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Proposal to the ISOLDE and Neutron Time of Flight Committee

**Studies of the Beta-Decay of Sr nuclei on and near the N=Z line with a
Total Absorption Gamma Ray Spectrometer**

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Abstract

In the framework of the investigation of the shapes of the ground states of the parent nucleus, we propose to carry out measurements of the complete Gamow-Teller strength distribution for the $^{76-80}\text{Sr}$ isotopes, with a new Total Absorption gamma Spectrometer installed on a new beam line. The results will be compared with theoretical calculations based on the mean field approach. A brief report on the IS370 experiment on $^{72-75}\text{Kr}$ decay, which was recently performed at ISOLDE, will be given and the performance of the sum spectrometer will be presented.

1 Introduction

1.1 Physical context

Currently, the only experimental access to nuclear levels out of the Yrast sequence in nuclei far from stability is provided by β - and isomeric-decay. As a result the study of β -decay makes a major contribution to our understanding of highly unstable nuclei. In addition, a very clear advantage of studying the β -decay process is the close relationship between the wave functions of the parent state and the states populated in the daughter nucleus which makes it amenable to theoretical calculation. In this particular proposal we concentrate on measurements of Gamow-Teller transition probabilities which are very important if we are to understand nuclear structure and astrophysical processes. The proposed measurements are planned in the $N=Z$ region where phenomena such as shape coexistence and n-p pairing play an important role.

In this context the first theoretical developments dedicated to the neutron deficient nuclei along the $N=Z$ line taking into account deformation and pairing correlations were carried out by Hamamoto and collaborators [1,2]. According to them, the GT process carries invaluable information on the sign of the nuclear deformation. Large differences appear in the calculated GT strengths - total intensity and energy distribution - depending on the shape of the parent nucleus. Of special interest in this respect are the $N = Z$ nuclei in the $A=70-80$ mass region, where an oblate to prolate transition is predicted, and for which various deformation amplitudes have already been inferred from experimental results [3,4]. More recently, extensive studies have been carried out on the decay of the even- and odd-mass nuclei by P. Sarriguren, E. Moya de Guerra and coworkers, using the self consistent HF plus RPA method with different types of Skyrme interaction, stressing the role of deformation, residual interactions, pairing and RPA correlations on the GT strength distributions [5,6,7].

In this spirit, high resolution measurements of the $\beta^+ - EC$ decay of two even-even, $N=Z$ isotopes ^{72}Kr and ^{76}Sr and searches for their delayed proton emission have been performed at the ISOLDE PSB facility. An indication of prolate shape for the ^{76}Sr ground state was obtained [8]. No indication for the expected oblate deformation of ^{72}Kr [8] was obtained. The experimental results revealed the limitations inherent in using semiconductor detectors to measure the gamma-ray intensities.

We have carried out experiments on the Kr isotopes using a different experimental technique [9] which we shall describe below, and we will propose the next series of measurements focussed on the Sr nuclei in chapter 2.

1.2 Description of the technique and report on the first experiment carried out with the new device

The idea of determining nuclear shapes which we have outlined above, relies not only on the precise determination of the total Gamow-Teller strength accessible in the Q_{ec} window, but even more on the strength distribution as a function of excitation energy in the daughter nucleus. The precise measurement of this distribution is a difficult task, which cannot be achieved using semiconductor Ge detectors alone. The reason is that the B_{GT} is derived from the feeding to the individual levels (assuming half life and Q_{ec} known), and the feeding is measured as the balance of the intensity of the gamma-rays feeding and de-exciting each level. Therefore, any missing gamma-ray distorts the derived B_{GT} distribution (we talk here about the β -delayed gamma decay, the part of the strength proceeding through β -delayed particles will be discussed later).

