Spectroscopy in Analysis of Artworks ¶

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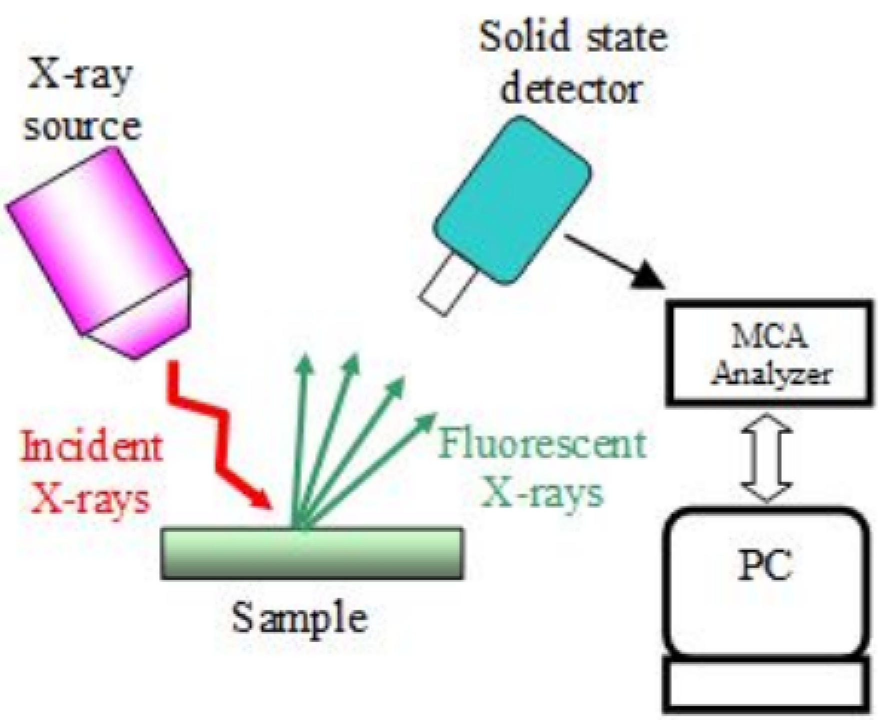
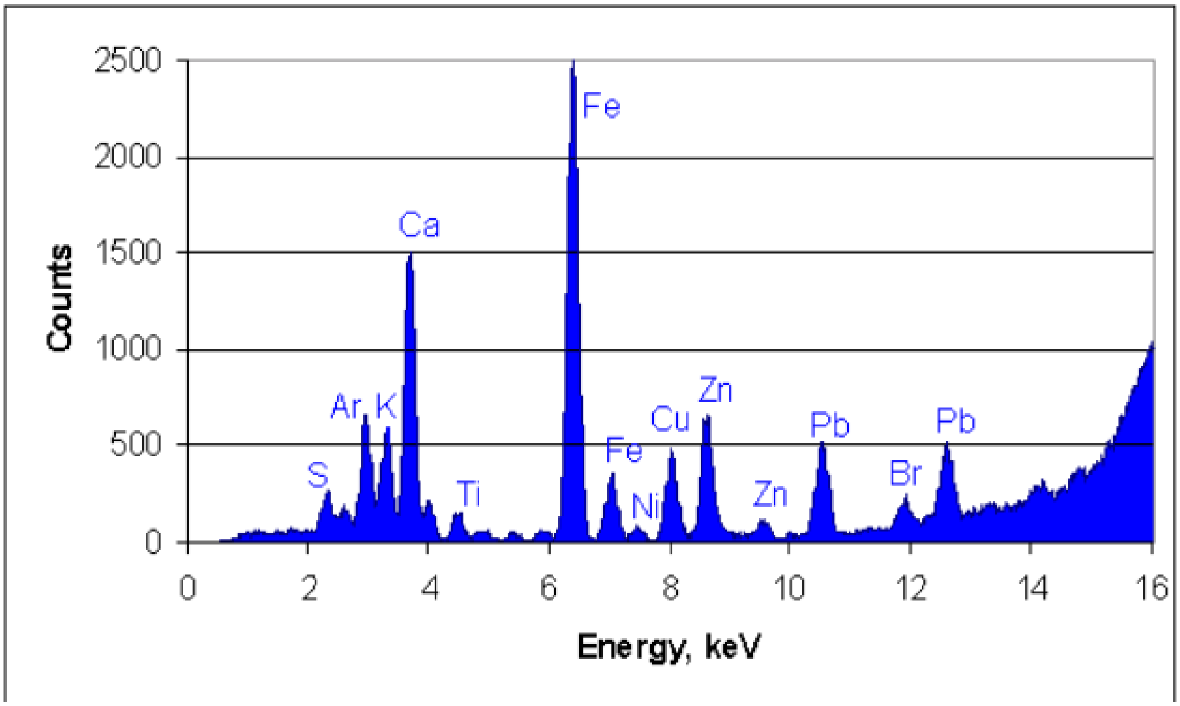
In modern art analysis, aspects of quantum physics are able to be used to determine the age, techniques, and materials used in te creation of a piece. One of the most commonly used methods is x-ray analysis, in which spectroscopy is used to perform an analysis of the pigment.

