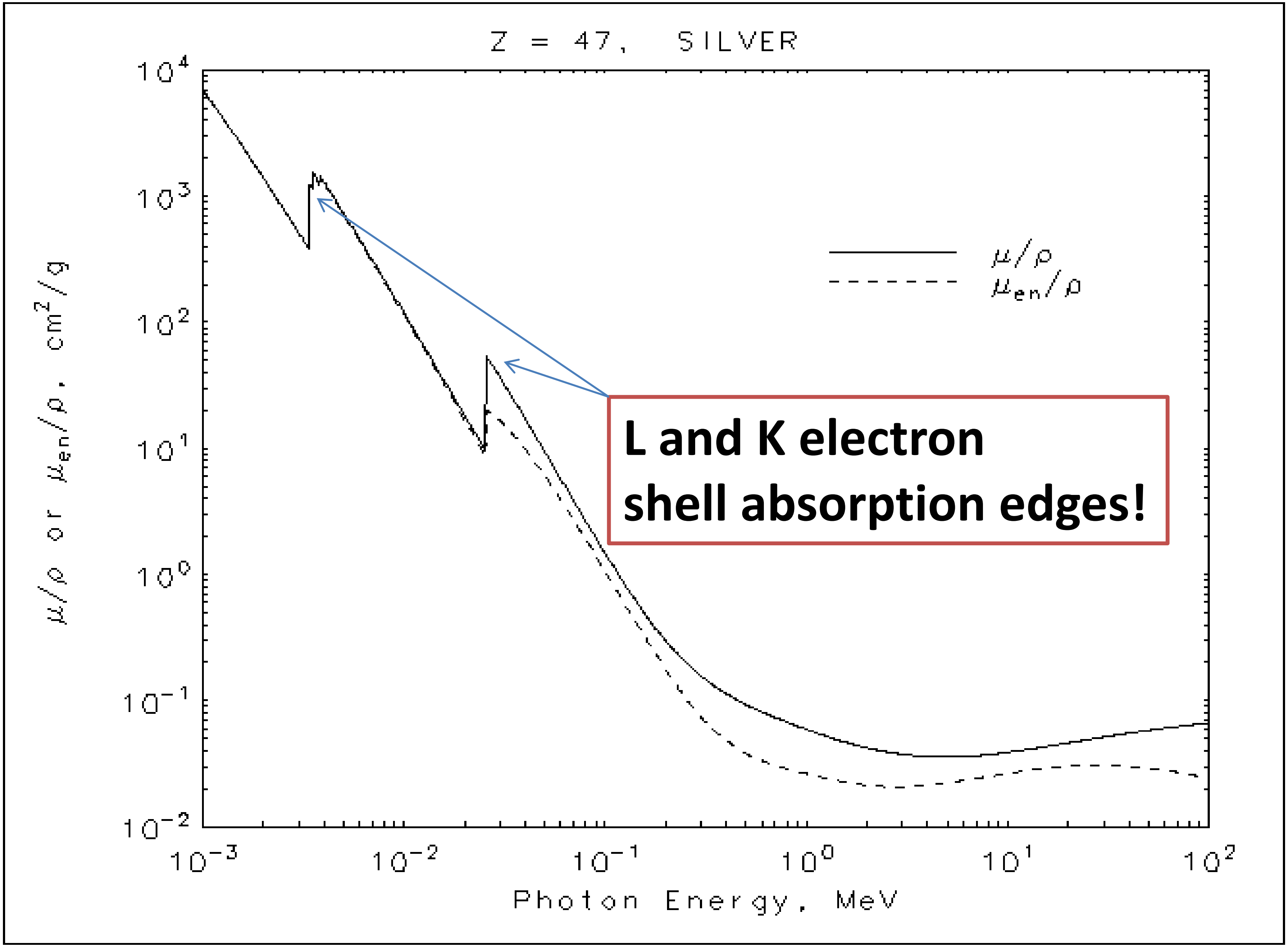
Dr. Buce J. Kaiser

Mass attenuation coefficients

material	Density	*6 keV*	*7 keV*	*8 keV*	*9 keV*	*10 keV*	*15 keV*	*22 keV*
aluminum	2.70E+00	**1.15E+02**	**8.03E+01**	**5.03E+01**	**3.90E+01**	**2.62E+01**	**7.96E+00**	**2.98E+00**
BSi glass	2.33E+00	**7.5E+01**	**5.2E+01**	**3.27E+01**	**2.40E+01**	**17.1E+01**	**5.21E+01**	**1.98E+00**
cobalt	8.90E+00	**9.37E+01**	**7.00E+01**	**3.25E+02**	**2.72E+02**	**1.84E+02**	**6.20E+01**	**2.42E+01**
iron	7.87E+00	**8.48E+01**	**5.32E+01**	**3.06E+02**	**2.60E+02**	**1.71E+02**	**5.71E+01**	**2.22E+01**
