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PIXE Analysis of Aerosol Soil Artificial Turf and Running Track Samples

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PIXE Analysis of Aerosol, Soil, Artificial Turf, and Running Track Samples

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Abstract

Proton-induced X-ray emission spectroscopy (PIXE) has been performed on aerosol, soil, artificial turf, and running track samples using the 1.1-MV tandem Pelletron accelerator in the Union College Ion Beam Analysis Laboratory. PIXE analysis of the aerosol and soil samples was performed with 2.2-MeV proton beams. X-ray energy spectra were measured with a silicon drift detector and analyzed with GUPIX software to determine the elemental concentrations in the aerosol and soil samples. Of particular interest are the concentrations of airborne pollutants, such as sulfur that can contribute to acid rain and the acidification of Adirondack lakes such as Piseco Lake. PIXE analysis was also performed on artificial turf and running track samples in order to determine the possible concentrations of lead in these samples. Significant concentrations of sulfur were present in small particle sizes in the aerosol samples, which indicate that the sulfur can travel great distances and may have originated as far away as the Midwest. Trace amounts of lead were present in the artificial turf, perhaps justifying recent concerns about the safety of artificial turf.

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1 Introduction

Proton induced X-ray emission spectroscopy (PIXE) is an ion beam analysis technique that is primarily used for elemental analysis and has a wide variety of applications. PIXE analysis is non-destructive and requires little sample preparation. Concentrations of elements can be detected with high sensitivity and low limits of detection [1]. In this study, PIXE was used to analyze aerosol and soil samples at Piseco Lake in the Adirondack Mountains of New York. Acid rain and the acidification of lakes has been a major and ongoing concern in the Adirondacks [2, 3]. One of the main causes of acid rain is sulfur dioxide, which can react with rain water to produce sulfuric acid. When acid rain falls over lakes, it can decrease the pH of the lakes, which can be life-threatening to any wildlife living in the lake [4]. Sulfuric acid can come from many sources, but the main sources are the combustion of fossil fuels from coal, industry, and automobiles [1, 5]. Piseco Lake in the Adirondacks has been a victim of acid rain and a target for environmental research, though there are signs of improvement [6]. Acid rain can also harm the soil surrounding Piseco Lake by hindering its ability to neutralize acids and stripping the soil of vital nutrients [4]. It can also increase the solubility of certain metals such as aluminum, which can be toxic to wildlife in the lake if the solution enters the lake [4, 7]. This experiment seeks to determine the concentrations of elements in the air and in the soil surrounding Piseco Lake, the main focus being the concentrations of sulfur in the air and soil that can contribute to acid rain and the acidification of Piseco Lake.

PIXE was also used to analyze artificial turf and running track samples from Union College, NY and Lexington High School, MA. There have been recent concerns about the safety of running tracks and artificial turf due to possible concentrations of heavy elements such as lead in the tracks and turf infill [8, 9]. Artificial turf is made up of artificial grass leaves and an infill made from car tires that help to absorb impacts and reduce the chance for injury [9]. However, when the artificial turf is in use, the turf infill can be kicked up into the air and inhaled, which can be dangerous if, in fact, there are heavy elements in the

turf. PIXE analysis on the turf and track samples was performed using an external proton beam. External beam facilities have proven to be effective at analyzing samples using PIXE without having to put the samples under vacuum[10]. Using an external beam can expedite the data collection, since very little to no sample preparation is necessary, and can be used to analyze virtually any sample [11]. In this experiment, an external proton beam was used to determine if there are significant concentrations of heavy elements in the artificial turf and running track samples.

2 Experimental Procedures and Methods

2.1 The Union College Pelletron Accelerator

The Union College 1.1-MV Pelletron Accelerator shown in Figure 1 was used to perform an elemental analysis of all of our samples. The accelerator created a 2.2-MeV proton beam that was used for proton induced X-ray emission spectroscopy (PIXE). The creation of the proton beam is described below.

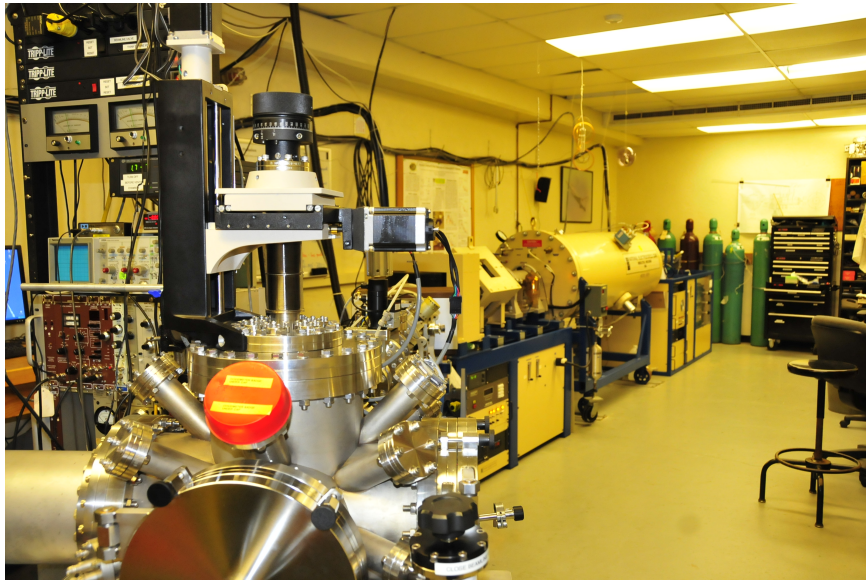


Figure 1: A photo of the Union College Pelletron Accelerator.

2.1.1 Ion Source

At the ion source shown in Figures 2 and 3, hydrogen gas is bled into a quartz bottle. A 100 MHz radio frequency splits the H_2 molecules into H^+ ions and electrons. These ions are accelerated via a 3.8 kV potential difference into a chamber where a mass of rubidium is heated to 200°C , creating a rubidium vapor. The H^+ ions undergo a charge-exchange reaction with the low density rubidium vapor and gain two electrons. Only the ions that gain two electrons and become H^- ions get accelerated into the accelerator tank.

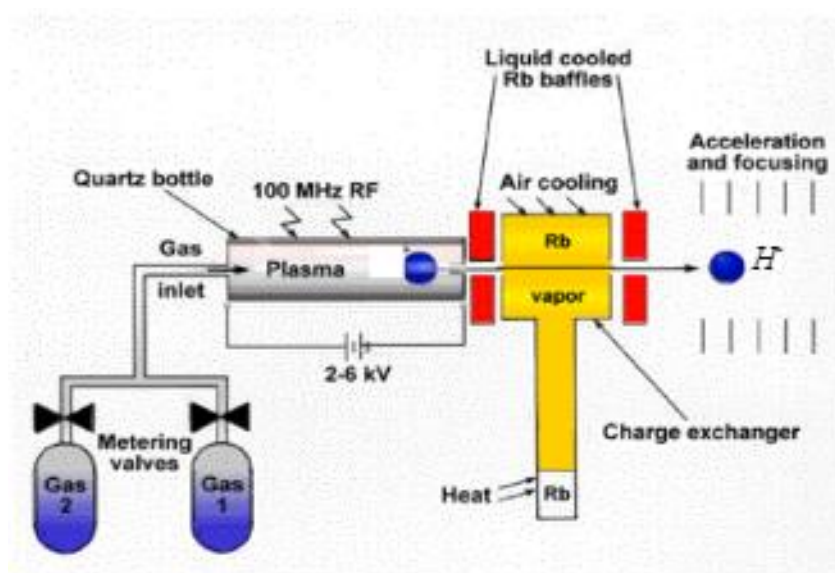


Figure 2: A schematic of the ion source [12].