In this analysis, an x-ray photon source is put above a sample, where the incident gamma rays will interact with material, exciting the orbiting electrons. The material will then release photons as it relaxes back down to its ground state. Due to the nature of quantum mechanics, these photons will be released with set energy levels, corresponding to the difference of energy between energy states. Since the difference between these energy states is determined in part by the atomic number of the atom the electrons orbit, measurement of these photon energies can be used to trace backwards to determine the type of atoms which make up the material, and ultimately which material makes up the sample.



Below we have an example of data collected from x-ray analysis of a sample. Each peak represents a measured photon, released in the relaxtion from an excited state back down to the ground state.



Below here, we have a list of the calculated energies for each peak in the image above. As we can see, we are able to determine which energy corresponds to which peak if we know a given materials atomic number.

$$E_x = (Z-1)^2 \cdot 13.6\,[eV] \cdot \left(1 - \frac{1}{2^2}\right)$$

$$\text{for S: } Z = 16; \quad E_x = (15)^2 \cdot 13.6\,[eV] \cdot \left(1 - \frac{1}{2^2}\right) = 2.29\,[eV]$$

$$\text{for Ca: } Z = 20; \quad E_x = (19)^2 \cdot 13.6\,[eV] \cdot \left(1 - \frac{1}{2^2}\right) = 3.68\,[eV]$$

$$\text{for Ti: } Z = 22; \quad E_x = (21)^2 \cdot 13.6\,[eV] \cdot \left(1 - \frac{1}{2^2}\right) = 4.50\,[eV]$$

$$\text{for Fe: } Z = 26; \quad E_x = (25)^2 \cdot 13.6\,[eV] \cdot \left(1 - \frac{1}{2^2}\right) = 6.37\,[eV]$$

$$\text{for Zn: } Z = 30; \quad E_x = (29)^2 \cdot 13.6\,[eV] \cdot \left(1 - \frac{1}{2^2}\right) = 8.58\,[eV]$$

Finally, we can then cross reference the atomic makeup of a given sample found using the x-ray analysis methods above with a chart like the one below. This specific chart is a list of pigments that were made from natrually avalible materials, commonly found in pre 1800 oil paintings.

White pigments		Green pigments	
Antimony white	Sb_2O_3	Basic copper sulfate	$Cu_x(SO_4)_y(OH)_z$
Lithopone	$ZnO + BaSO_4$	Chromium oxide	Cr_2O_3
Permanent white	$BaSO_4$	Chrysocolla	$CuSiO_3 \cdot nH_2O$
Titanium white	TiO_2	Cobalt green	$CoO \cdot 5ZnO$
White lead	$2PbCO_3 \cdot Pb(OH)_2$	Emerald green	$Cu(CH_3COO)_2 \cdot 3Cu(AsO_2)_2$
Zinc white	ZnO	Guignent green	$Cr_2O_3 \cdot nH_2O + H_3BO_3$
Zirconium oxide	ZrO_2	Malachite	$CuCO_3 \cdot Cu(OH)_2$
Chalk	$CaCO_3$	Verdigris	$Cu(CH_3COO)_2 \cdot nCu(OH)_2$
Gypsum	$CaSO_4 \cdot 2H_2O$		
Yellow pigments		Blue pigments	
Auripigmentum	As_2S_3	Azurite	$2CuCO_3 \cdot Cu(OH)_2$
Cadmium yellow	CdS	Cerulean blue	$CoO \cdot nSnO_2$
Chrome yellow	$2PbSO_4 \cdot PbCrO_4$	Cobalt blue	$CoO \cdot Al_2O_3$
Cobalt yellow	$K_3[Co(NO_2)_6] \cdot 1.5H_2O$	Cobalt violet	$Co_3(PO_4)_2$

References

Wiescher, Michael, "Radioactivity: Lecture 25, Radioactivity and Art Analysis". From "Radioactivity and its implications for environment and society [Fall 2017]" class. University of Notre Dame, Institute for Structure and Nuclear Astrophysics, URL: https://isnap.nd.edu/assets/258293/radioactivity_lecture_25.pdf (https://isnap.nd.edu/assets/258293/radioactivity_lecture_25.pdf)

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