nickel	8.90E+00	**1.09E+02**	**7.50E+01**	**4.95E+01**	**1.90E+02**	**2.09E+02**	**7.08E+01**	**2.78E+01**
copper	8.90E+00	**1.16E+02**	**7.50E+01**	**5.26E+01**	**2.78E+02**	**2.16E+02**	**7.41E+01**	**2.92E+01**

Data used from this web site ***http://physics.nist.gov/PhysRefData/XrayMassCoef/cover.html***

My mass does a lot of intimidating!

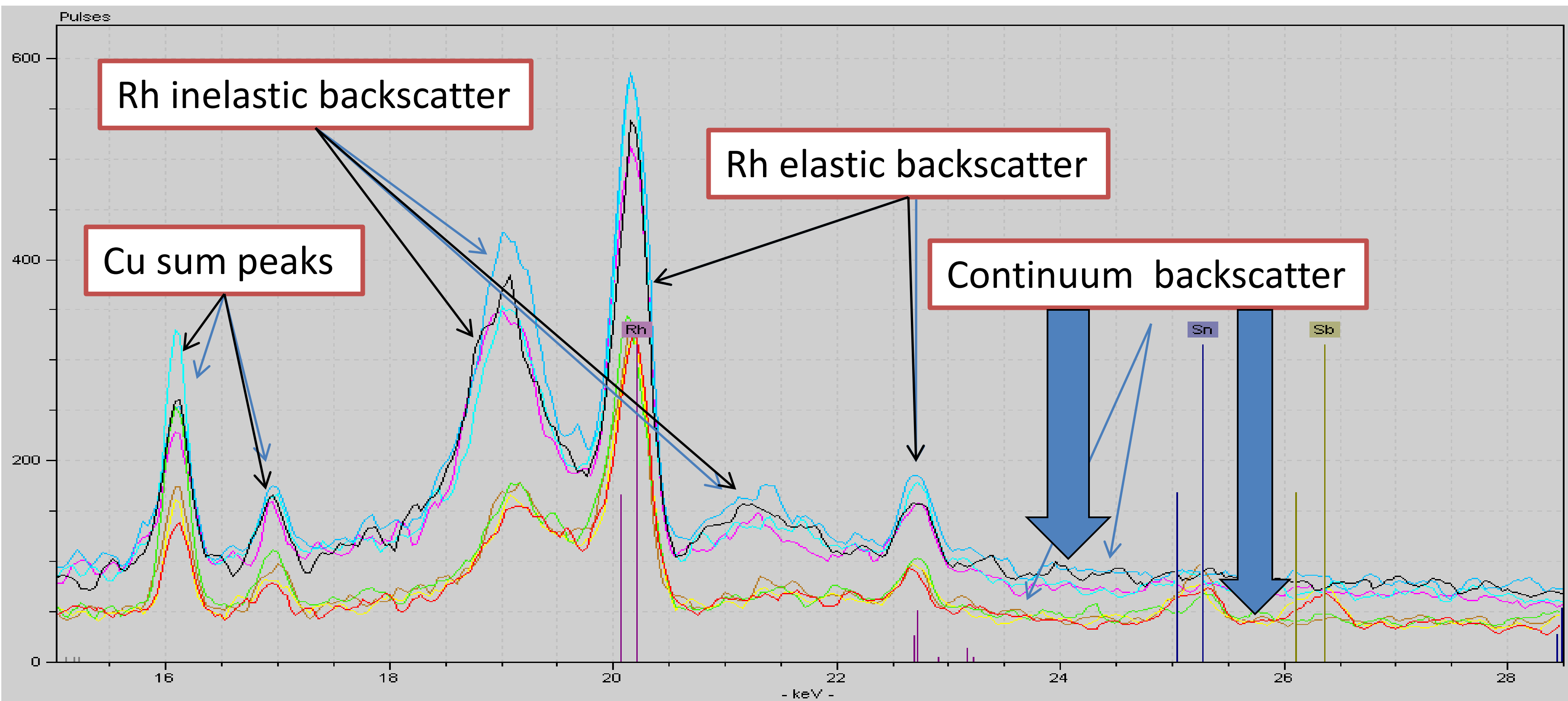


Z = 47, SILVER
10^4
10^3
10^2
10^1
10^0
10^{-1}
10^{-2}
μ/ρ or μ_{en}/ρ, cm^2/g
μ/ρ
μ_{en}/ρ
L and K electron
shell absorption edges!
10^{-3}
10^{-2}
10^{-1}
10^0
10^1
10^2
Photon Energy, MeV

