Ion-Beam Analysis of Airborne Pollution

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Introduction

An undergraduate laboratory research program in ion-beam analysis (IBA) of atmospheric aerosols is being developed to study pollution in the Capitol District and Adirondack Mountains of New York. The IBA techniques applied in this project include proton induced X-ray emission (PIXE), proton induced gamma-ray emission (PIGE), Rutherford backscattering (RBS), and proton elastic scattering analysis (PESA). These methods are well suited for studying air pollution because they are quick, non-destructive, require little to no sample preparation, and capable of investigating microscopic samples. While PIXE spectrometry is used to analyze most elements from silicon to uranium, the other techniques are being applied to measure some of the remaining elements and complement PIXE in the study of aerosols. The airborne particulate matter is collected using nine-stage cascade impactors that separate the particles according to size and the samples are bombarded with proton beams from the Union College 1.1-MV Pelletron Accelerator. The reaction products are measured with SDD X-ray, Ge gamma-ray, and Si surface barrier charged particle detectors. Here we report on the progress we have made on the RBS and PESA analysis of aerosol samples.

Particle Accelerator

At the Union College Ion-Beam Analysis Laboratory, ions are provided by a pelletron accelerator as shown in Figure 1. Here, ions are produced at the source, then accelerated through the tank up to 2.2 MeV for protons. The quadrupole and switcher magnets focus and steer the beam, respectively.

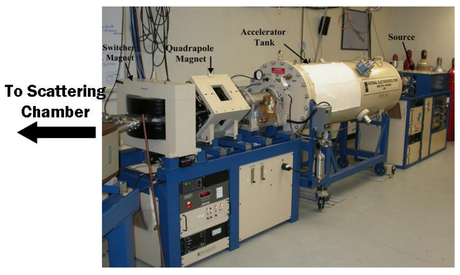

Figure 1: Union College's 2.2 MeV pelletron accelerator.

Environmental samples for RBS and PESA analysis are placed in the scattering chamber seen in Figure 2. An ion-beam enters the chamber and hits the target in the center. Most of the ions pass through the target and exit to the Faraday cup, but a small fraction will deflect and scatter at various angles. The Faraday cup counts the charge accumulated on the sample, and is important for elemental concentration calculations. A silicon surface barrier detector sits at a specific angle, counting ions to produce an RBS or PESA energy spectrum.

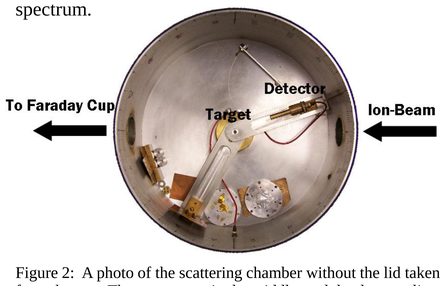

Figure 2: A photo of the scattering chamber without the lid taken from the top. The target rests in the middle, and the detector lies at various angles around the perimeter.

Aerosol Sampling

One application of IBA is to study air samples. A nine stage cascade impactor separates particles into stages based on their size. Particles are impacted on Kapton backings. The impactor and our experimental apparatus, seen in Figure 3, are quick and easy to assemble and transport to collection sites. The pump pulls air through the tubing to the impactor, and the valve controls the flow rate which is monitored by the flow meter [1].

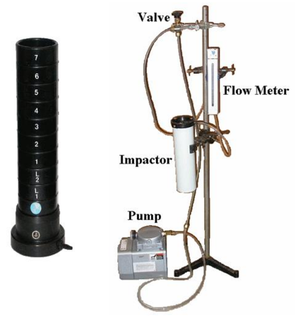

Figure 3: The nine stage impactor (left) and our experimental apparatus with the impactor, pump, flow meter, and valve labeled.

Vale Cemetery Crematorium

Schenectady's Vale Cemetery Crematorium is one of our collection sites (Figure 4). We investigated concerns that the cremation process releases toxic metals, such as mercury, into the atmosphere. Our apparatus sat on the roof of the Crematorium with the pump in the garage connected to a power source. We collected samples for about two days at a flow rate of 1 L/min.