To overcome this problem we have designed and installed a new Total Absorption gamma Spectrometer "Lucrecia" on a new beamline at ISOLDE. The main idea is two fold, first to use a device sensitive to the β -feeding rather than to the individual gamma-rays, second to achieve $\sim 100\%$ total efficiency for each gamma cascade produced in the decay. A device with these characteristics has been used successfully at the GSI On-line Mass-Separator [10] where the Gamow-Teller resonance near ^{100}Sn [11] and ^{146}Gd [12] has been observed. The new spectrometer consists of a very large, cylindrical

NaI mono-crystal (38 cm diameter, 38 cm long) with a hole of 7.5 cm diameter perpendicular to the symmetry axis. It was manufactured by Saint Gobain Crystals and Detectors (see Fig. 1). The light is collected by eight five-inch photomultiplier tubes. The crystal acts as a sum spectrometer detecting all the gammas emitted in a cascade after the beta or the EC process. The stability of the PMT signal is continuously monitored by a Light-Emitting Diode. Two ancillary detectors are coupled to the NaI crystal. They consist of a Ge telescope with a small planar detector in front with 400 eV energy resolution at 6 keV to measure the characteristic X-rays, and a thin plastic detector to detect the ΔE signal left by the positrons. Both detectors are used in coincidence with the NaI crystal allowing us to separate the β -decay from the EC process. The crystal and the ancillary detectors are mounted on movable tables and are coupled to a tape transport system operated in vacuum. The detectors are housed within layers of neutron and gamma shielding made of boron polyethylene (10cm), lead (5 cm), copper (2 cm) and aluminum (2 cm).

The NaI crystal has a measured energy resolution of 5.2 % at 1.33 MeV, very good linearity in energy and a high total efficiency (evaluated to be 90 % at 5 MeV).

In June 2001 we carried out the first experiment with “Lucrecia”. We measured the β -decay of mass 72 to 75 krypton isotopes in carrying out the approved experiment IS370 which was based on the physics outlined in the introduction. The experiment was performed with a Niobium cold plasma ion source mounted on the High Resolution Separator. The transmission of the ions was, after 40 metres of beam line, of the order of 60%.

The raw spectra clearly show previously unobserved strength at high excitation energy. It should be noted at this point that the process of data analysis is far from trivial. Although the total efficiency of the detector is very high for single gamma rays, the photopeak efficiency for a gamma cascade can be small and depends on the multiplicity of the cascade. In other words we face the so called ill-posed inverse problem which consists of extracting the β -feedings out of a continuum spectrum involving the response function of the spectrometer. A method of solving this problem has been developed over the last few years [13] and successfully applied to experiments performed at GSI. However the response of the spectrometer to the different particles, betas and gammas, depends strongly on the individual apparatus and has to be treated specifically. We are now making an effort in this direction with the Monte-Carlo simulation code GEANT 4 which has proved to give a much better description of the penetration of the betas in the crystal than GEANT 3.

Preliminary results on the study of the krypton decays, together with a description of the sum spectrometer “Lucrecia”, will be presented to the panel.

The case of the Sr isotopes presented in the next chapter is intimately linked to the previous proposal on the Kr nuclei and it is important to study them under the same conditions. Thus the present proposal can be viewed as a continuation of the proposal IS370. The newly determined response function of the spectrometer will be valid only in so far as nothing is changed in the present geometry.

2 Proposed experiment

As mentioned in the introduction, the onset of deformation as well as the existence of shape coexistence are two of the attractive aspects of studying $N=Z$ nuclei. Different kinds of ground state deformation are predicted for nuclei which differ only slightly in the number of protons and neutrons. In general, mean field calculations of the energy surface predict a second minimum only a few hundred keV away and with a different deformation. Which of the two states becomes the ground state depends on the details of the calculation and the effective interaction.

Experimentally one has evidence of shape coexistence in the case of the ^{74}Kr [14] and ^{72}Kr [15] isotopes where a second 0^+ isomeric state has been observed in fragmentation reactions. However such experiments do not determine the shape of the isomer or the ground state; the assignments are entirely based on the theoretical predictions. For the Sr cases no shape isomerism has been observed so far, but an indication of prolate deformation has been extracted from the β -decay of ^{76}Sr [8].