Figure 3: A photo of the ion source and low energy instruments.

2.1.2 Accelerator Tank

The accelerator tank shown in Figure 4 contains low and high energy columns and a central terminal that is charged to 1.1 MeV via a Pelletron charging system shown in Figure 5. A chain of metal pellets located in the high energy column first passes through an inductor electrode where electrons leave the pellets. The positively charged pellets travel to the central terminal where the positive charge is transferred directly to the terminal pulley and passes through a suppressor, which prevents sparking. The process is repeated when the pellets leave the central terminal, pass through another inductor electrode where the pellets gain electrons from the terminal pulley and travel to the drive pulley [13].

H^- ions from the ion source are accelerated towards the positively charged central terminal and gain 1.1 MeV of energy. Nitrogen gas is bled into a stripper channel and strips electrons from the H^- ions. If the nitrogen gas strips one electron from the H^- ions, then the H^- ions would become neutral and have an energy of 1.1 MeV. However, if two electrons are stripped from the H^- ions, then the H^- ions would become H^+ ions. Since the central terminal is positively charged, the H^+ ions are repelled from the central terminal and gain an additional 1.1 MeV, creating 2.2-MeV protons.



Figure 4: A photo of the accelerator tank.

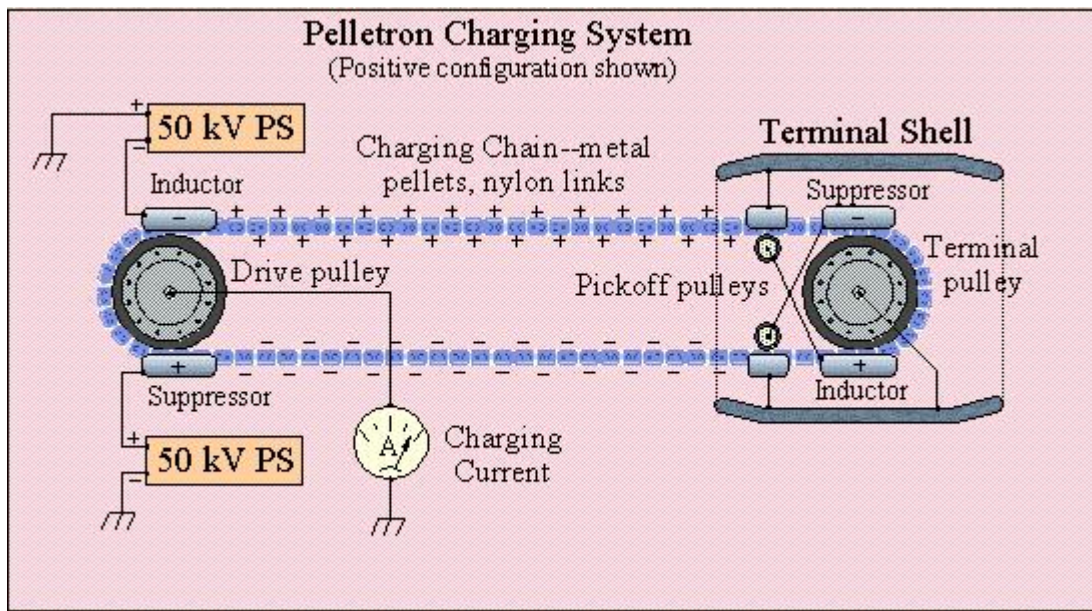


Figure 5: A schematic of the Pelletron charging system in the accelerator tank [12].

2.1.3 Quadrupole Magnet

Once the 2.2-MeV protons leave the accelerator tank, the protons travel in a straight line. However, the proton beam may not be completely collimated and focused. Thus, the beam passes through a quadrupole magnet, shown in Figure 6, which focuses and reduces the divergence of the beam. The currents of the magnets can be manually adjusted until the desired shape of the beam is reached.

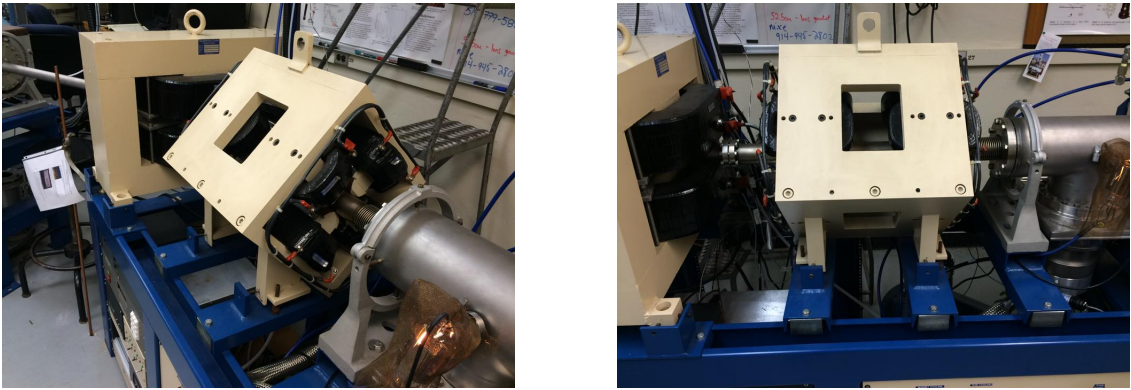


Figure 6: Two photos of the quadrupole magnet.

2.1.4 Switcher Magnet

Up until this point, the beam is made up of 2.2-MeV protons, 1.1 MeV protons, and possibly other contaminants such as carbon, oxygen, and nitrogen that have entered the vacuum. In order to select only the 2.2-MeV protons, the beam passes through a switcher magnet (shown in Figure 7) that creates a magnetic field pointing downward. The beam experiences a magnetic force that bends the beam toward the scattering chamber. The magnetic field of the switcher magnet can be manually adjusted to only allow 2.2-MeV protons to successfully make it through the magnet. All other particles are deflected at other angles.

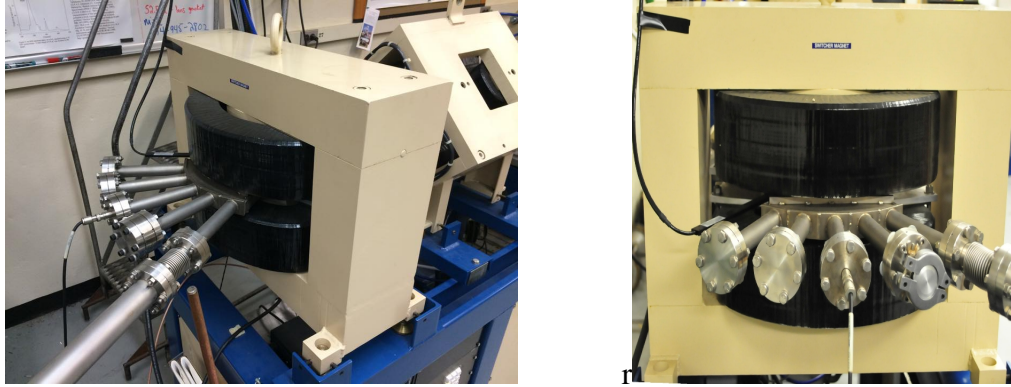


Figure 7: Two photos of the switcher magnet.