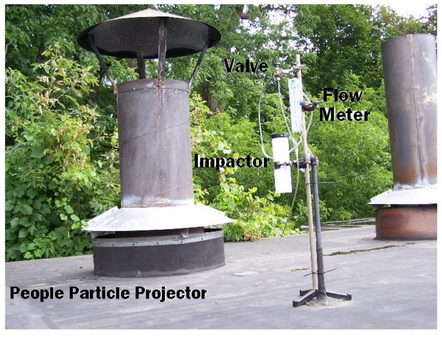

Figure 4: Our apparatus next to the cremation emission stack at Vale Cemetery.

Proton-Induced X-Ray Emission

PIXE analysis measures X-rays. When a proton beam is incident on a sample, some fraction of the time an inner shell electron is ejected from some nucleus in the sample, creating a void. This hole is filled by an outer shell electron, which gives off an X-ray in the transition process. The energy and amount of a certain X-ray relates to an element and its concentration present in the sample [2].

IBA analysis primarily employs the use of PIXE because it distinguishes between a large range of elements in a sample. Figure 5 shows a PIXE spectrum taken on an aerosol sample at the crematorium containing particles between 2 and 4 μm in diameter along with a spectrum of a blank Kapton foil. Many peaks are present in the PIXE spectrum, each corresponding to an element.

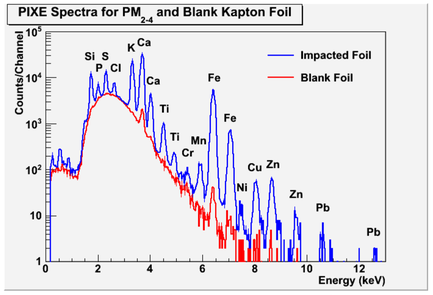

Figure 5: A comparison between PIXE spectra taken on an aerosol sample (blue) and a blank Kapton foil (red). The sample was for particulate matter between 2 and 4 μm, and the peaks are labeled according to the corresponding elements. A total charge of 15 μC was collected for each spectrum.

Rutherford Backscattering

RBS studies backscattered ions. A beam of ions is incident on target. Most of the ions pass through the target, but some fraction of the time an ion collides with a nucleus. We assume an elastic collision, and there is a probability that the ion will backscatter, as opposed to forward scatter. Elements in the sample are identified by measuring the energy and angle of the scattered ions, and applying conservation of momentum and kinetic energy laws. Elemental concentrations are determined by measuring the number of ions scattered at a particular angle and energy [3].

Two fitted RBS spectra taken on standards are seen in Figures 6 and 7. The first standard is consists of gold foil evaporated on a Mylar backing using a 1.8 MeV proton beam at 140 degrees, while the second is gold foil evaporated on aluminum using a 3.3 MeV alpha beam at 140 degrees. The black line is the data, while the red is the RUMP simulation [4]. It is well known that alpha particles produce better resolution than protons, but PIXE analysis requires a proton beam, so we settle for less resolution in our RBS analysis. In Figure 6, we modeled the gold peak nicely, determining a thickness of 230 angstroms which agrees with the thickness provided by the manufacturer. But, Mylar—a hydrocarbon—is tough to model. The fit has the right shape, but it is a work in progress. Figure 7 shows carbon and oxygen peaks separated as expected with the alpha particles. This spectrum proved easier to fit.

Vale Cemetery Analysis

Unlike the standards, analyzing environmental materials with RBS is non-trivial. Figure 8 shows an RBS spectrum of aerosol particles between 0.25 and 0.5 μm taken at the Crematorium. We observe no distinct single-element peaks, and our sample is practically lost in the Kapton foil.

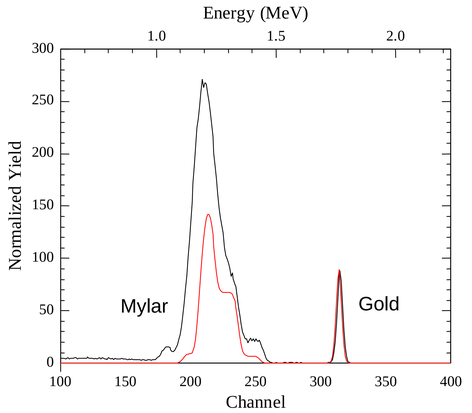

Figure 6: A labeled RBS energy spectrum of a gold standard evaporated on Mylar using a 1.8 MeV proton beam. The red curve is a fit to the data using RUMP [4].

