Proton-Induced X-Ray Emission Analysis of Indoor Atmospheric Aerosols

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Introduction

The Union College Ion Beam Analysis Laboratory (UCIBAL) uses a 1.1-MV pelletron accelerator to do Ion Beam Analysis (IBA) by detecting various types of reaction products that scatter from the interaction between an ion beam and a target sample in order to determine the elemental composition of the target. This interaction takes place inside of the part of the particle accelerator called the scattering chamber. We are installing and commissioning a new scattering chamber that increases the capabilities of UCIBAL. We are performing Proton-Induced X-Ray Emission (PIXE) analysis on atmospheric aerosol samples taken from inside Union College academic buildings as the commissioning experiment for the new chamber.

PIXE Analysis

PIXE is the main IBA technique used for elemental analysis of atmospheric aerosols in the Union College Ion-Beam Analysis Laboratory because it is a very powerful tool for the study of environmental pollution. It is well suited for this kind of work because of its high sensitivity and low detection limits for elements from Na to U, its non-destructive nature, its short sample preparation time, and its short analysis time.

Figure 1 shows a schematic diagram of PIXE in action. The sample of interest is bombarded with a beam of protons or alpha particles, occasionally knocking an inner-shell electron out of an atom in the sample, creating a vacancy (Figure 2). An outer-shell electron will lower its energy to fill this vacancy, emitting an X-Ray that can be detected (Figure 3). These X-Rays have energies that are characteristic to certain elements, allowing us to determine the elemental concentration of our sample. The concentration C_Z of an element Z present in the sample is given by

$$C_z = \frac{Y_z}{Y_t \cdot H \cdot Q \cdot \varepsilon \cdot T}$$

where Y_Z is the intensity of the principle X-ray line for element Z, Y_t is the theoretical charge intensity, H is an experimental constant determined by running on a set of standards, Q is the measured beam charge incident on the sample, ε is the intrinsic efficiency of the detector, and T is the coefficient for transmission through any filters or absorbers between the target and the detector.

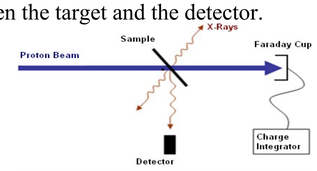

Figure 1: A schematic of a basic PIXE experimental setup for thin targets

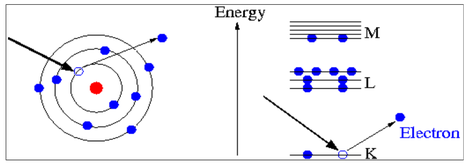

Figure 2: The ejection of an inner shell electron by a proton.

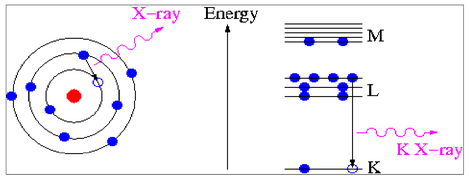

Figure 3: An X-ray is emitted when the void is filled by an outer shell electron.

Sample Collection

We use a nine-stage cascade impactor to collect the aerosol samples. The impactor uses principles of aerodynamics and inertia to and separate particulate matter based on its size and deposit it onto kapton foils. Figure 4 shows a schematic diagram and a picture of the impactor. We use a pump to draw air through the impactor at a rate of about one liter per minute for about forty eight hours. After the aerosol samples are deposited on the kapton foils, we remove them and place them in the scattering chamber to run PIXE analysis on them. Our new scattering chamber is useful for this because it is big enough to hold multiple samples on a target ladder that I designed.

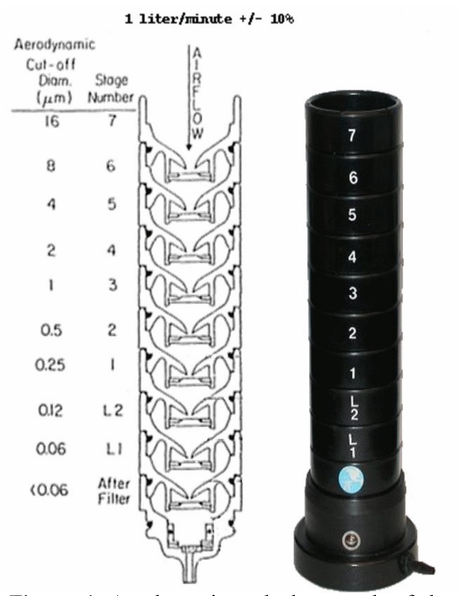

Figure 4: A schematic and photograph of the nine stage cascade impactor.

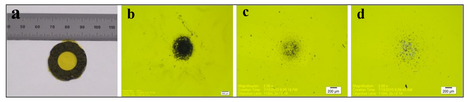

Figure 5: A kapton impaction foil (a) and several microscopic images of aerosol deposits (b-d).

Experiment

The PIXE experiments were performed using the Union College Pelletron Accelerator shown in Figure 6. Proton beams with an energy of about 2.2 MeV and a diameter of 2 mm were incident on the samples positioned at 45° to the beam in a small scattering chamber. Beam currents of 2 to 4 nA were measured in a Faraday cup behind the scattering chamber. We use an Amptek Silicon Drift Detector (SDD) to detect the energies and quantities of the emitted X-Rays. The SDD detector was calibrated using an ^{241}Am source. We collect energy spectra of the emitted X-Rays for each aerosol sample. Figure 7 shows me with the new scattering chamber installed on the particle accelerator.