2.1.5 Steering Magnets and Beam Profile Monitor

After the switcher magnet, the proton beam travels in a straight line to the scattering chamber. X and Y steering magnets shown in Figure 8 can steer the beam in case the beam is not completely centered. The beam profile monitor, which is also shown in Figure 8, contains a wire that crosses the beam in the x and y directions and measures the beam intensity in both directions. The resulting intensity data is displayed by an oscilloscope in the control panel to monitor the profile of the proton beam.

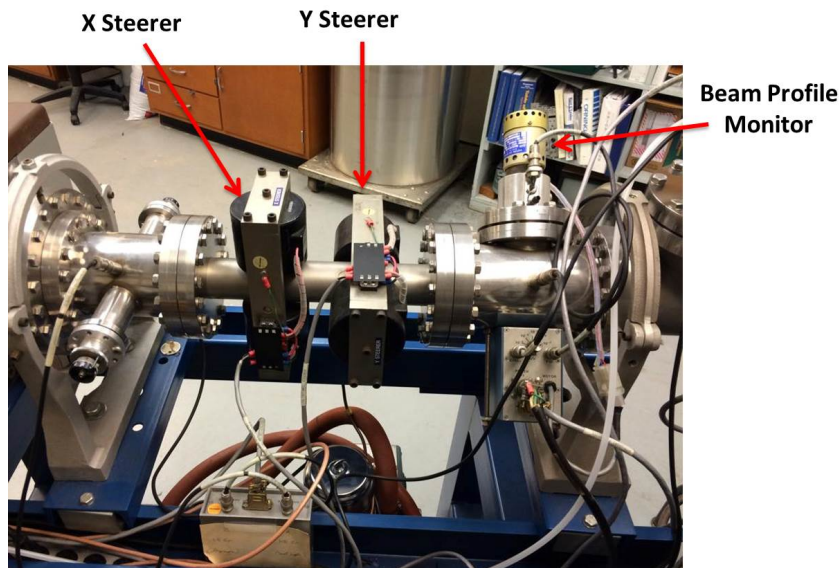


Figure 8: A photo of the x and y steering magnets and the beam profile monitor.

2.1.6 Scattering Chamber

The proton beam is directed at a target in the scattering chamber, shown in Figure 9. The scattering chamber is designed to hold three different targets in a target ladder that can be moved up and down with a 3-axis target manipulator. Another feature of the scattering chamber is the ability to perform many ion-beam analyses at the same time such as proton induced X-ray emission spectroscopy (PIXE), Rutherford backscattering spectroscopy (RBS), proton induced γ -ray emission spectroscopy (PIGE), and proton elastic scattering analysis (PESA). The scattering chamber is under high vacuum, thus only samples that can survive in a vacuum, like solids, can be used as targets.

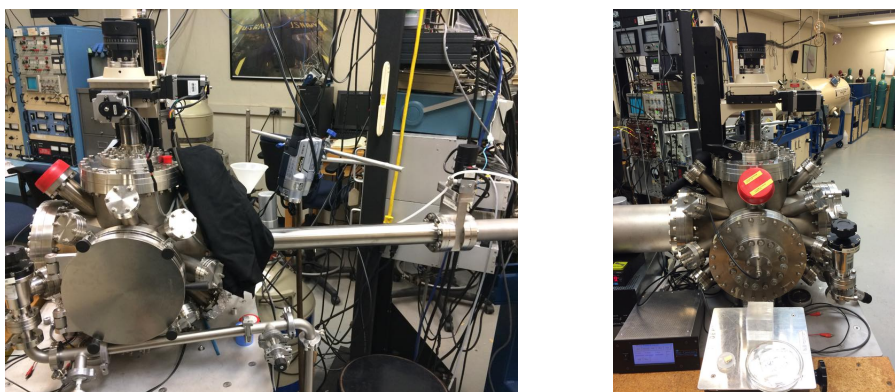


Figure 9: Photos of the scattering chamber.

2.2 Development of an External Beam Facility

The need for an external beam facility is evident, since not all samples of interest can survive in a vacuum. Creating an external beam facility allows us to analyze any sample without having to put it under vacuum. Photos of our external beam apparatus attached to the scattering chamber are shown in Figure 10. A 1.25" outer diameter aluminum pipe with a 7.5- μm thick Kapton window and supported by an end cap with a 0.25" diameter hole was used to allow the proton beam to exit the vacuum into the air. A sample is placed 2 cm away from the window and an X-ray detector and a γ -ray detector are set up approximately 160° with respect to the direction of the beam on both sides as shown.

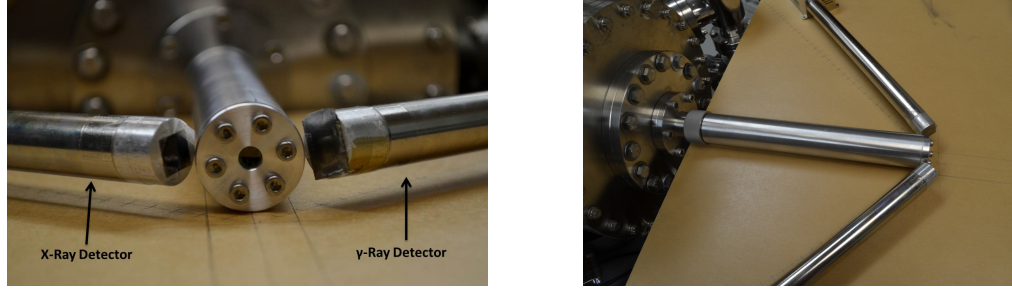


Figure 10: Front and top-down views of the external beam setup.

When the beam enters open air, it ionizes air molecules in its path and loses energy. Figure 11 shows the external beam exciting nitrogen molecules in the air that, when deexcited, emit blue-violet light. The protons continue to ionize air molecules until they do not have enough energy to ionize. A SRIM simulation, also shown in Figure 11, was created to determine the energy of the beam 2 cm away from the exit window [14]. The proton beam was determined to have an energy of about 1.7 MeV at a distance of 2 cm from the exit window.

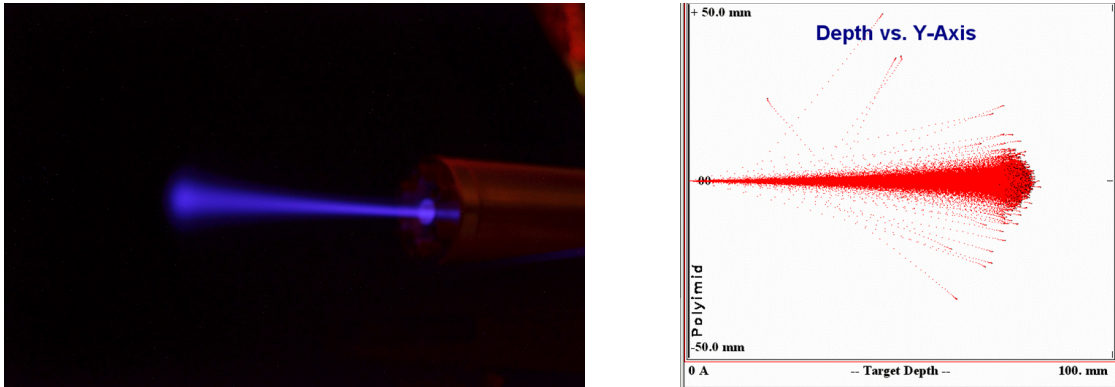


Figure 11: A photograph of the external proton beam and a SRIM simulation of the 2.2-MeV proton beam after travelling through the Kapton window.