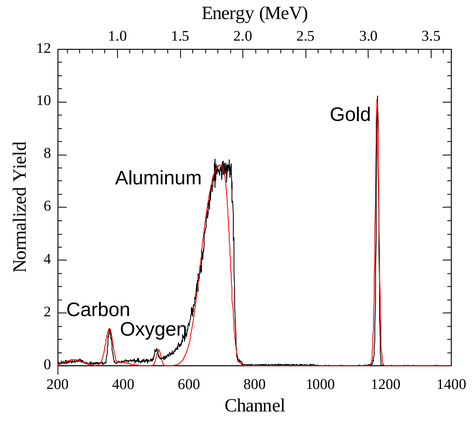

Figure 7: A labeled RBS energy spectrum of gold a standard evaporated on aluminum using a 3.3 MeV alpha beam. The red curve is a fit to the data using RUMP [4].

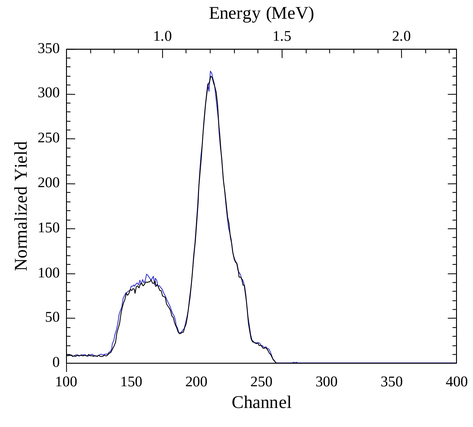

Figure 8: An RBS energy spectrum of aerosol particles between 0.25 and 0.5 μm in diameter taken at the Vale Cemetery Crematorium. (blue), and an RBS spectrum of blank Kapton (black).

Proton Elastic Scattering Analysis

PESA is a form of elastic recoil detection. When protons or alpha particles strike a hydrogen atom, the hydrogen bounces away from the beam. The hydrogen atom will strike the detector with a certain energy, dependant on the beam energy and the angle at which it off the beam [5].

We placed the silicon surface barrier detector at angles of 25 (Figure 9), 30, and 40 degrees. When the beam interacted with the particles, protons could be knocked out of the sample, or protons could deflect off heavier particles. The graphs of the energies of the deflected particles had two main peaks: a peak for hydrogen, and a peak for all other elements.

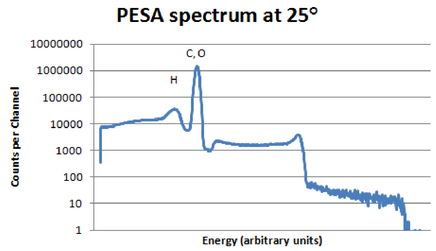

Figure 9: A PESA spectrum taken on an aerosol sample with particles between 0.25 and 0.5 μm at 25° with peaks labeled.

There seem to be other peaks besides those of hydrogen and the large peak of other elements. We are not sure what causes those peaks. Most spectra we have found in papers cut off their spectra after the carbon/oxygen peak. A future task would be to determine exactly what causes the extra peaks. Also, though we have a formula to calculate yields, there are still problems, as we regularly find the amount of hydrogen in the sample is greater than expected by about a factor of 100.

Conclusion

We have investigated secondary IBA techniques, RBS and PESA, to complement PIXE. We must consider PIGE and continue to develop these methods. To fully apply our analysis we must construct a scattering chamber that allows for the simultaneous application of all four IBA techniques.

References

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[2] S.A.E. Johansson, J.L. Campbell, and K.G. Malmqvist, "Particle-Induced X-Ray Emission Spectrometry (PIXE)" (Wiley, New York, 1995).
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[4] GENPLOT and RUMP Documentation, http://genplot.com/.
[5] Cohen, D. D. (1993), Applications of simultaneous IBA techniques to aerosol analysis, Nuclear Inst. Methods, B79, 385-88.

Acknowledgements

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