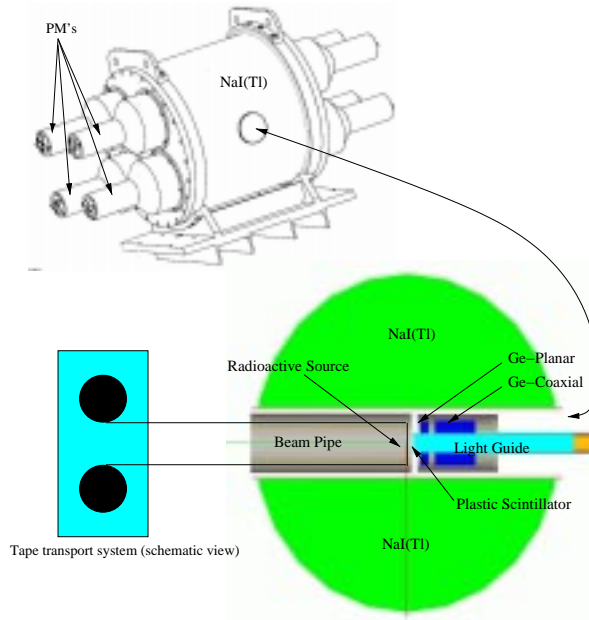


Figure 1: Experimental device.

Theoretically there are several relevant studies of $N \sim Z$ nuclei. In particular, for the Sr isotopes calculations have been carried out using several approaches: both relativistic and non-relativistic frameworks with a Skyrme SIII force [16]; in the Dirac-Hartree-Bogoliubov (DHB) approximation [17]; with the finite-range droplet macroscopic model and the folded-Yukawa single particle microscopic model of Möller and Nix [18] who predict prolate deformation parameter for the ground states of the non-spherical nuclei. These calculations do not always arrive at the same conclusions, for instance in refs [17] and [18] different shapes are predicted for the ground state of ^{78}Sr . The $N=Z=38$ ^{76}Sr nucleus is particularly interesting since it has the largest ground state deformation known in the region [19].

A completely independent method of determining the sign of the deformation is based on the study of the beta strength distribution. The basic idea is that the single particle deformed orbitals involved in the β process may lie at different energies depending on the deformation. This may lead to sizeable differences in the B_{GT} distribution.

Figure 2 shows the results of P. Sarriguren et al. [7]. It shows the B_{GT} distribution obtained from HF-BCS-QRPA calculations using the SG2 Skyrme force. It is very clear that the difference in the strength distribution between the prolate and the oblate shape solutions increases as one moves from the Ge to Sr nuclei. Meanwhile the authors of this publication are calculating the odd cases where similar differences are expected [20]. Consequently the Sr chain seems to be an ideal testing ground for the method of determining the shape of the g.s from the B_{GT} distribution.

There is another factor which helps to make these cases cleaner in comparison with the Kr isotopes; the two potential energy minima are better separated here. Consequently, one expects smaller admixtures in the strontium ground state wave functions. In turn this implies that we might need the Sr results in order to interpret the Kr measurements where strong admixtures are predicted [21].

We should also mention that the part of the strength which proceeds via particle emission has already been measured for the $^{76,77}\text{Sr}$ cases [8,22]. However a further experiment, which combines the particle detection and the high efficiency of the NaI spectrometer, will be the subject of a future proposal.

3 Measurements

It is proposed to measure the decay of the $^{76-80}\text{Sr}$ isotopes using the the newly installed Total Absorption gamma-ray Spectrometer “Lucrecia”. For the isotopes of interest, the main features of their decay are quoted in Table 1.

ISOTOPE	Half life (s)	S_p (keV)	Q_{ec} (keV)
^{76}Sr	7.89	3526 (17)	6090 (300)#
^{77}Sr	9.0	3137 (14)	6856 (150)
^{78}Sr	159	4054 (12)	3761 (11)
^{79}Sr	135	3924 (10)	5320 (11)
^{80}Sr	6378	5020 (8)	1868 (11)

Table 1. General features of the decay of Sr isotopes.

The separated parent activity produced by ISOLDE will either be caught on tape at the centre of the TAgS [in the case of the very short-lived isotopes] or will be carried to a remote counting position by the tape. By requiring coincidences with signals from the beta detector, the positron component of the β^+ -EC decay can be selected, whereas coincidences with characteristic X-rays recorded by the Ge detector can be used to select the EC events. Similar measurements on the decay of the daughter activities will be carried out in those cases where the half life difference is not enough to measure the Sr species cleanly.

