Energy calibration of the Bucharest 3 MV Tandetron accelerator

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Low and medium energy particle accelerators find increasing applications in nuclear and atomic physics researches as well as in many disciplines, such as medicine and biology, material sciences, environmental studies and the study of art works and archaeological artifacts. In particular, the number of accelerators commercially manufactured and mostly dedicated to applied research is steadily growing. The precise knowledge of the energy and of the energy spread of the charged particle beams extracted from the accelerators is very important and mandatory in many applications. The informations on the beam energy as inferred from the accelerator parameters supplied by the manufacturer can sometimes be not sufficient for specific applications. The accelerators needs therefore to be calibrated by a method ensuring an absolute energy determination. For very accurate energy calibrations it is usually not enough to calibrate the energy at just one point.

There are a number of techniques by which a measurement of particle bema energies may be obtained.

Two common techniques for calibrating an ion accelerator are the measurement of neutron threshold energies of sharp (p,n) or (α,n) reactions or the use of nuclear (p,γ) or (p,p) reactions having narrow, well known resonances with large cross sections.

Threshold energies have been determined from absolute measurements of the incident particle energy for a number of reactions. Recommended values of threshold energies for calibration purposes have been tabulated by Marion [1]. A convenient method for measuring neutron threshold energies is the observation of the emitted neutrons at 0^0 using a simple neutron detector such as a long counter. This technique can be utilized with (p,n) reactions up to 6 MeV. Above this proton energy the neutron background becomes prohibitively large.

A technique by which a measurement of particle beam energy may be obtained is based on gamma-ray resonances. The $^{27}Al(p,\gamma)^{28}Si$ reaction has been used most frequently, since the resonance width is ~ 80 eV, and the location of the resonance at 991.90±0.04 keV is ideally suited for those machine that are routinely used for Rutherford backscattering spectrometry measurements. Commonly, backscattering is used more than other analysis methods and the resonances for the (p,p) and (α,α) reactions can be easely used for quick, fairly accurate energy calibrations.

Other investigators have used the precise measurement of gamma ray energies arising from direct capture reactions in high-resolution Ge detectors to measure the beam energy [2]. Time of flight have also been used for calibration purposes [3]. The time-of-flight technique provides a relatively simple method for measuring absolute beam energy if a time-modulated beam of sufficient intensity is available. In contrast with the use of resonances or thresholds, which occur only at specific energies, this technique is useful over a wide range of particle types and energies.

The use of RBS (Rutherford Backscattering Spectrometry) measurements to determine an internal energy calibration offers several advantages, the most obvious being that it is not restricted to discrete resonance energies or thresholds energies but can be used continously. This technique uses the conventional backscattering spectrometry setup. Two measurements are required. The first are backscattering measurements of two calibration samples. These data defines two linear equations that relate the energy per channel a and the energy intercept b of the system to the beam energy E. The second measurement is of some positive-Q nuclear reaction or the measurement of the α particles from a radioactive source, at the same gain. We obtain a third linear equation. Variations of this technique have been attempted in some earlier reports [4-8]. In these reports the elastic scattering approach was used to calibrate the accelerator energy scale. Another absolute method for the determination of the energy of a charged particle beam which uses a backscattering technique is based on scattering kinematics and exploits the variation with angle of the energy of particles scattered by elastic and inelastic processes [9]. Normally, this method is applied to beam energies above a few MeV.

The method adopted for calibration of the Bucharest 3 MV Tandetron accelerator consists simply of comparing the energies of alpha particles from a radioactive source with the energies of ^{4}He projectiles back-scattered into an silicon detector by carbon and gold layers.

The uncertainty on the high voltage is only 100 V when set to 2-3 MV using a high voltage power supply based on the dynamitron process for wich no slits are required. After a precise calibration of the gigh voltage, such accelerators show remarcable stability and reliability for up to few years.