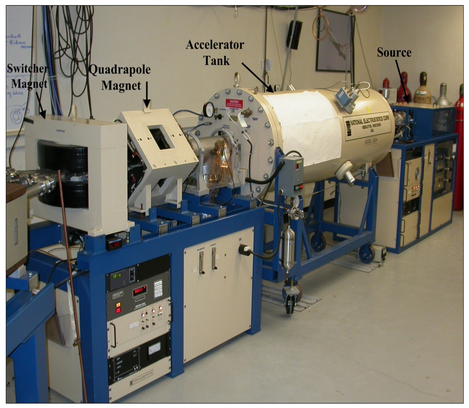

Figure 6: A photograph of the Union College Pelletron Accelerator.

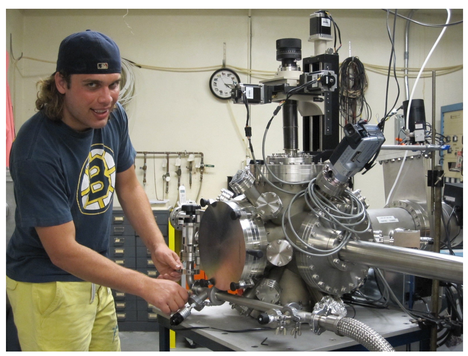

Figure 7: The new scattering chamber uses electronic motors to position the samples in the beam line.

Data Fitting

After acquiring PIXE spectra, we use GUPIX software to analyze the data and generate a fit in order to determine the elemental contents and concentrations of the sample. After running GUPIX on a set of PIXE spectra generated by running on standards, we determine an H value for the software to use with the concentration equation. I have done a comparative study to determine when it is appropriate to subtract the blank kapton contribution to the spectrum before running GUPIX. Pictured below are some spectra and a concentration chart from samples taken inside of the science and engineering building.

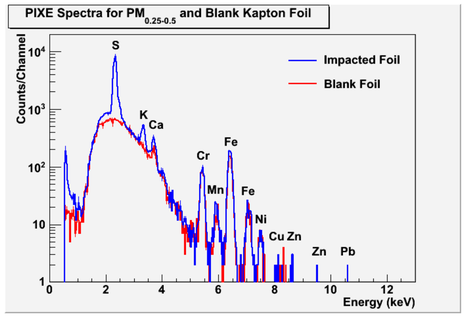

Figure 8: The PIXE spectrum for particulate matter between 0.25 and 0.5 microns in size taken from inside the Science and Engineering building. The spectrum is superimposed over the blank kapton spectrum. Only sulfur, potassium and calcium show a concentration significantly greater than the kapton contribution.

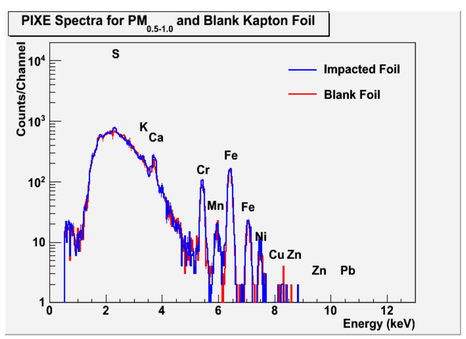

Figure 9: The PIXE spectra for particulate matter of sizes greater than 0.5 microns in size did not show any concentrations significantly greater than the kapton contribution. This could be caused by missing the aerosol deposit with our beam.

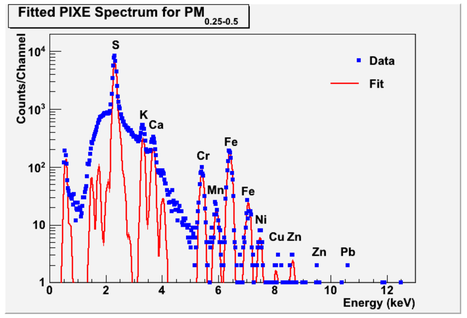

Figure 10: GUPIX software generates a fit to the PIXE spectra. This is the GUPIX fit for the PIXE spectrum for particulate matter between 0.25 and 0.5 microns in size taken from inside the Science and Engineering building. Here, we did not subtract the kapton contribution to the PIXE spectrum before running GUPIX.

Element	SE1 Concentration (ng/cm²)	Kapton Concentration (ng/cm²)	Subtracted Concentration (ng/cm²)	Subtracted Concentration (μg/l)
S	3,677	10.7	3,666.3	1.27×10^{-3}
K	183.2	14.03	169.17	5.87×10^{-5}
Ca	141.2	80.55	60.65	2.1×10^{-5}

Figure 11: A table of the elemental concentrations of sulfur, potassium and calcium found for particulate matter between 0.25 and 0.5 microns in size taken from inside the Science and Engineering building. The concentrations for these elements on the blank kapton foil are also shown. We have subtracted the concentrations to give us a better idea for the concentrations due to the aerosol deposit only. GUPIX gives these numbers in units of ng/cm². We have converted these to units of μg/L to give us a better idea of the actual concentration of the aerosols in their environment.

Future Work

As an environmental application of nuclear physics, we plan to acquire and analyze aerosol samples from inside of both he science and engineering and Wold buildings in order to compare the effectiveness of their air filtration systems.