

Experiment proposal:

Energy calibration of the Bucharest FN tandem accelerator

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The FN-tandem in Bucharest was commissioned in March 1973 but its operation was stopped for quite long time periods, due to the strong earthquakes in Romania in the years 1977 (7.2 Richter scale) and 1986 (6.9 Richter scale). To prevent the consequences of similar seismic events in the future, a seismic protection system was designed and installed. Due to sustained efforts made by the Tandem accelerator team, the accelerator was recommissioned in the second half of 1991. In 2006 a program of modernization and development of the accelerator was started. A new RMN fluxmeter (made by METROLAB, Switzerland) for measuring the magnetic field in the analysing magnet gap was installed. In the past the analysing magnet has been calibrated up to 14.2 MeV equivalent proton energy using both threshold (p,n) and (α ,n) and resonance (p,p) reactions. The absolute calibration points used resulted from measurements of both (p, n) and (α ,n) thresholds and narrow (p, p) resonances. The calibration measurements were made during several separate experimental runs over a time period from 1975 to 1999. Data were taken on two separate occasions: July 1975-May 1976, 1980 and December 1999. The last calibrations based on the measurement of the narrow resonance from $^{12}\text{C}(p,p)^{12}\text{C}$ elastic scattering at $E=14.231$ MeV were performed in 1980 and 1999. The result of the last calibration has evidenced a 21.5 keV shift in the energy of the resonance. So, a new and more complete calibration of the energy analysis system is needed since the last magnet calibration was based on only one calibration point. A new energy calibration has been completed for ^4He beams over the energy range from 4.278 to 5.594 MeV.

The objective of the performed experiments was to determine the beam energy as accurately as possible near 5 MeV where there is a dearth of suitable resonance or threshold calibration energies. The experimental arrangement was that typically used in RBS measurements. Data were taken on two separate occasions: January 2010 and March 2011.

The method adopted for calibration of the analysing magnet fields of the Bucharest FN tandem accelerator consists simply of comparing the energies of alpha particles from a radioactive source with the energies of ^4He projectiles back-scattered into a silicon detector by thin carbon and gold layers. 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 continuously. The method adopted is based on alpha-particle backscattering technique and consists of comparing the energies of alpha particles from a radioactive source with the energies of ^4He projectiles back-scattered by thin C and Au layers. The field of the 90° magnet was measured with a NMR fluxmeter. The relativistic relationship between the energy E of the analysed particle and the magnetic field B is given by the expression:

$$E = K_1 B^2 \frac{Q^2}{M} \left(1 + \frac{E}{2Mc^2} \right)^{-1} \quad (1)$$

Where Q is the effective charge of the particle, M is its mass and (E/Mc^2) is the ratio of its kinetic energy to rest mass energy. E is in MeV, Q in units of electronic charge and B is in Tesla. The mass M, expressed in nuclidic mass units, is obtained by subtracting the mass of the appropriate number of electrons from the atomic mass, neglecting the electron binding energies. The magnetic field B is correlated with the frequency f of the RMN in MHz by the expression:

$$B = 2.3487 \times 10^{-2} f \quad (2)$$

The relationship between particle energy E and the measured NMR frequency is given by the expression:

$$E = Kf^2 \frac{Q^2}{M} \left(1 + \frac{E}{2Mc^2} \right)^{-1} \quad (3)$$

The calibration of the analysing magnet consists in a precise determination of the constant K. The constant K may be a weak function of the magnetic field due to saturation and fringing field effects.

The method which was used consisted in determining the beam energy and the calibration parameters of the pulse height analysis system simultaneously. The data are the peaks from the alpha source and the peaks from the scattered beam by two elements, C and Au.

If a linear relation is assumed between the energy E and the channel number N the following system of equations can be formed:

$$E_C = K_C E = a N_C + b$$

$$E_{Au} = K_{Au} E = a N_{Au} + b$$

K_C and K_{Au} are the kinematic factors for backscattering from C and Au, respectively. E_C , E_{Au} , N_C , N_{Au} are the energies and channel numbers for backscattering from C and Au, respectively.