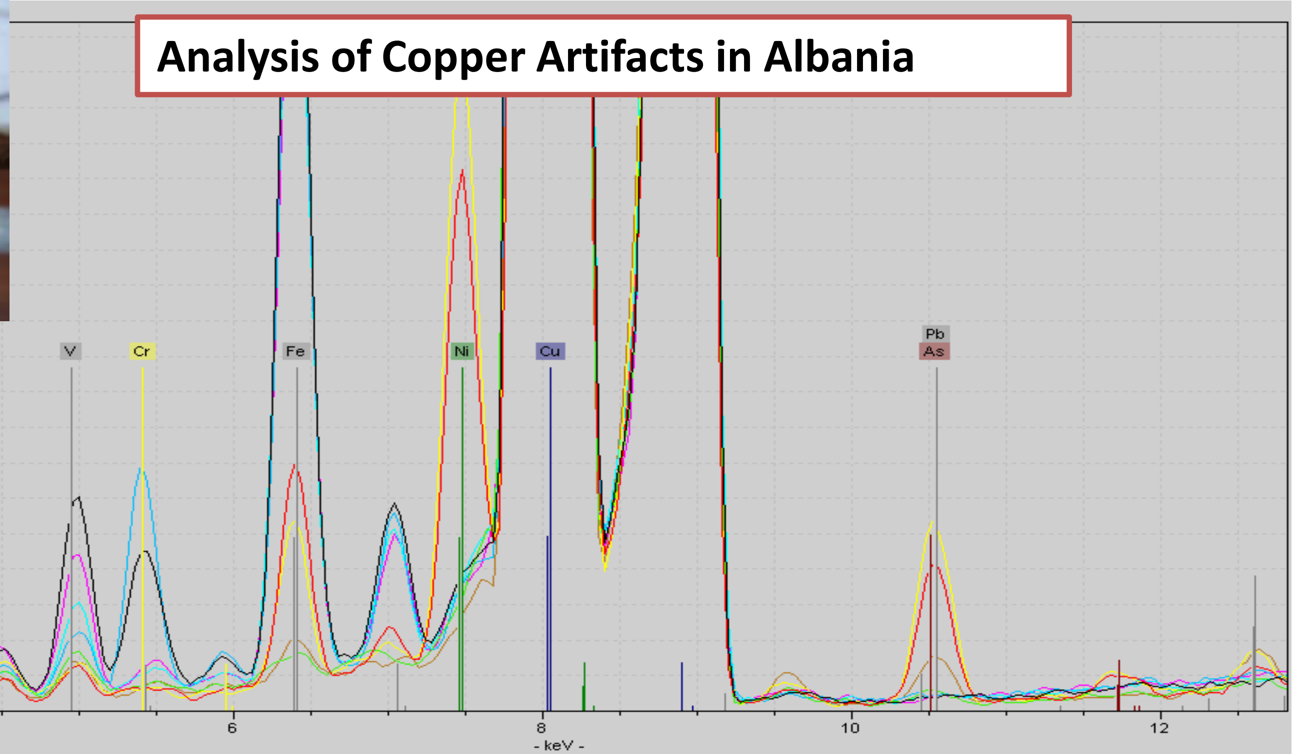
Analysis of Copper Artifacts in Albania

Maliq4687.2
Makiq4693.1
Maliq4687.1
Blaz16391.4
Blaz16391.1
Blaz16391.2
Blaz16391.3
Maliq4693.2

Below are the spectra of the analysis listed on the left.
This is a look at the overlay at the Rh k backscatter part of the spectra.
It is clear that the backscatter from Blaz is much more. Also the plot on the next page clearly shows the presence of Ca and Fe. This indicates that the Cu is covered with foreign material, including lower mass elements like O and C. **This is a non uniform material and thus the weight percent in the analysis is wrong on the next page for Blaz**. The backscatter for Maliq is typical of a Cu metal alloy and thus the weight percent numbers are accurate. ***See next page***