When the target is thin, it can be assumed that the number of particles scattered from the beam is negligible and thus a faraday cup can be placed behind the sample to estimate the total incident charge. When the target is thick, however, the beam loses too much energy and does not make it all the way through the sample. To estimate the charge incident on a thick target, a faraday cup was placed 2 cm away from the exit window where the sample

would be placed. The amount of charge incident on the faraday cup and number of X-rays emitted from argon in the air were then measured. Figure 12 shows the amount of charge collected in the faraday cup vs. the number of argon X-rays measured. There is a clear linear correlation between the number of argon X-rays and the amount of charge collected.

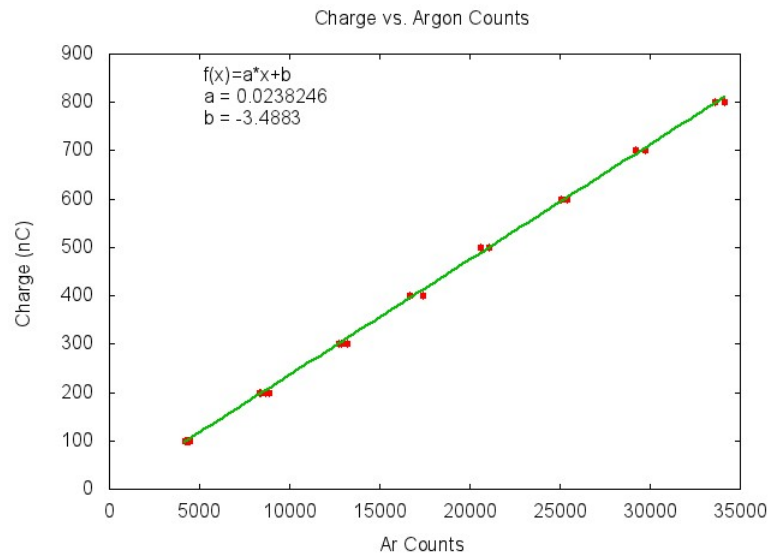


Figure 12: Graph of the charge collected on a faraday cup vs. the number of X-rays measured from Ar in the air.

2.3 Sample Collection and Preparation

2.3.1 Piseco Lake

The aerosol and soil samples were collected in July 2012, June 2013, and June 2014, near Piseco Lake in the Adirondack Mountains in order to study the airborne pollution that causes the acidification of Adirondack lakes. Figure 13 shows the location of Piseco Lake.



Figure 13: A map of New York, indicating the location of Piseco Lake [15].

The air samples were collected using a PIXE international nine-stage cascade impactor, which distributes particulate matter in the air onto Kapton foils by particle size [16]. The impactor collected particulate matter between $0.06\mu\text{m}$ and $16\mu\text{m}$ in diameter. A nucleopore filter in the lowest stage of the impactor collected any particulate matter (PM) that was less than $0.06\mu\text{m}$ in diameter. The impactor, which is shown in Figure 14, was attached to a vacuum pump that pulled air through the impactor at a flow rate of $1 \frac{\text{L}}{\text{min}}$. The Kapton foils in each stage of the impactor were attached to 1-inch plastic rings. Microscopic images of the particulate matter on the Kapton foils are shown in Figure 15. The Kapton foils were then used as targets in the PIXE experiments.

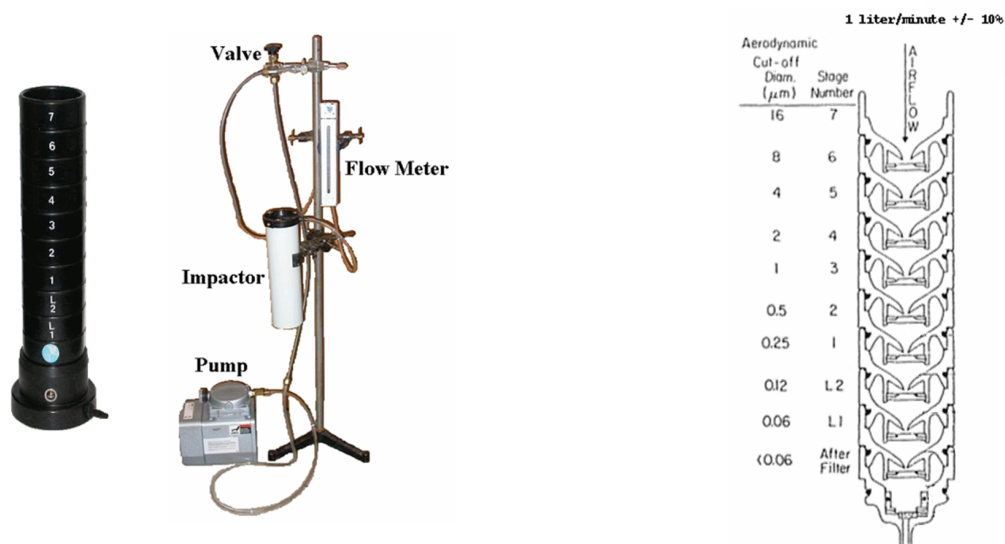


Figure 14: Photo and a diagram of the nine-stage cascade impactor and the sampling system.

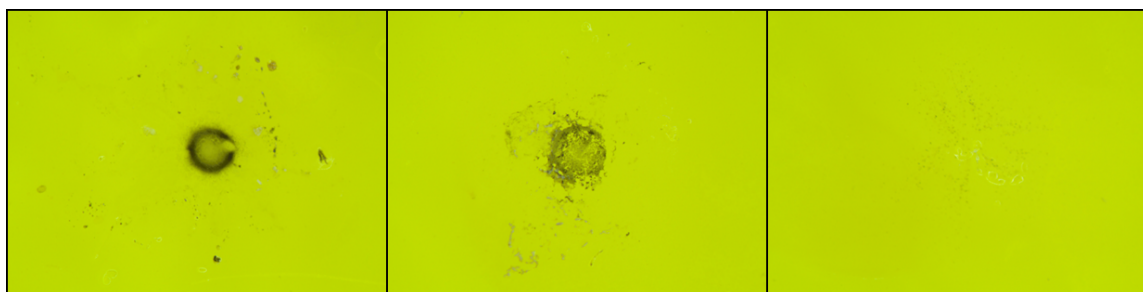


Figure 15: Microscopic photographs of Kapton foils with deposits of PM-0.25, PM-0.5 and PM-4 (left to right).

Soil samples were also collected near Piseco Lake. The soil was then dried under vacuum, and compressed into a pellet using a RIIC 20 ton hydraulic press. The soil pellets were then used as targets in the PIXE experiments.

2.3.2 Artificial Turf and Running Track

The samples of artificial turf were collected from the Union College football field and the running track samples were collected from the running track at Union College and the running track at Lexington High School in Lexington, MA. The samples are shown in Figure 16 and were analyzed using the external proton beam.



