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Undergraduate Research and Training in Ion-Beam Analysis of Environmental Materials

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Abstract

We have an active undergraduate research program at the Union College Ion-Beam Analysis Laboratory (UCIBAL) focused on the study of environmental materials. Accelerator-based ion-beam analysis (IBA) is a powerful tool for the study of environmental pollution because it can provide information on a broad range of elements with high sensitivity and low detection limits, is non-destructive, and requires little or no sample preparation. It also provides excellent training for the next generation of environmental scientists. Beams of protons and alpha particles with energies of a few MeV from the 1.1-MV tandem Pelletron accelerator (NEC Model 3SDH) in the UCIBAL are used to characterize environmental samples using IBA techniques such as proton-induced X-ray emission, Rutherford back-scattering, and proton-induced gamma-ray emission. Recent projects include the characterization of atmospheric aerosols in the Adirondack Mountains of upstate New York, the study of heavy metal pollutants in river sediment, measurements of Pb diffusion in sulfide minerals to help constrain the determination of the age of iron meteorites, and the search for heavy metals and toxins in artificial turf.

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Keywords: Atmospheric aerosols; river sediment; artificial turf; Pb diffusion; heavy metals; PIXE; RBS; ERDA

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1. Introduction

Ion-beam analysis (IBA) is a powerful group of analytical techniques for determining the elemental composition of materials using ion beams with energies of a few MeV, Natasi et al. (2015). The IBA methods are non-destructive, highly sensitive, often require little or no sample preparation, and can be used to perform the analyses of materials much more quickly than many other analytical procedures. The applications of the IBA techniques of proton-induced X-ray emission (PIXE), proton-induced γ -ray emission (PIGE), Rutherford back-scattering (RBS), proton elastic scattering analysis (PESA), and elastic recoil detection analysis (ERDA) can provide quantitative information on a broad range of elements from hydrogen to lead. These techniques can also be used to obtain elemental depth profiles and maps of elemental distributions along surface layers of materials.

In this paper, we describe our lively undergraduate research program at the Union College Ion-Beam Analysis Laboratory (UCIBAL) on elemental analysis of environmental materials. The instrumentation in the UCIBAL is described in Section 2. In Section 3, we briefly discuss several recent projects. These include the characterization of atmospheric aerosols in the Adirondack Mountains, the study of heavy metal pollutants in river sediment, measurements of Pb diffusion in sulfide minerals to help constrain the determination of the age of iron meteorites, and the search for heavy metals and toxins in artificial turf. Finally, a summary is presented in Section 4.

2. The Union College Ion-Beam Analysis Laboratory

The primary instrument in the UCIBAL is the 1.1-MV tandem Pelletron accelerator (National Electrostatics Corporation Model 3SDH) shown in Fig. 1. An RF charge-exchange ion source is used to produce beams of H^- and He^- ions for injection into the tandem accelerator. The negative ions are accelerated toward the positively charged terminal at the center of the accelerator tank where they pass through a low-pressure nitrogen gas to strip electrons off the ions. The positive ions are then accelerated away from the terminal. At the high-energy end of the accelerator tank there is a mixture of charge states and energies. The ions then pass through a quadrupole magnet used for focusing and a dipole magnet used to bend the beam of interest into the beam-line toward the scattering chamber. The beam-line is equipped with steering magnets and a beam profile monitor. The accelerator produces proton and α -particle beams with energies up to 2.2 and 3.3 MeV, respectively, and currents of 1 - 30 nA on target.

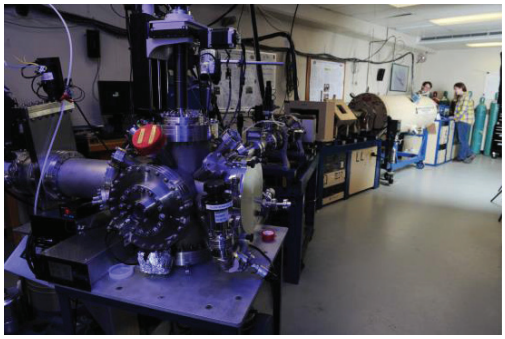

Fig. 1: A photograph of the 1.1-MV tandem Pelletron accelerator in the UCIBAL.

Most of the samples of interest are bombarded with the ion beams in the multipurpose scattering chamber that we developed to support our IBA program, LaBrake et al. (2013). The chamber was constructed from a ten-inch, multi-way cross and includes a four-axis target manipulator and target ladder assembly that can hold three targets. It is equipped with an eight-inch turbo pump that allows the chamber to be rapidly pumped down to operating vacuum. The chamber can accommodate multiple silicon drift X-ray detectors for PIXE measurements, a CdTe γ-ray detector for PIGE analysis, and multiple charged particle detectors for RBS, PESA, and ERDA measurements. A photograph of the inside of the scattering chamber is shown in Fig. 2.