Particle Induced X-Ray Emission of Atmospheric Aerosols

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Introduction

We are developing a research program in ion-beam analysis (IBA) of atmospheric aerosols at the Union College Ion-Beam Analysis Laboratory to study the transport, transformation, and effects of airborne pollution in Upstate New York. The simultaneous applications of the IBA techniques of particle-induced X-ray emission (PIXE), Rutherford back-scattering spectrometry, particle-induced gamma-ray emission, and proton elastic scattering analysis is a powerful tool for the study of airborne pollution because they are non-destructive and provide quantitative information on nearly all elements of the periodic table.

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. Some of the properties that make it well suited for this kind of work are its high sensitivity and low detection limits for elements from Na to U, it is non-destructive, requires little sample preparation, and has short analysis times[1].

A schematic of a basic PIXE experimental setup is shown in Figure 1. The sample of interest is bombarded with a beam of protons, occasionally, knocking an inner-shell electron out of an atom in the sample, creating a vacancy (Figure 2). This allows an outer-shell electron to fill the hole, releasing an X-ray that can be detected (Figure 3). Each element emits characteristic X-rays which allow us to determine the elements present in the 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 intensity per micro-Coulomb of charge, H is an experimental constant determined by taking data 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.

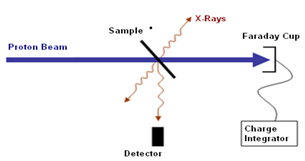

Figure 1: A schematic of a basic PIXE experimental setup for thin targets

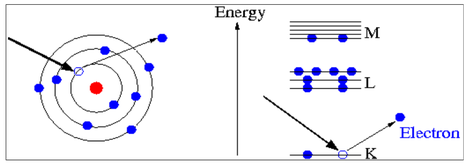

Figure 2: The ejection of an inner shell electron by a proton.

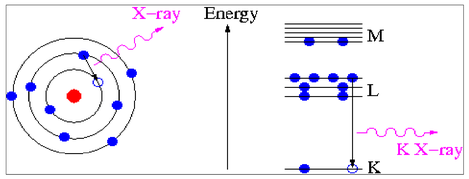

Figure 3: An x-ray is emitted when the void is replaced by an outer shell electron.

Sample Collection

A nine-stage cascade impactor is used to collect the aerosols and separates them based on their particle size [2]. Shown in Figure 4 is a schematic and photograph of the impactor. The impactor was attached to a vacuum pump which drew air through the impactor at a rate of 1 L/min for approximately 48 hours. This corresponds to a total of approximately 2.7 m^3 of air that flowed through the impactor. Particles of different aerodynamic diameter ranges were impacted on Kapton foils in each stage. The thin Kapton foils, shown in Figure 5, were removed and used as targets in the PIXE experiments with the accelerator.

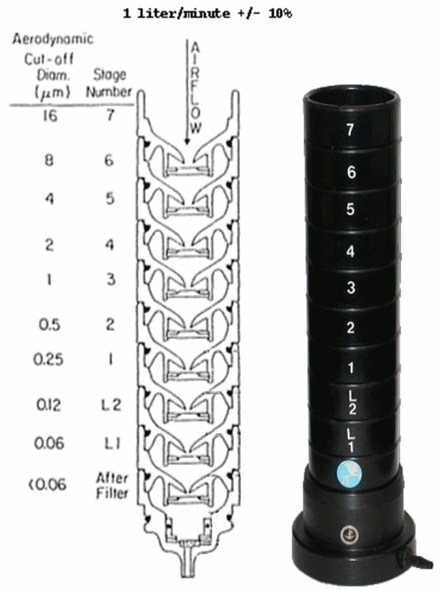

Figure 4: A schematic and photograph of the nine stage cascade impactor [2].

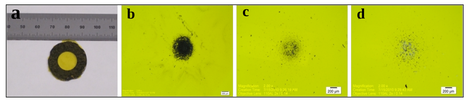

Figure 5: A photograph of an impaction foil (a) and several microscopic images of aerosol deposits (b-d).

Experiment

The PIXE experiments were performed using the Union College Pelletron Accelerator shown in Figure 6. Proton beams with an energy of 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. The X-rays were detected with a silicon drift detector (SDD) at 45° to the target, after passing through a 76-μm thick Be vacuum window on the chamber. The SDD detector was calibrated using an ^{241}Am source. Energy spectra of the emitted X-rays were collected for all the aerosol samples and a set of Micromatter standards [3]. A picture of the scattering chamber, the Faraday cup, and the SDD detector is shown in Figure 7.

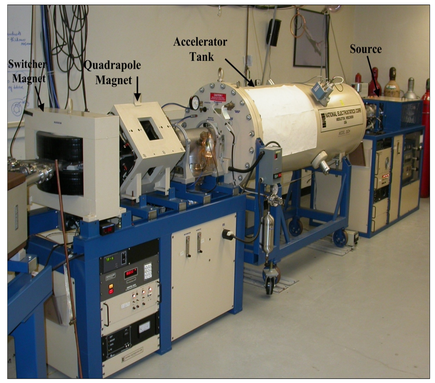

Figure 6: A photograph of the Union College Pelletron Accelerator.