Analysis of Copper Artifacts in Albania



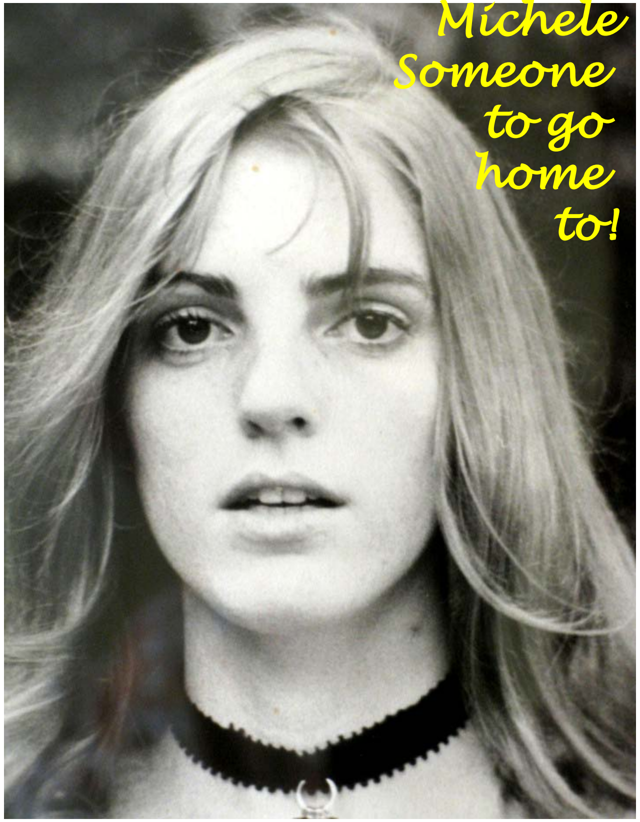
	Makiq4693.1	Maliq4693.2		Blaz16391.1	Blaz16391.2	Blaz16391.3	Blaz16391.4		Maliq4687.1	Maliq4687.2
Mn	0.00	0.01	Mn	0.01	0.03	0.05	0.05	Mn	0.00	0.00
Fe	0.00	0.03	Fe	0.84	1.01	1.04	1.03	Fe	0.22	0.31
Ni	0.00	0.00	Ni	0.00	0.00	0.00	0.00	Ni	0.96	0.78
Cu	99.29	97.98	Cu	95.87	94.81	94.93	94.27	Cu	94.71	94.95
ZnKa	0.00	0.36	ZnKa	0.47	0.64	0.42	0.73	ZnKa	0.17	0.20
ZnKb	0.07	0.58	ZnKb	0.06	0.18	0.06	0.04	ZnKb	0.32	0.21
AsKa	0.00	0.02	AsKa	0.00	0.00	0.00	0.00	AsKa	0.26	0.22
AsKb	0.06	0.07	AsKb	0.12	0.17	0.13	0.16	AsKb	0.34	0.35
PbLb	0.07	0.22	PbLb	0.00	0.00	0.00	0.00	PbLb	0.19	0.12
RhKa	0.00	0.00	RhKa	0.00	0.00	0.00	0.00	RhKa	0.00	0.00
Ag	0.01	0.01	Ag	0.05	0.07	0.08	0.11	Ag	0.01	0.02
Sn	0.14	0.33	Sn	0.21	0.22	0.28	0.26	Sn	0.28	0.31
Sb	0.07	0.11	Sb	0.22	0.30	0.31	0.38	Sb	0.33	0.30
SUM	99.72	99.71	SUM	97.84	97.42	97.30	97.04	SUM	97.79	97.75

Heavy metal poisons analysis on ethnographic collections

Poison analysis in the Tasmanian tiger at the Australian National Museum in Canberra

- 0.001” Cu, .001” Ti, and .012 Al Filter
- 40 kV
- 4 to 8 micro amps
- No vacuum
- These settings allow
  - All the x rays from 14 keV to 40 keV to reach the sample thus efficiently exciting the elements Hg, Pb, Br, As.
  - There is little or no sensitivity to elements below Ca with these settings reducing unneeded detector activity
  - Eliminates any background x rays under the peaks of interest