Figure 16: From left to right: turf leaf (green) and turf infill (black) from the Union College football field, track from the Union college running track (red) and the Lexington High School running track (blue).

2.4 PIXE

2.4.1 PIXE Spectroscopy

Proton induced X-ray emission spectroscopy (PIXE) is an ion beam analysis technique in which a sample is bombarded with a proton beam with an energy of a few MeV that will occasionally knock out an inner shell electron from an atom in the sample [17]. Figure 17 shows a proton ejecting an inner shell electron from an atom. An outer shell electron fills the vacancy and loses energy in the form of an X-ray with an energy that is characteristic of the atom, as shown in Figure 18.

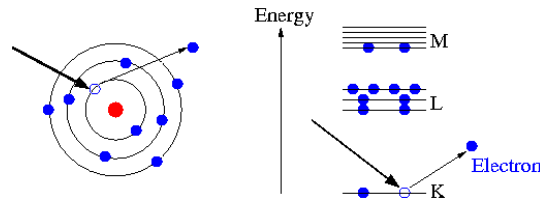


Figure 17: Diagram of a proton colliding with an inner shell electron, ejecting it from the atom.

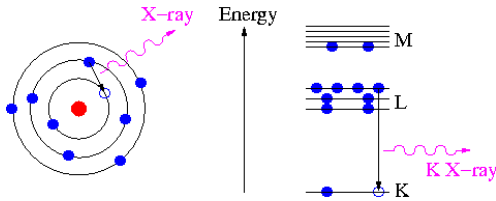


Figure 18: Diagram of an outer shell electron filling the vacancy left by the ejected, inner shell electron and emitting an x-ray.

Every atom has characteristic energy levels associated with it. The energies of the emitted X-rays identify the elements present in the sample and the intensity of the X-rays can be used to determine the concentrations. The concentration C_Z of an element Z in a sample can be calculated using the equation

$$C_Z = \frac{Y_Z}{Y_t H Q \epsilon T}$$

where Y_Z is the intensity of the principle X-ray line for element Z, Y_t is the theoretical intensity per μC 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. Using the measured X-rays from a sample, a spectrum of the number of X-rays vs. the energy of a given X-ray can be made. Shown in Figure 19 are example PIXE spectra taken with the external proton beam on artificial turf infill and with no target present.

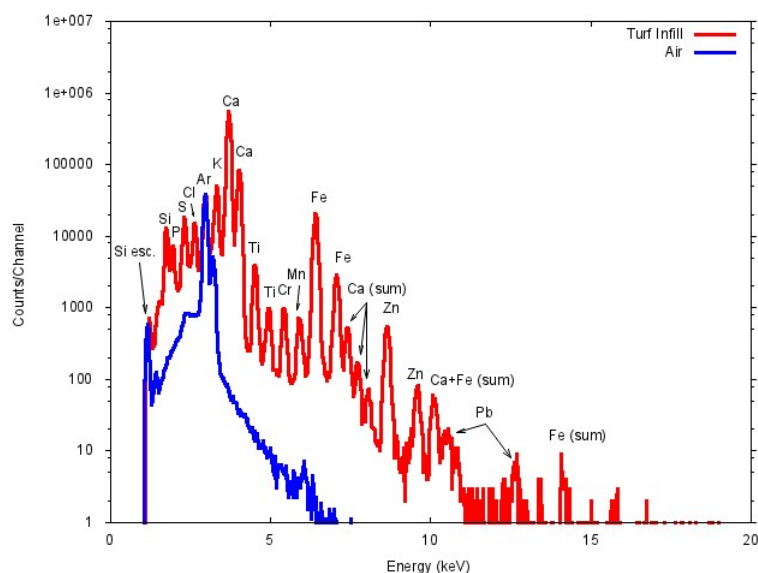


Figure 19: Example PIXE spectra of artificial turf infill (red) from the Union College football field and from the air with no target present(blue).

2.4.2 Aerosol PIXE Analysis

The PIXE experiments on the Piseco Lake aerosol samples were performed using 2.2-MeV proton beams with currents of 1-12 nA and diameters of 1-2mm. Because the Kapton foils are thin, the proton beams lose a nominal amount of energy penetrating the foils. The emitted X-rays were detected in the scattering chamber using an Amptek silicon drift detector (SDD) after passing through a 76- μ m thick Be filter. A faraday cup placed behind the sample was used to estimate the amount of charge incident on the sample. X-ray energy spectra were acquired for each sample and a set of standards with known concentrations per area [18]. The spectra were then analyzed using GUPIX software in order to calculate the concentrations of the elements in the samples [19]. Because GUPIX can only calculate concentrations of elements in mass per unit area (that is, mass per unit area on the Kapton foil), the following equation was used to convert the concentrations into mass per unit volume:

$$C_V = \frac{AC_A P_{std} T}{(\Delta t) f P T_{std}}$$

where C_V is the concentration in mass per unit volume, A is the area of the aerosol deposit on the Kapton foil, C_A is the elemental concentration in mass per unit area, P_{std} is the standard pressure, which is equal to 760 mmHg, T is the average temperature during the sample collection, Δt is the sample collection time, f is the measured flow rate, which was kept at $1 \frac{L}{min}$, P is the average pressure during the sample collection, and T_{std} is the standard temperature and is equal to 298K.

2.4.3 Soil, Turf and Track PIXE Analysis

The PIXE experiments on the Piseco Lake soil samples were also performed using 2.2-MeV proton beams with currents of 1-12 nA and diameters of 1-2mm. The emitted X-rays were detected using the SDD detector in the scattering chamber. However, because the soil pellets are thick, the proton beam cannot fully penetrate the pellet and thus, an estimate of the charge cannot be made using a faraday cup. Thus, only a qualitative analysis of the soil samples was made.

PIXE experiments on the turf and track were made using a 1.7-MeV external proton beams with currents of 1-12 nA. The beams were incident on samples positioned 2 cm from the exit window. The turf and track samples are thick and thus, the proton beams cannot fully penetrate the samples. The emitted X-rays were detected with the SDD detector after passing through a 76- μ m thick Be filter and 4 cm of air. X-ray spectra were acquired for each sample and a set of standards [18]. The relative normalization of the spectra was determined using the strong X-ray peaks from argon in air. To estimate the beam charge incident on the samples, a Faraday cup was positioned 2 cm from the window in order to measure the amount of charge as a function of the X-ray yield from argon in air (see Figure 12).

3 Results

3.1 Aerosol Samples

Figures 20 and 21 shows PIXE spectra for impacted Kapton foils for $PM_{0.5}$ and PM_2 and a blank Kapton foil. Significant concentrations of silicon, sulfur and iron with trace amounts of potassium, calcium, titanium and manganese were measured on the Kapton foil for $PM_{0.5}$. Significant concentrations of silicon, phosphorus, sulfur, potassium, calcium, manganese and iron with trace amounts of titanium were measured on the Kapton foil for PM_2 .