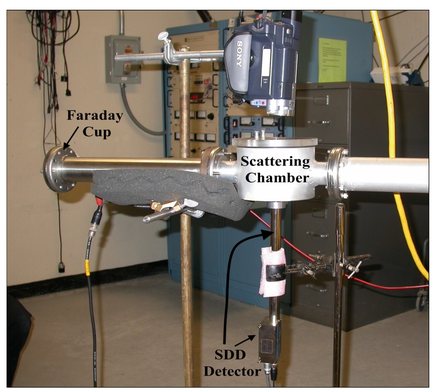

Figure 7: A photograph of the scattering chamber, SDD detector, and Faraday cup.

Preliminary Results

Preliminary results are presented in Figures 8-11. Shown in Figure 8 is a GUPIX [4] fit to the data for aerosols with a diameter between 2-4 microns. The fit is used to extract the elemental concentration for each element present in the sample. Figure 9 shows a comparison of PIXE spectra for a blank Kapton foil and an impacted foil for aerosols between 2-4 microns in diameter. Figures 10-12 are PIXE spectra comparing samples taken at the Vale Cemetery crematorium and the Union College Boathouse in Schenectady, NY for aerosols ranging between 0.25-0.5 microns, 0.5-1 micron, and 2-4 microns, respectively. The samples at Vale Cemetery were taken during the winter of 2010 whereas the samples at the Union College Boathouse were taken during the summer of 2009. We want to understand the differences in elemental concentrations from the two locations and be able to identify possible sources of pollution. We plan to continue the study of aerosols at these locations and to perform a comparative study of urban to rural aerosols.

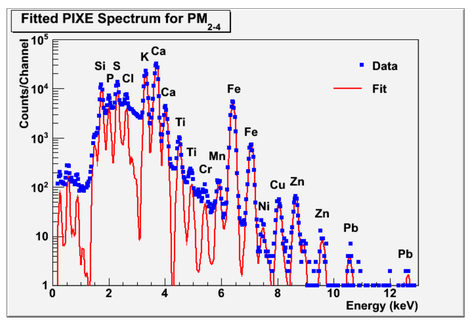

Figure 8: PIXE spectrum for particulate matter ranging in size between 2-4 microns. The red line is the fit of the data (blue) generated by GUPIX [4].

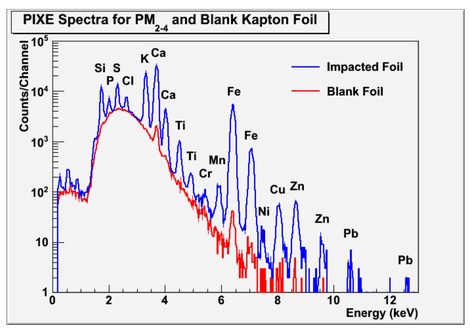

Figure 9: Comparison of PIXE spectra taken on an impacted Kapton foil with particulate matter between 2-4 microns (blue) and a blank Kapton foil (red).

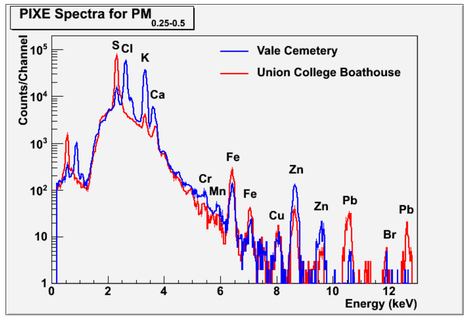

Figure 10: PIXE spectra comparing samples taken at Vale Cemetery (blue) and the Union College Boathouse (red) for particulate matter between 0.25-0.5 microns.

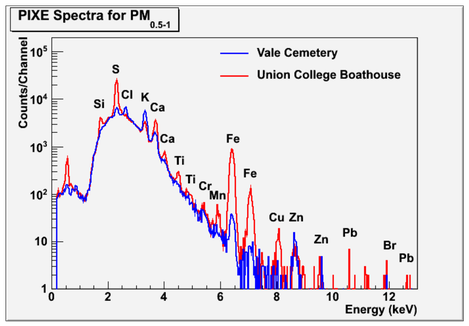

Figure 11: PIXE spectra comparing samples taken at Vale Cemetery (blue) and the Union College Boathouse (red) for particulate matter between 0.5-1 micron.

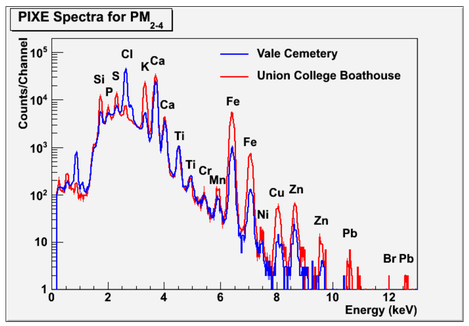

Figure 12: PIXE spectra comparing comparing samples taken at Vale Cemetery (blue) and the Union College Boathouse (red) particulate matter between 2-4 microns.

References

[1] Johansson, Sven, John Campbell, and Klas Malmqvist. *Particle Induced X-Ray Emission Spectrometry (PIXE)*. New York, NY: John Wiley & Sons, 1995.
[2] PIXE International Corporation, P.O. Box 2744, Tallahasee, FL 32316 U.S.A.
[3] MicroMatter Co., 18218 18th Ave. NW, Arlington, WA 98223, U.S.A.
[4] GUPIX, the versatile PIXE spectrum fitting software, University of Guelph.