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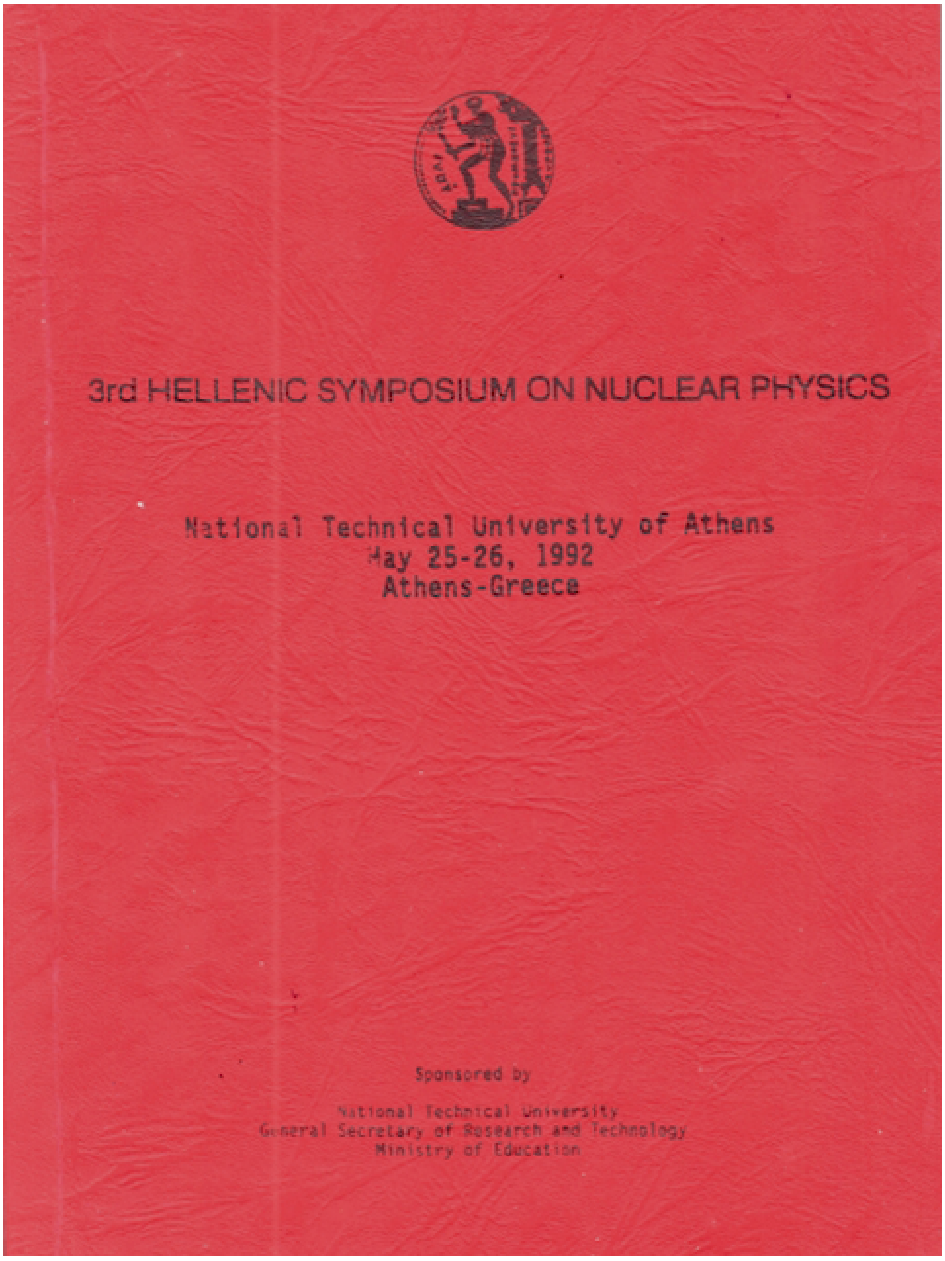

Determination of Light Elements (Z≤15) by PIGE Spectroscopy

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Proton Induced Gamma Ray Emission (PIGE) {1-4} is used for quantitative analysis of light elements (Z≤15) which are beyond the region of either XRF or PIXE . The analytical methods based on X-ray detection become inappropriate for low Z elements analysis because the energy of the corresponding Ka 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,α), (p,p'γ), (p,nγ), (p,αγ) {5}. By bombarding with protons, a sample that contains elements with adjacent atomic number , 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.