For the alpha source we have:

$$E = aN + b$$

where E and N are the energy and the channel number for the alpha source peak, respectively.

E is the ^4He bombarding energy and a and b are the energy per channel and the energy intercept of the pulse height analysis system. Fig. 1 shows a backscattering spectrum for ^4He on the Au/SiC/Al sample measured in January 2010. 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. The N_C , N_{Au} channels were determined from the RBS spectrum; the N channel was determined from the alpha spectrum of the $^{239}\text{Pu} + ^{241}\text{Am}$ source, measured at the same gain as the backscattering spectrum. Solving the equation system a value of $E = (4278.0 \pm 1.5) \text{keV}$ was obtained for the beam energy. The solution is implemented in the code RUMP.

It may be observed from Fig.1 that RUMP simulation is very close to the experimental spectrum.

The energy E was used in conjunction with the reading of the NMR fluxmeter to calculate K. To minimize effects of differential hysteresis the magnetic field was recycled before starting the measurements. The magnetic current was increased smoothly from zero to the maximum and then reduced to zero. This was done three times and then the field was increased to the required value without overshooting. All data were taken in the direction of the increasing energy.

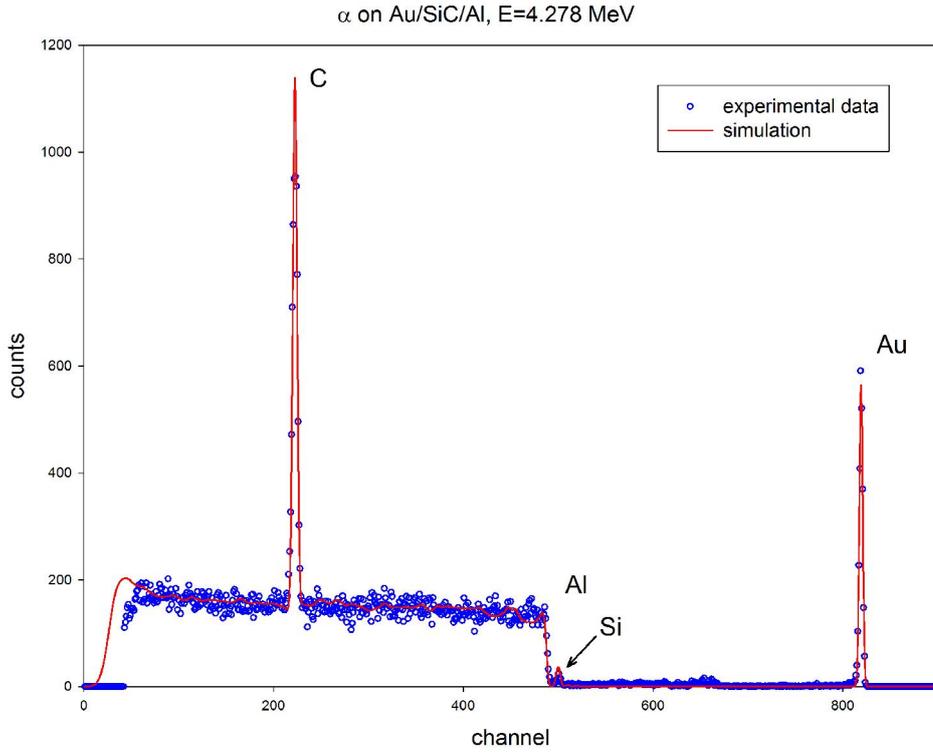


Fig. 1

In Fig. 2 we present a plot of all the measured beam energies versus squares of the corresponding NMR frequencies. The solid line represents the best linear fit to the experimental points. Note the good linear fit to the data points.