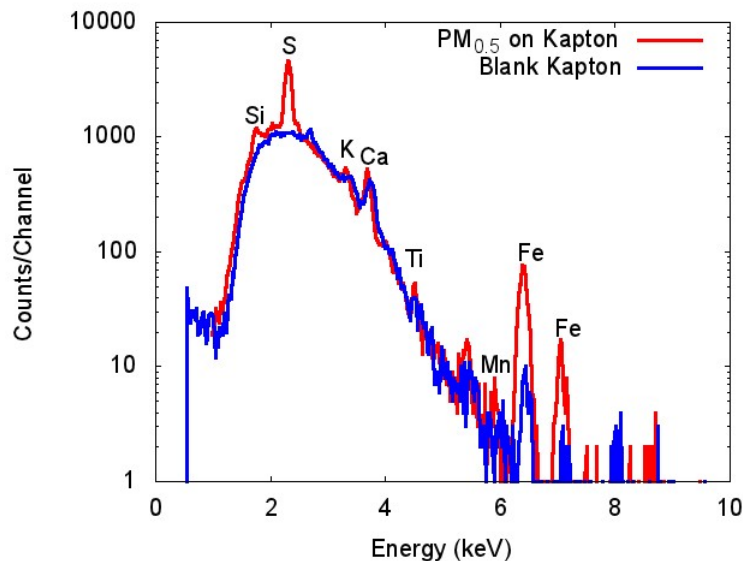


Figure 20: PIXE spectra taken on a blank Kapton foil (blue) and an impacted Kapton foil (red) for $PM_{0.5}$.

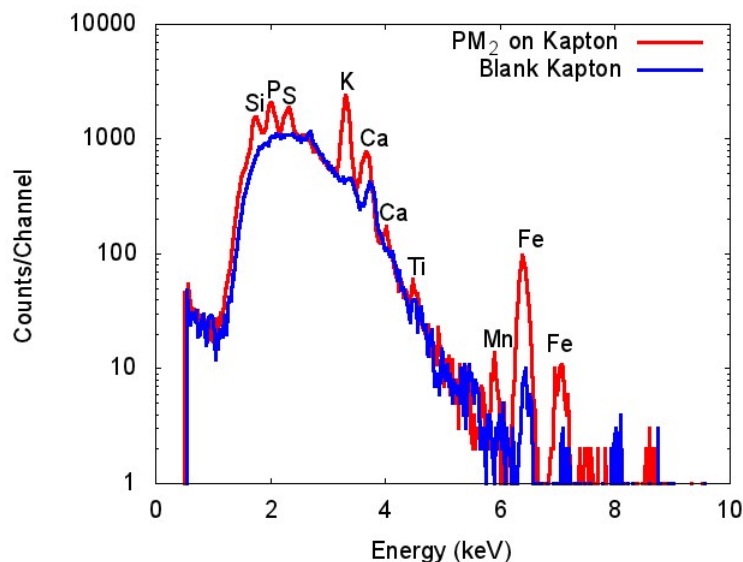


Figure 21: PIXE spectra taken on a blank Kapton foil (blue) and an impacted Kapton foil (red) for PM₂.

Figure 22 shows a bar graph of the concentrations in $\frac{ng}{m^3}$ of elements ranging from silicon and iron for particulate matter between PM_{0.25} and PM₄. Figure 23 shows the concentrations in $\frac{ng}{m^3}$ of Si, P, S, K, Ca, and Fe as a function of particle size. The smaller the particle size, the longer the particle can remain suspended in the air. Because there are higher concentrations of sulfur at smaller particle sizes, it is possible that the sulfur may have originated from coal combustion and industry as far away as the Midwest [11]. Also, because there are higher concentrations of Si, P, K, Ca, and Fe at larger particle sizes, it is possible that these elements originated in the soil [1]. The size of the error bars in both figures were calculated by adding the statistical and fit errors from the GUPIX output in quadrature.

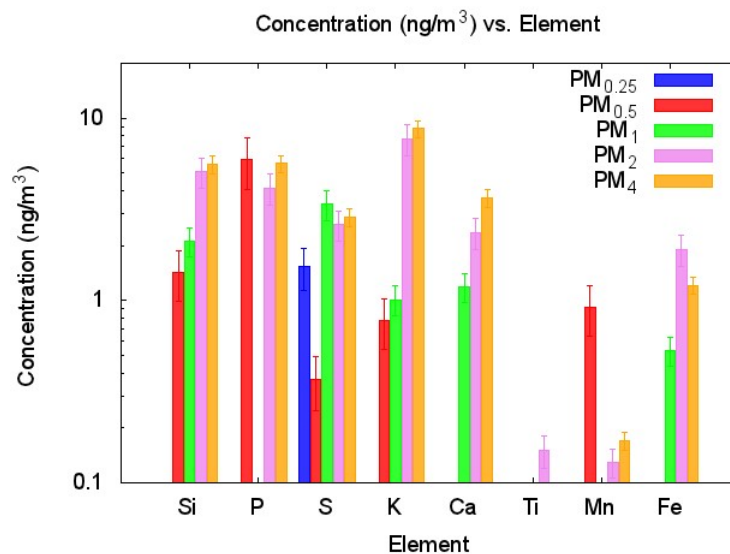


Figure 22: A bar graph of the concentration in $\frac{ng}{m^3}$ of the elements for various particle sizes from June 2014 aerosol samples.

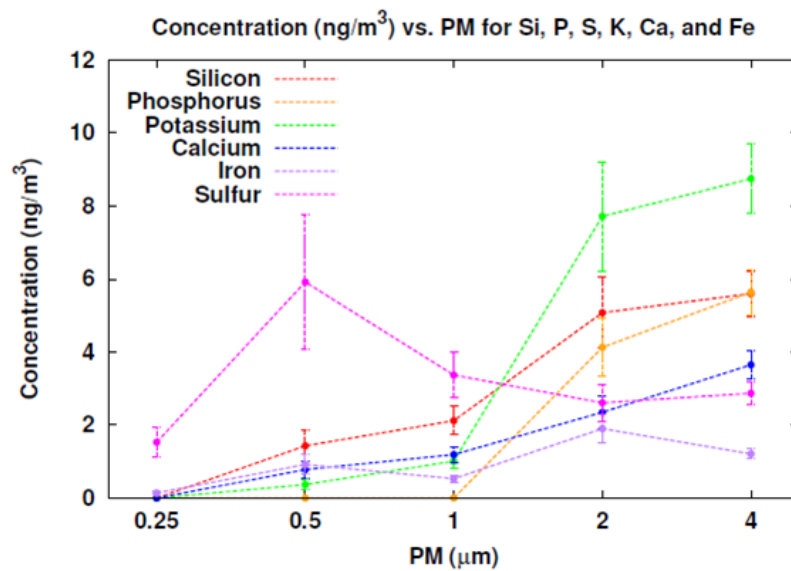


Figure 23: A scatter plot of the concentration of Si, P, S, K, Ca, and Fe in $\frac{ng}{m^3}$ vs. PM from aerosol samples collected in June 2014.

3.2 Soil, Turf and Track Samples

3.2.1 Soil Samples

Figure 24 shows a PIXE spectrum of the soil sample from Piseco Lake. Significant concentrations of Si, K, Ca, Ti, Cr, Mn and Fe were measured. The fact that there are higher concentrations of these elements at larger particle sizes in the aerosol samples supports our conclusion that these elements originate in the soil.