The analysis of the data will be carried out using the methods of analysis established in Ref. [23] including the determination of the response function of the large NaI(Tl) crystal [24] and the pulse pile-up correction [25]. It is anticipated that this should allow a reliable extraction of the B_{GT} distribution up to the limit imposed by the Q_{ec} window.

4 Beam Time Request

For the production of strontium isotopes a Nb metal target will be used with a W surface ionisation ion source. To obtain pure alkali earth element beams the chemical selectivity created by partial CF_4 pressure in the source is essential. Our beam time request is based on production yields obtained in previous experiments at the ISOLDE PSB facility, the run performed on the Kr isotopes and the need to record at least 5.10^5 coincidence events in the TAgS spectrum.

Accordingly:

- 15 shifts are required for β -decay measurements of the $^{76-80}\text{Sr}$ isotopes,
- 3 shifts are required for data taking of the daughter activities.

The total request is 18 shifts.

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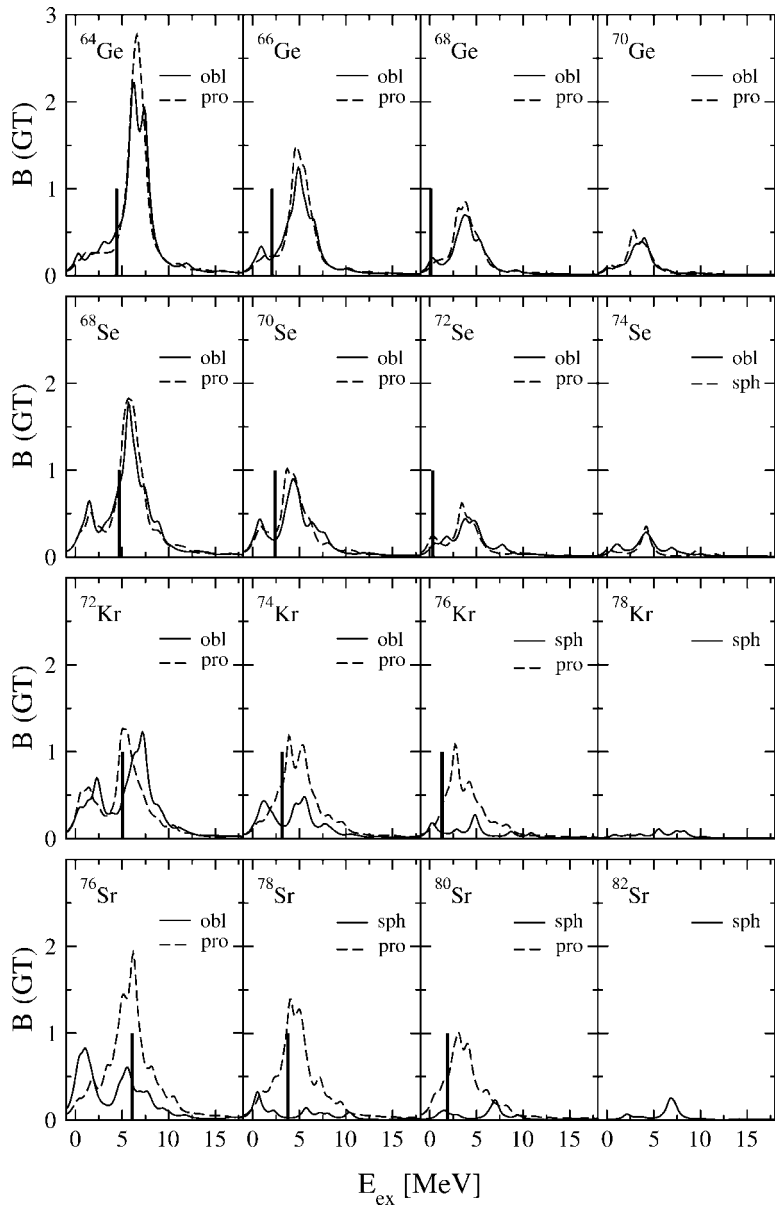


Figure 2: Calculated Gamow-Teller strength distributions for even Ge, Se, Kr and Sr isotopes [7].