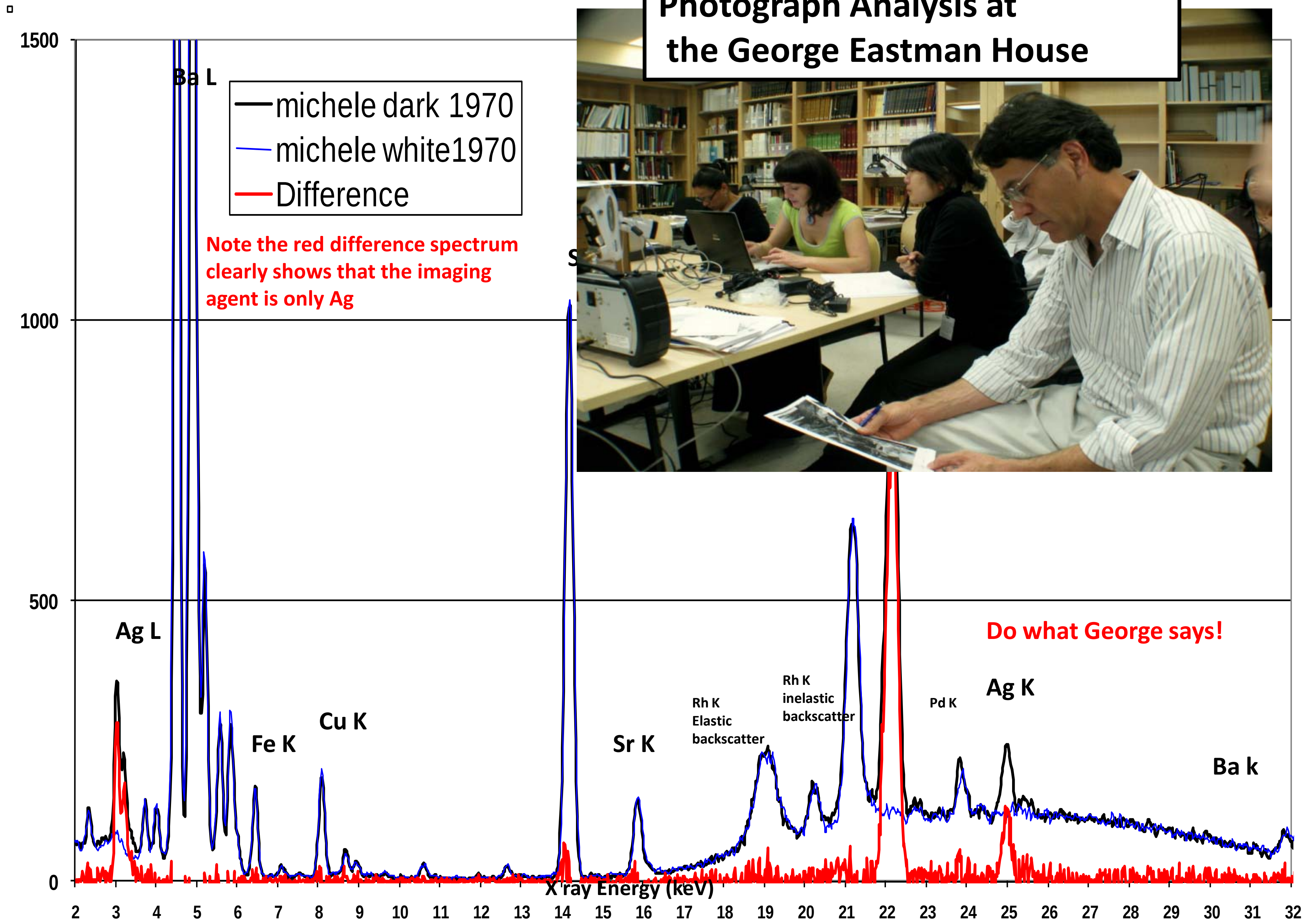
Measurement of Toning Agents on Photographs



- Use .006” Cu, .001 Ti, .012” Al filter
- Analyze at photograph
  - 40kV
  - 6 micro amps(what is available)
  - No vacuum
  - 5 to 10 min in
    - White area where there in no toner
    - Areas tone varies grey to black
- Take the difference (toned – white)

- The difference will give you a very good clean spectrum of the toning agent. And the grey to black variation will give you an estimate of the amount of agent. The reason this works so well are
  - The toning materials are very thin and have very little effect on the spectrum from the paper
  - The white are is just the paper and mounting materials
  - The filter used removes most of the backscattered x rays

Photograph Analysis at the George Eastman House



The operating parameters for these spectra was 15kV so this is particularly sensitive to the lower mass elements below Zn.