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THE USE OF PIGE AS A MULTIELEMENT ANALYTICAL METHOD FOR LOW Z ELEMENTS *

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Proton Induced Gamma Ray Emission (PIGE)[1-4] is used for quantitative analysis of light elements (below Z=15) which are beyond the region of either XRF or PIXE. The analytical methods based on X-ray detection become inapropriate for low Z elements analysis because the energy of the corresponding Kα ray is low and not detectable.

The aim of this work is the accurate and simultaneous measurement of Li, B, F, Na, Mg, Al, Si and P in thick targets. The reactions used are of the type (p,γ), (p,p$'\gamma$),(p,nγ) and (p,$\alpha\gamma$)[5]. By bombarding with protons a sample that contains elements with adjacent atomic numbers, interference may take place mainly from elements that result in the same residual nucleus. Therefore the proton energy as well as the detected gamma-ray for each element must be chosen carefully.

For each element, pellets were made by mixing powdered graphite, cellulose and a certain compound containing the element under investigation. It should be noticed that Carbon, Nitrogen and Oxygen have quite low cross sections under proton irradiation $Ep< 4$ MeV .

Measurements were taken at two energies, 1770 KeV and 4000 KeV, which are points free of resonances and provide minimal interference between γ-rays of the same energy coming from reactions on different elements. The measurement at 1770 KeV provided determination of Li, B, F, Na, Mg and Al, while the measurement at 4000 KeV was used for all of the above (with different detection limit), plus P and Si as shown in the following tables.

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* Presented by A. Savidou

Measurement at 1770 KeV

Element	γ-ray (KeV)	reaction
Li	478	^{7}Li(p,p'γ)^{7}Li
B	429	^{10}B(p,$\alpha\gamma$)^{7}Be
F	6129	^{19}F(p,$\alpha\gamma$)^{16} O
Na	440	^{23}Na(p,p'γ)^{23}Na
Mg	585	^{25}Mg(p,p'γ)^{25}Mg
Al	1779	^{27}Al(p,γ)^{28}Si

Measurement at 4000 KeV

Element	γ-ray (KeV)	reaction
Li	478	^{7}Li(p,p'γ)^{7}Li
B	718	^{10}B(p,p'γ)^{10}B
F	197	^{19}F(p,p'γ)^{19}F
Na	440	^{23}Na(p,p'γ)^{23}Na
Mg	585	^{25}Mg(p,p'γ)^{25}Mg
Al	1014	^{27}Al(p,p'γ)^{27}Al
Si	1779	^{28}Si(p,p'γ)^{28}Si
P	1266	^{31}P(p,p'γ)^{31}P

Prompt γ-rays observed from thick sample bombardment by charged particles of energy E_0 is given by the formula:

$$N(E_0) = \frac{\mathcal{N} \cdot f_A \cdot N_0 \cdot \epsilon \cdot c}{M_A} \cdot \int_0^{E_0} \frac{\sigma(E)}{S(E)} dE, \tag{1}$$

where: $\mathcal{N}$: Avogadro number

f_A: Isotopic abundance of A

N_0: Total number of incident particles

ϵ: Detection sensitivity for the radiation (including detector efficiency and solid angle)

c: Mass concentration of A nuclei

M_A: Atomic mass number of isotope A

σ(E): The cross section of gamma-ray emmission at the angle fixed by the detector position (cm^2/st)

S(E): The dE/ρ·dx, stopping power

This relation can be written as

$$\frac{N(E_0)}{N_0} = K \cdot \frac{c}{S(E_{1/2})}, \qquad (2)$$

where

$$K = \frac{\mathcal{N} \cdot f_A \cdot \epsilon}{M_A} \int_0^{E_0} \sigma(E) d(E). \qquad (3)$$

Eq. 2 is linear and was used for the calibration of the measurements. Utilizing the pellets for each element,the calibration lines were produced.

An essential element of the analysis is the correct normalization to the stopping power of the target. It has been proven by the LARN group[1-4] that the values of dE/dx should be calculated at an energy $E_{1/2}$, where the yield is half of the one observed in the energy in which the measurement was taken. Excitation functions of the above γ-rays were taken to determine the energy $E_{1/2}$[6,7]. ($E_{1/2}$ is almost equal to E_m^{act} as is defined in Ref. 7).

At these two bombarding energies the spectra of each of the above mentioned light elements, as well as those of heavier elements that are usually met in solid samples, were studied. It should be noticed that PIGE must be combined with XRF in order to acquire accurate information on all elements present in a sample. By using information from XRF for heavier elements, a more accurate knowledge of stopping power leads to better estimation of the content in light elements and also the possibility of interference from heavy (Z>15) elements can be predicted.

An article is under preparation for submission to Nuclear Instruments and Methods.

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