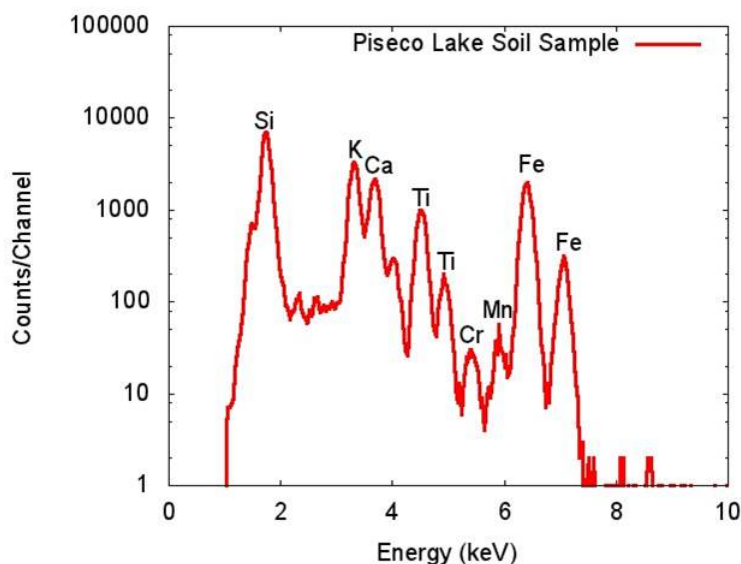


Figure 24: PIXE spectrum of a soil sample from Piseco Lake.

3.2.2 Artificial Turf and Running Track

Figures 25 and 26 show PIXE spectra of the turf leaf and turf infill samples from the Union College football field. Both spectra were normalized with a spectrum of air such that the argon peaks were the same. Significant concentrations of elements ranging from Si to Zn in both samples were measured. Argon is typically found in the air and was assumed to not be present in the samples. Trace amounts of lead were measured in the turf infill sample, perhaps justifying the recent concerns about the safety of artificial turf [8, 9]. The peaks labeled “Ca (sum),” “Ca+Fe (sum),” and “Fe (sum)” are pile-up peaks. Pile-up peaks occur when the rate of X-rays entering the X-ray detector exceeds the rate at

which the pulse processor can resolve and record the X-ray energies. When this happens, it is possible that two X-rays could reach the detector almost simultaneously and cannot be distinguished from one X-ray. The probability of a pile-up X-ray peak is low, but they can occur when there are large beam currents. A Ca+Fe pile-up peak occurs when a calcium X-ray and an iron X-ray cannot be distinguished from an X-ray having an energy equal to the sum of their energies. Similarly, a Fe pile-up peak occurs when two iron X-rays (either two K_α X-rays, a K_α X-ray and a K_β X-ray, or two K_β X-rays) cannot be distinguished from an X-ray having an energy equal to the sum of their energies.

The peak labeled “Si esc.” is the silicon escape peak. When an Ar X-ray enters the silicon drift detector, it may knock out an inner shell electron out of a silicon atom in the detector before being measured by the detector. When this happens, the X-ray’s energy is reduced by the energy needed to knock out the electron in the silicon atom. Thus, the difference between the energy of the argon K_α X-ray and the energy of the silicon escape peak is the energy of a silicon K_α X-ray. Again, the probability of an escape peak is low, but they can occur at large beam currents.

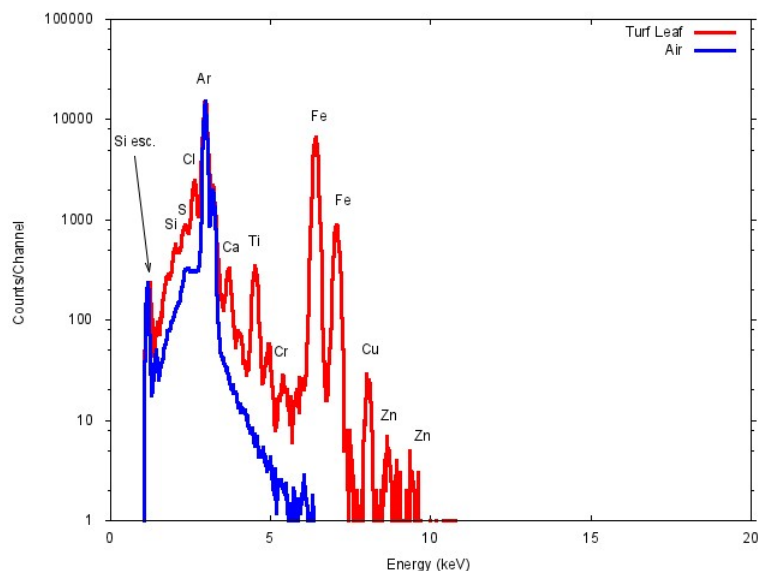


Figure 25: PIXE spectra of air (blue) and artificial turf leaf (red) from the Union College football field.

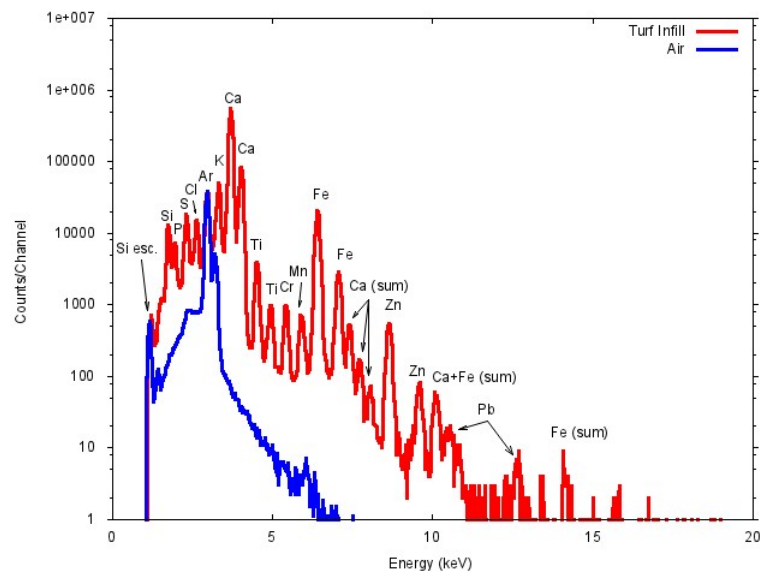


Figure 26: PIXE spectra of air (blue) and artificial turf infill (red) from the Union College football field.

Figures 27 and 28 show PIXE spectra of the Union College and Lexington High School running track samples. Both spectra were also normalized with a spectrum of air such that the Ar peaks were the same. Concentrations of elements ranging from silicon to zinc were measured in both the Union College and Lexington High School track samples. One side of the Lexington High School running track sample was blue and the other side was black. The difference in concentrations of elements such as Cl, Ti, and Cu are most likely due to one side being colored with blue paint.