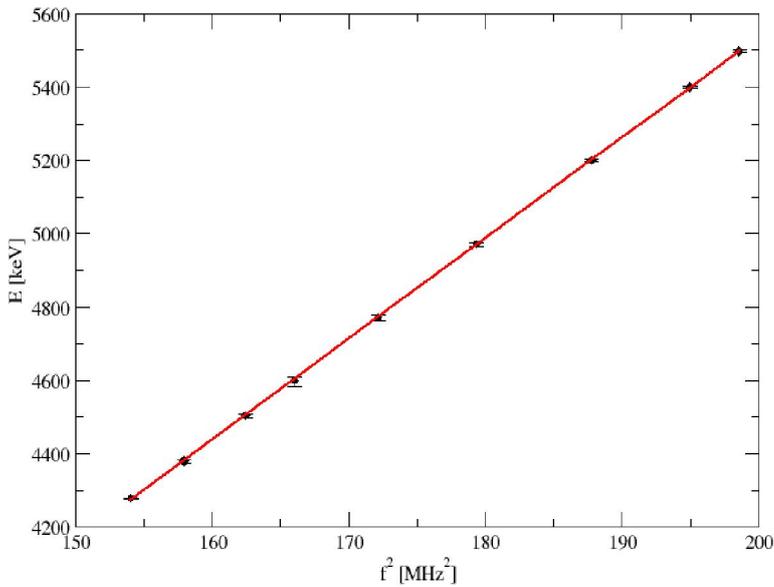


Fig.2

A plot of K values versus equivalent proton energy is presented in Fig. 3. The magnet constant decreases with equivalent proton energy from 2 to 4 MeV. This is most probably a

result of the rapid onset of saturation of the iron at the entrance and exit edges of the pole faces. As the saturation increases, a higher field is required over the remainder of the orbit and at the NMR probe position to maintain the same average field over the trajectory. Other similar studies have shown the same effect.

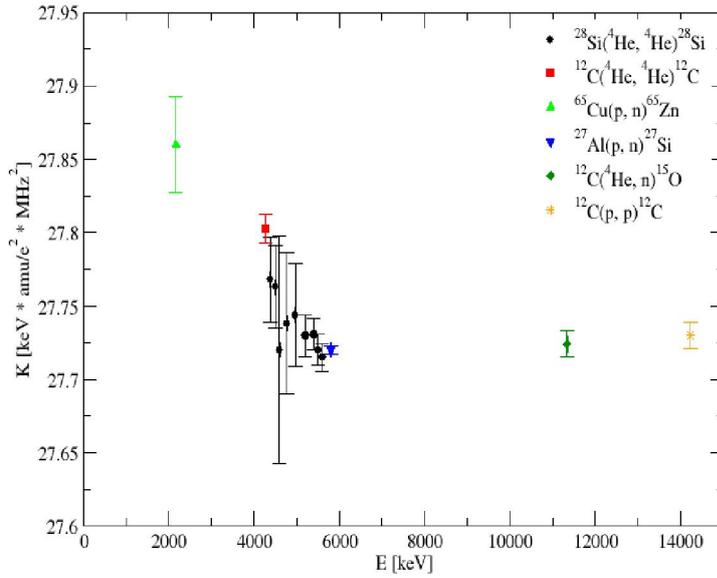


Fig. 3

For higher equivalent proton energies the value of K remains constant down to about 4 MeV. We were calculating an average value for K by the method of least-squares. All data from our measurements were included in the average. A value of $K=27.742 \pm 0.004$ keV·amu/e²·MHz² was obtained. This value is in agreement with the average value $K=27.720 \pm 0.003$ keV·amu/e²·MHz² obtained from previous measurements.

Using the same method based on proton and alpha-particle backscattering technique of comparing the energies of alpha particles from a radioactive source with the energies of ¹H and ⁴He projectiles back-scattered by thin C and Au layers we intend to extend our measurements to lower and higher energies.

We also intend to measure the narrow ¹²C(p,p)¹²C elastic scattering at E=14.231 MeV. The exact resonance energy is (14.23075±0.00020) MeV and the width of the resonance is (1.2±0.2) keV.

Beam energy spread and hysteresis effect of the analysing magnet will be investigated. For these measurements we ask for 7 days beam time (21 shifts).