Proton Induced Gamma-Ray Emission (PIGE) Spectroscopy

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Introduction

Using proton induced gamma-ray emission (PIXE), Fluorine samples were analyzed to determine the effectiveness of using proton induced gamma-ray emission with the Union College Pelletron Accelerator and our Germanium Lithium gamma-ray detector (Figures 1, 3). This was done so that we could develop a method for analyzing samples through a process known as Particle Induced Gamma-Ray Emission, or PIGE. If this method proves effective, then we would have a more useful method for determining the concentration of lighter elements in our samples. PIGE is most sensitive for lighter elements, and would allow us detect elements which cannot be picked up be PIXE, RBS or PESA, such as lithium and oxygen. This makes PIGE a good complementary technique for these other analytical methods. A 1.8 MeV beam of protons was incident on the fluorine standards on thin Mylar backings produced gamma-rays that were measured using a germanium detector. The gamma-ray spectra were fit using Peakfit software to determine the yields of the fluorine peaks.

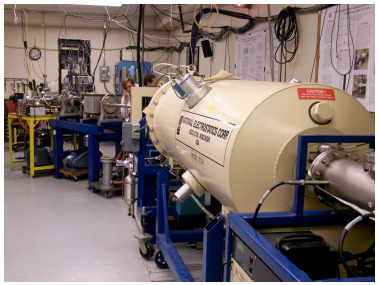

Figure 1: A photo of the Union College Pelletron Accelerator, showing the accelerator tank, ion pump, and scattering chamber.s

PIGE Spectroscopy

Gamma rays are emitted from the nucleus whenever a proton or neutron induces a transition to a higher energy state. This happens naturally for some radioactive nuclei, but has to be induced in most. In PIGE, high energy proton beams are used to bombard samples in order to excite the particles inside the nucleus and induce the higher energy transition. A fraction of the protons that hit the sample are able to penetrate the electron cloud and interact with the nucleus. The rest of the protons that interact with the atom are responsible for PIXE, RBS and PESA. The proton then induces a nuclear reaction, causing the nucleus to emit a gamma-ray along with possibly a proton, neutron, alpha particle or beta particle (Figure 2). The energy of the emitted gamma ray is characteristic of a particular elemental nuclear reaction, so the composition of a sample can be determined by the measuring the gamma-ray energies. In the case of our experiment, we were looking for fluorine, which has two gamma ray peaks at 110 and 197 keV.

PIGE is most effective when used to analyze lighter elements, typically ranging from lithium (Z = 3) to calcium (Z = 20). This is because as the atom number of the atom rises, so does the magnitude of the repulsive coulomb force of the nucleus, making it more difficult for the proton beam to interact with the nucleus and excite one of the protons or neutrons inside it. While using PIGE exclusively is limiting, it does serve as a excellent complementary analytical technique to other forms of ion beam analysis, such as PIXE.

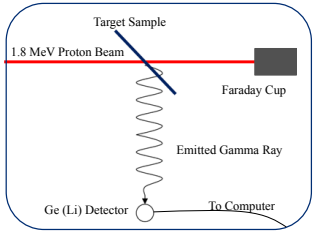

Figure 2: A cartoon diagram of the PIGE process. The proton beam (Red) induces the target sample (Navy Blue), to emit a gamma-ray that is picked up by the Ge (Li) detector.

Procedure

We used a 1.8 MeV proton beam from the Union College Pelletron Accelerator to induce the nuclear reaction in our fluorine samples. 10 μC of charged protons were used per sample. A Germanium-Lithium detector from Figure 2 was used to measure the energies of the emitted gamma rays. The detector was calibrated using an Americium-241 source. Gamma-ray spectra were taken of four fluorine samples on thin Mylar backings. The data from the germanium detector was then recorded, and the yields of the peaks were found using Peakfit software [5].

Figure 3: A photo showing the sample analysis chamber, the Ge (Li) detector, and the liquid nitrogen used to cool the detector.

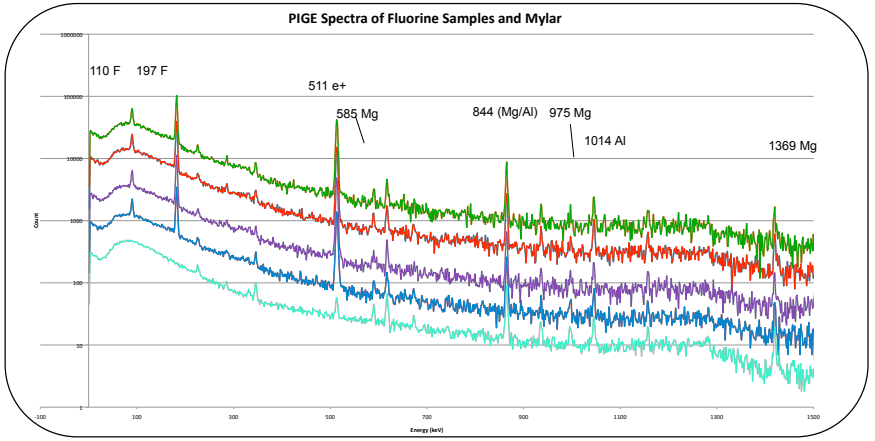

Figure 4: PIGE spectra taken on Mylar (Teal) ErF_3 (Blue) SrF_2 (Violet) GdF_3 (Red) and NdF_3 (Green) samples with mylar backings. The spectra have been vertically scaled to prevent overlapping. The known peaks are labeled with their energies in keV and associated element.

Analysis

In order to determine how the concentration of our samples, we needed to compare the calculated concentration of fluoride to the known concentration of the standard [Table 1]. We were able to do this using the equation $[Y(E, \theta) = \sigma(E, \theta)N_pN_f\Omega\varepsilon]$ where Y is the yield of the gamma ray, σ is the nuclear cross section of fluorine at an incident energy E and a detection angle of θ, N_p is the number of incident protons, N_f is the number of fluorine nuclei per target surface area, Ω is the solid angle of the germanium detector, and ε is the efficiency of the Ge (Li) detector [1].

Results

Using the Germanium detector, we were able to take gamma-ray spectra of the mylar backing, along with fluorine standards, including ErF_3, SrF_2, GdF_3, and NdF_3. All of the samples displayed the characteristic 511 keV peak that occurs as a result of positron-electron annihilation, and is commonly seen during PIGE analysis. The fluorine spectra clearly showed gamma ray peaks at both 110 and 197 keV, which was expected. More importantly, these peaks did not appear on the blank mylar sample. We also found several other peaks ranging from 580 to 1371 keV, which appear to be due to concentrations of aluminum and magnesium inside the mylar backing [2, 3].

Sample	Concentration (μg/sq.cm)	Concentration (at/sq.cm)	Calculated Concentration (at/sq.cm)	% err
SrF2	15.3368	4.86E+17	5.05E+17	3.76E+00
ErF3	11.8919	3.77E+17	3.73E+17	-1.15E+00
GdF3	12.5286	3.97E+17	4.08E+17	2.62E+00
NdF3	12.3519	3.92E+17	3.71E+17	-5.23E+00

Table 1: A table showing the samples used, the known concentration of the samples in both μg/cm^2 and atoms/cm^2 ,along with the calculated concentration of the samples in cm^2 , and the % error.

References

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[5] Peakfit Software, Systat Software Inc., http://www.sigmaplot.com/