Analytical Use of Alpha-Source Induced Gamma-Ray Emission

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Analytische Anwendung der \( \alpha \)-induzierten \( \gamma \)-Emission

Zusammenfassung. Eine zerstörungsfreie Multielementmethode, die auf Kernreaktionen und Coulombanregung induziert durch \( \alpha \)-Quellen beruht, sowie die Messung prompter \( \gamma \)-Strahlung werden beschrieben. Die Methode eignet sich für leichte und mittelschwere Elemente und ist besonders empfindlich bei leichten Elementen. Der für Promptmessungen notwendige experimentelle Aufbau ist recht einfach. Die Empfindlichkeit der Methode bei Benutzung eines 0,34 mCi starken \( ^{241} \)Am-Präparats wird für die leichten Elemente Li, Be, F und Na diskutiert. Der Einfluss von Probengröße, Luftdruck usw. auf die Ausbeute eines dicken Targets wurde untersucht. Monte-Carlo-Rechnungen wurden ausgeführt, um die Modifizierung der isotropen Abstrahlung der Quelle durch deren Schutzabdeckung zu studieren und um den mittleren Energieverlust zu erhalten. Eine Li-Bestimmung in einigen Mineralen wurde durchgeführt.

Summary. A non-destructive multi-element method based on nuclear reactions and Coulomb excitation induced by alpha-sources and the measurement of prompt gamma-rays is described. The method is suitable for light and medium \( Z \) elements and is particularly sensitive to light elements. The experimental set-up necessary for the prompt measurements is quite simple. The sensitivity of the method is discussed for the light elements Li, Be, F and Na. The influence of sample size, air pressure etc. on the thick target yield has been investigated. Monte-Carlo calculations have been performed to study the modification of the isotropic behaviour of the alpha-source due to the protective covering and to calculate the average energy loss. The lithium determination in some minerals has been carried out.

Introduction

The analysis of elements by the detection of prompt gamma-rays following the bombardment by charged particles (protons, deuterons, alpha-particles etc.) is a well-known technique. The method involves the bombardment of the samples with low-energy (1 to 6 MeV) particles and the detection of gamma-rays from nuclear reactions and inelastic scattering by light nuclei and Coulomb excitation by heavy nuclei. As particle accelerator, a Van de Graaff is commonly used.

Using this prompt technique, elemental analyses in a variety of materials like blood serum [5], human bones [17], atmospheric aerosols [23], plants [5], coal [24], cement [13], glass [2, 12], minerals [3 – 5, 13], metals and alloys [11, 31] and archaeological samples [4, 12] have been carried out. The advantages offered by this method are 1) high sensitivity to light elements like Li, Be, N and F etc., 2) non-destructive approach which allows multi-element analysis in a single irradiation, 3) rapidity of analysis and 4) simplicity of sample preparation. Other physical methods such as neutron activation analysis, X-ray fluorescence analysis and particle induced X-ray emission (PIXE) have proved to be of value in elemental analysis of medium \( Z \) elements \((Z > 15)\) and light elements \((Z < 15)\) are difficult to detect by these methods.

Sometimes, a situation arises where the analyst is unable to obtain certain analytical information for want of irradiation facilities with particle accelerators. In such cases, one can think of alpha-sources as an alternative mode of irradiation. Though a Van de Graaff is capable of delivering several \( \mu \)A \((1 \mu \text{A} = 3.1 \times 10^{12} {\text{He}}^2^+ \text{ions/s})\) of beam current, for reasons like dead time caused by high count rates in the multichannel analyzer or heat produced with high beam currents which some matrices cannot withstand, a low intensity beam (1 to 100 nA) is often preferred in prompt techniques [13, 17, 23, 37]. The fluxes of commercially available alpha-sources (1 Ci = \( 3.7 \times 10^{10} \) alpha/s) are in the same range. Moreover, the alpha-energies (5 to 6 MeV) of these sources are comparable to those obtainable from a Van de Graaff. It means that an alpha-source can serve the purpose of an alpha-particle beam from a Van de Graaff accelerator, for certain analytical purposes.

The main advantages of performing irradiations with an alpha-source are that the irradiations are inexpensive and the errors introduced in the flux measurement with a Van de Graaff can be avoided. But, in contrast to the parallel beam of particles which one obtains from a Van de Graaff, the emission of particles from an alpha-source is isotropic.

With the exception of a few publications involving the principles of activation analysis [27, 29], alpha-source induced X-ray emission [1, 9] and back-scattering [40], the full exploitation of the sources in the analytical field has not been made so far. In this work, the potential of Alpha-Source Induced Gamma-ray Emission (ASIGE), for elemental analysis, has been investigated by taking the light elements Li, Be, F and Na as examples. Monte-Carlo calculations have been performed to understand the following: 1) modification of the isotropic behaviour of the...
source due to 'covering' which is of general interest for any kind of experiment performed with the sources and 2) calculation of the average energy loss for the average path length of the alpha-particle, in air or vacuum, which is required for quantitative analysis. Moreover, because of the contamination problems, the behaviour of an 'open' source, which is also included in this study, is easier to understand with Monte-Carlo calculations than by real experiments. Finally, as an example, lithium determination in some lithium bearing minerals has been carried out.

Monte-Carlo Calculations

Two types of alpha-sources can be obtained commercially: 'covered' and 'open' (uncovered). For covered sources, the protective coating usually consists of Ag, Pd or Au of thickness ranging up to a few microns to prevent the loss of alpha activity. The former type is useful for routine irradiation purposes and the latter as standard for energy calibration in alpha-spectroscopy.

In Fig. 1, a covered source is schematically shown. In this figure, 4 alpha-particles leaving at different angles are shown. The first particle lost all its energy in the protective covering and so could not leave the covering. The second particle lost most of its energy in the covering and the remaining energy is small which would be lost before reaching the sample if the medium between source and sample were air. The third particle lost some energy in the covering and the rest energy is just sufficient to reach the sample where as minimum energy is lost for the fourth particle which is incident at $0^\circ$ on the sample surface. The angle of isotropic emission is thus restricted by the covering and emission in $2\pi$ geometry is possible only for an open source.

The angle $\theta_{\text{max}}$ in air or vacuum, depends on the initial energy ($E$) of the alpha-particle, material and thickness of covering ($d_c$) and the distance ($d$) between the source and the sample. $E$ and $d_c$ are constant for a given source. The value of $d_c$ is provided by the manufacturer and $d$ is the only variable. Using the stopping power tables [28], one can calculate the relation between $\theta_{\text{max}}$ in air and distance $d$. This is shown, in Fig. 2, for the $^{241}\text{Am}$ source with and without covering. The value at $d = 0$ also corresponds to $\theta_{\text{max}}$ in vacuum.

In the next step, we take into account, additionally, the finite sizes of the source and the sample. To calculate the mean angle of the particle $\theta_{\text{mean}}$ in air or vacuum, Monte-Carlo method is used. It is assumed here that the activity is uniformly distributed on the source. The emission of alpha-particles is isotropic. The starting point on the source and the direction of the alpha-particles are randomly picked. An event is accepted only if a) the particle strikes the sample and b) the angle of emission $\theta$ does not exceed $\theta_{\text{max}}$. The calculations are made for circularly shaped source and sample, with radii $r_s$ and $r_a$ respectively, which are of common occurrence (Fig. 3). $r_{so}$ is assumed to be 1 cm.