The beam energy will be calibrated using the α's from ^{241}Am with a modified version of Scott's method [8]. Two measurements will be performed. The first are backscattering measurements of two samples (C and Au). These data defines two linear equations that relate the energy per channel a and the energy intercept b of the system to the beam energy E.

$$E_C = K_C E = aN_C + b \qquad (4)$$

$$E_{Au} = K_{Au} E = aN_{Au} + b \qquad (5)$$

where E_C, N_C, K_C and E_{Au}, N_{Au}, K_{Au} are the energy, channel number and the kinematic factor for backscattering from C and Au respectively. If E is not known and is to be determined we must obtain a third equation relating E to a and b. This equation cannot be homogeneous if the set is to have a unique solution.

The third equation is obtained by counting the α particles from the ^{241}Am radioactive source, at the same gain. The radioactive source used contained two alpha emitters ^{239}Pu and ^{241}Am. So the third equation is

$$E_\alpha = aN_\alpha + b \qquad (6)$$

After solving the system of equations the solution is implemented in the code RUMP [10] and the simulated spectrum is compared with experimental spectrum.

As an example Fig. 1 shows a backscattering spectrum for ^{4}He on the Au/SiC/Al sample measured in January 2010 during an energy calibration of the analyzing magnet of the 9 MV Tandem accelerator. The C peak is strongly enhanced in this spectrum due to the resonance in the cross section near 4.26 MeV. The simulation using RUMP is presented with solid line.

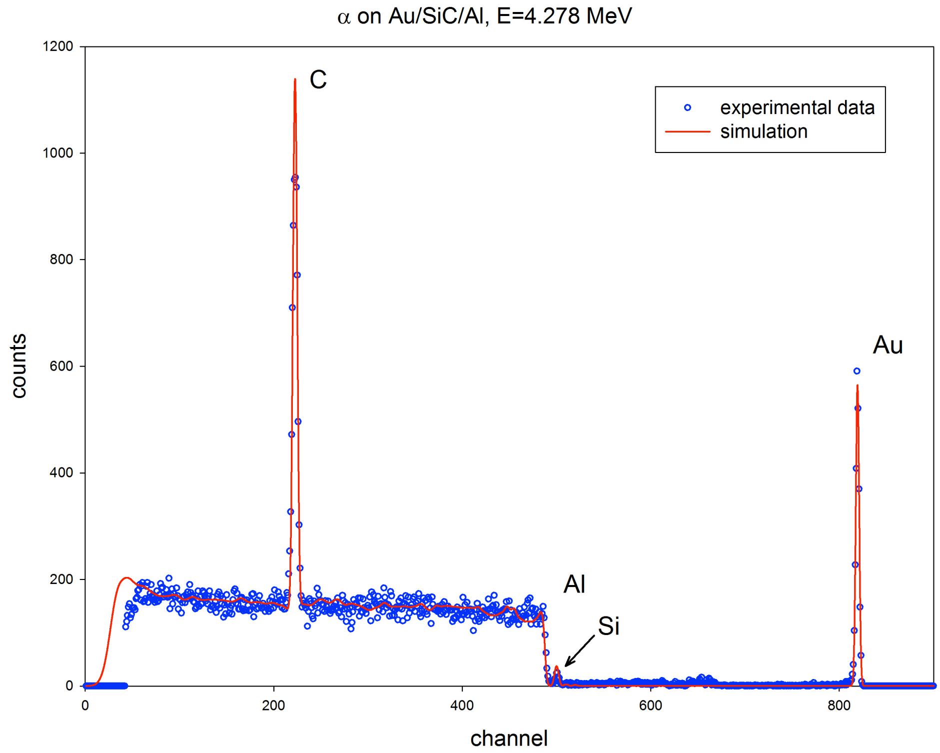

Fig. 1

The N_C, N_{Au} channels were determined from the RBS spectrum; the N_α channel was determined from the alpha spectrum of the ^{239}Pu+^{241}Am source, measured at the same gain as the backscattering spectrum. Solving the equation system a value of E=(4278.0±1.5)keV was obtained for the beam energy. The solution is implemented in the code RUMP. It may be observed from Fig.3 that RUMP simulation is very close to the experimetal spectrum. We also intend to use some resonance reactions. We need 5 days (15 runs).

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