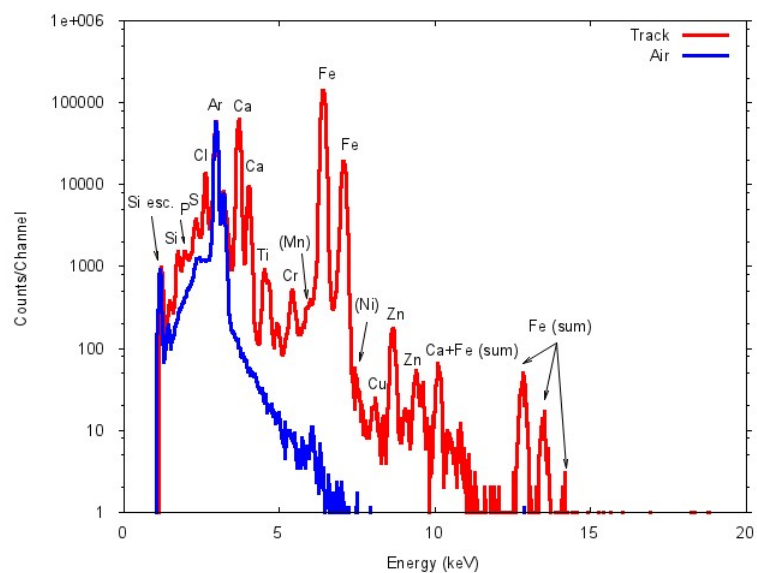


Figure 27: PIXE spectra of open air and running track from Union College. For the Lexington High School running track, spectra were made for the top (blue side) and bottom (black side) of the track.

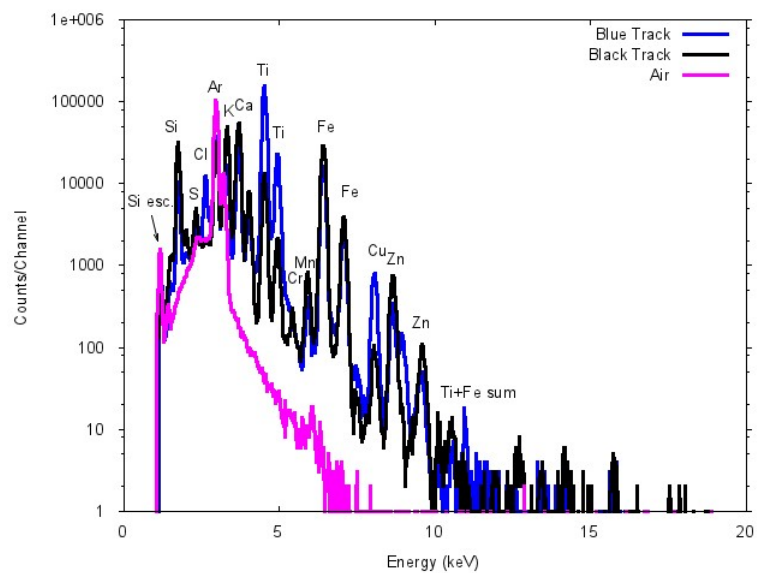


Figure 28: PIXE spectra of air (purple) and running track from the Lexington High School. Spectra were made for the top (blue side) and bottom (black side) of the track.

4 Discussion and Conclusions

PIXE analysis was performed on the Piseco Lake aerosol and soil samples and on the artificial turf and running track samples from Union College and Lexington High School. In the aerosol samples, there were high concentrations of sulfur at small particle sizes, which indicates that the sulfur can travel long distances before settling down and may have originated from industry and coal combustion as far away as the Midwest. This sulfur may be in the form of sulfur dioxide which could contribute to acid rain and the acidification of Adirondack lakes. There were also high concentrations of Si, P, K, Ca, and Fe at larger particle sizes, indicating that these elements do not travel very far before settling down. Because these elements appeared in large concentrations in the PIXE spectrum of the soil sample, it is likely that these elements originated in the soil.

In the artificial turf samples, there were small traces of lead in the turf infill, perhaps justifying the recent concerns about heavy elements being present in artificial turf. When the infill is kicked up during use of the turf, the lead can be inhaled. Lead is known to have many negative health effects when inhaled [20]. In the running track samples, significant concentrations of elements ranging from silicon to zinc were measured. However, no lead or other heavy metals were measured in significant quantities in the running track samples.

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References

- [1] D.D. Cohen, G.M. Bailey and R. Kondepudi, “Elemental Analysis by PIXE and Other IPA Techniques and Their Application to Source Fingerprinting of Atmospheric Fine Particle Pollution.” *Nucl. Instru. and Meth. B*, 218 (1996).
- [2] Brescher Shea, Shannon. “Acid Rain, Rain Go Away.” *New York State Department of Environmental Conservation*, last modified 2008. <http://www.dec.ny.gov/pubs/43763.html>
- [3] “Acid Rain.” *Adirondack Council*, accessed in March 2016. <http://www.adirondackcouncil.org/page/acid-rain-86.html>
- [4] “Acid Rain and Acid Deposition.” *Ocean World*, last modified 2008. <http://oceanworld.tamu.edu/resources/environment-book/acidrain.html>
- [5] “Acid Rain: Effects Felt Through the Food Chain.” *National Geographic*, accessed in March 2016. <http://environment.nationalgeographic.com/environment/global-warming/acid-rain-overview/>
- [6] Williams, Stephen. “Adirondacks bouncing back from acid rain devastation.” *Adirondack Council*, last modified July 27, 2014. <http://www.adirondackcouncil.org/page/in-the-news-36/news/-adirondacks-bouncing-back-from-acid-rain-devastation-502.html>
- [7] “Effects of Atmospheric Deposition on the Quality of Ground Water and Surface Water.” *USGS*, accessed in March 2016. <http://pubs.usgs.gov/circ/circ1139/htdocs/boxs.htm>
- [8] Michael Goot, “School Seeks Answers on Health Risks of Artificial Turf.” *The Post Star*, last modified November 7, 2014. <http://poststar.com/news/local/school->

seeks-answers-on-health-risks-of-artificial-turf/article_6d4a5d24-6616-11e4-97b5-bf53f782af9e.html

- [9] Hannah Rapple, “How Safe Is the Artificial Turf Your Child Plays On?” *NBC*, last modified October 8, 2014. <http://www.nbcnews.com/news/investigations/how-safe-artificial-turf-your-child-plays-n220166>
- [10] M. Luomajärvi, E. Rauhala and J. Räsänen. “An External Beam Method for Ion Backscattering.” *Nucl. Instr. and Meth. B*, 6 (1985) 543-546
- [11] F. Lucarelli, et. al., “The Upgraded External-Beam PIXE/PIGE Set-up at LABEC for Very Fast Measurements on Aerosol Samples.” *Nucl. Instr. and Meth. B*, 218 (2014) 55-59.
- [12] <http://www.pelletron.com/>
- [13] National Electrostatics Corporation. “Charging System.” Last modified December 3, 2001. <http://www.pelletron.com/charging.htm>
- [14] J. F. Ziegler, J. P. Biersack, and M. D. Ziegler. *SRIM-The Stopping and Range of Ions in Matter*. V 15 (2015) (www.SRIM.org).
- [15] <http://www.newyorkvacation.com/regions/Piseco-Lake-New-York.html#MT1>
- [16] PIXE International Corporation, P.O. Box 2744, Tallahassee, FL 32316 U.S.A.
- [17] Sven Johansson, John Campbell, and Klas Malmqvist, “Particle Induced X-ray Emission Spectrometry (PIXE),” New York, NY: John Wiley & Sons, 1995.
- [18] MicroMatter Co., 18218 18th Ave. NW, Arlington, WA 98223, U.S.A.
- [19] GUPIX, the versatile PIXE spectrum fitting software, University of Guelph.
- [20] “Lead Exposure in Adults - A Guide for Health Care Providers.” *New York State*, last modified March 2009. <https://www.health.ny.gov/publications/2584/>