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Applications of Particle Induced X-ray Emission.

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In Particle Induced X-ray Emission (PIXE) analysis samples are bombarded by protons or α-particles of a few MeV/u [1,2,3]. The induced characteristic x-rays are detected with a x-ray detector e.g. a Si(Li)-detector. The energies of the x-ray peaks are characteristic for the elements in the samples and the intensities of the x-ray transitions are proportional to the abundances of the elements.

PIXE constitutes a fast multielemental method giving accurate elemental analyses of small thin samples with detection limits at the nanogram level for elements heavier than phosphorus. In a typical sample of airborne particulates 10-15 elements are found and quantified with an accuracy of 10 % in one to three minutes. Lighter elements may be analysed simultaneously by detecting backscattered particles or particles, including photons, from nuclear reactions e.g. $^{19}F(p,\alpha\gamma)^{16}O$ -- here is still work to be done for physicists.

The cost of PIXE analysis is very low compared to other methods provided the properties of PIXE are fully appreciated. A favorable extreme for PIXE may be a series of several hundred samples weighing 10-100 μg in which 10-15 elements, expected in the 1-100 ng range, are interesting.

A series of samples of the kind just mentioned is usually not realistic to analyse by other analytical methods. Therefore experiments and sampling devices are not designed to deliver this kind of samples. Hence it is very important that physicists working with PIXE engage themselves in multidisciplinary teams and actively participate in planning, performance and evaluations of experiments in which

PIXE may be used.

The research area which first attracted those of us working with PIXE was the study of sources, transport and deposition of airborne particulates. Information about sources, transport, wet deposition, dry deposition and health effects may be obtained from the elemental composition of different size fractions of the particles. However both sampling and analysis have been too expensive to investigate elemental compositions of different size fractions extensively. By using PIXE it is possible to use a small cascade impactor for size fractionation and several large scale investigations with this combination have already been performed[4]. This kind of investigations is a good example of experiments for which special knowledge of PIXE is necessary already in the planning stage. Another example from the same research field is the kind of investigations where a high time resolution of the elemental concentrations on airborne particles is crucial. Jensen and Nelson[5] have developed a small filter device giving a two-hour resolution for a period of a week. The samples for all the period are deposited on a 5 mm wide and 168 mm long area. Each two-hour sample represents only a few litres of air and is too small for other methods. This is especially the case if thousands of the two-hour samples have to be analysed.

Other applications where PIXE is already known to be competitive are trace elemental analysis of water below the ppb-level[6] and analyses requiring a space resolution of 1-10 μm[7].

Although standard samples are not necessary for PIXE, it is convenient to use standards for mass calibration and for control of the experimental arrangements[8]. Due to the smooth variations of x-ray production cross sections with particle energy and x-ray energy analyses of a few standards are sufficient for extrapolations. Thus for K x-rays the production cross sections are known with sufficient accuracy. For L and M x-rays there are still uncertainties e.g. in the variations of the relative intensities of the lines.

There are probably interesting ideas to elaborate on for the alert scientists working in the field of Atomic Inner Shell Phenomena, which would be beneficial to PIXE. Peak-to-background ratios are directly related to detection limits. Thus means of enhancing the x-ray production (heavy ions) and/or decreasing the background contributions should be looked for. By using a low Z chrystal as a backing its contribution to the background could be minimized by using certain angles for bombardment and detection. Also there may be coincidence arrangements by which the bremsstrahlung components are suppressed. A major disadvantage with PIXE as applied today is its inability to resolve the different oxidation states of elements. There may be chemical shifts which are useful for analytical purposes, especially where good chrystal spectrometer arrangements are available.

In conclusion, PIXE has already been shown to be competetive in trace elemental analysis. However, there is still much to do for physicists in developing the full potential of low-energy accelerators as analytical tools, both in understanding the physics and in working in multidisciplinary teams.

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