The chosen bombarding energies are 1.77 MeV and 4 MeV which are points free of resonances and provide minimal interference between γ-rays of the same energy coming from reactions on different elements. The measurements at 1.77 MeV provided determination of Li, B, F, Na, Mg and Al, while the measurement at 4 MeV was used for all of the above (with different detection limit), plus P and Si . In the following tables the detection limits for the detected gamma-rays in several matrixes are given. At 1.77 MeV the estimation of the detection limits corresponds to 200 μC collecting charge and at 4 MeV to 30 μC. These detection limits can be achieved within 30 min.

Measurement at 1.7 MeV

Ele	γ keV	Reaction	Detection limits for 200 μC collecting charge (ppm)						
			C	Ti	Fe	Co	Cu	Sn	Pb
Li	478	$^{7}Li(p,p'\gamma)^{7}Li$	1	2	1	2	1	0.1	0.1
B	429	$^{10}B(p,\alpha\gamma)^{7}Be$	6	10	5	10	5	1	1
F	6129	$^{19}F(p,\alpha\gamma)^{16}O$	5	15	5	13	5	1	1
Na	440	$^{23}Na(p,p'\gamma)^{23}Na$	10	20	10	16	10	1	1
Mg	585	$^{25}Mg(p,p'\gamma)^{25}Mg$	1500	3000	1500	2800	1200	200	200
Al	1779	$^{27}Al(p,\gamma)^{28}Si$	2000	4400	2100	3100	2200	180	180

Measurement at 4 MeV

Ele	γ keV	Reaction	Detection limits for 30 μC collecting charge (ppm)						
			C	Ti	Fe	Co	Cu	Sn	Pb
Li	478	$^{7}Li(p,p'\gamma)^{7}Li$	3	15	10	15	10	3	2
B	718	$^{10}B(p,p'\gamma)^{10}B$	90	830	400	700	510	140	80
F	197	$^{19}F(p,p'\gamma)^{19}F$	10	50	40	60	40	15	10
Na	440	$^{23}Na(p,p'\gamma)^{23}Na$	10	60	45	50	45	10	10
Mg	585	$^{25}Mg(p,p'\gamma)^{25}Mg$	250	2100	1600	1900	1500	400	300
Al	1014	$^{27}Al(p,p'\gamma)^{27}Al$	30	80	50	120	70	30	15
Si	1779	$^{28}Si(p,p'\gamma)^{28}Si$	60	130	55	160	120	50	30
P	1266	$^{31}P(p,p'\gamma)^{31}P$	60	190	100	220	150	60	40

Prompt gamma rays observed from thick sample bombardment by charged particles of energy Eo is given by the formula:

$$N(Eo) = \frac{N . f . No . \varepsilon . c}{M} \int_{o}^{Eo} \frac{\sigma(E)}{S(E)} dE \qquad (1)$$

where:
N : Avogadro number
f : Isotopic abundance of the parent nuclei
No: Total number of incident particles
ε : Detection sensitivity for the radiation (including detector efficiency and solid angle)
c : Mass concentration of the parent nuclei
M : Atomic mass number of the parent nuclei
$\sigma(E)$: The cross section of gamma-ray emmission at the angle fixed by the detector position.
S(E) : The $dE/\varrho dE$, stopping power

It should be noticed that the 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 elemens .

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