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NUCLEAR PHYSICS A

The neutron-rich Mg isotopes: first results from MINIBALL at REX-ISOLDE

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After the successful commissioning of the Radioactive beam EXperiment (REX) at ISOLDE (CERN) in 2002, first physics experiments were performed in 2003 which focussed on the neutron-rich Mg isotopes in the vicinity of the “island of inversion”. After introducing the REX facility and the modern γ spectrometer MINIBALL first preliminary results will be presented showing the high potential and physics opportunities offered by this new radioactive beam facility.

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1. The REX-ISOLDE facility

The radioactive beam experiment REX-ISOLDE [1–3] at ISOLDE (CERN) is a pilot experiment for the post-acceleration of radioactive ion beams at the ISOLDE facility [4]. The radioactive 1^+ ions delivered by ISOLDE are first accumulated, cooled and bunched in a Penning trap (REX-TRAP). After charge breeding to an $A/q<4.5$ in an electron beam ion-source (REX-EBIS) the radioactive ions are finally injected into a linear accelerator (consisting of an RFQ, an IH-structure, and three 7-gap resonators) where they are accelerated to energies between 0.8 and 2.25 MeV/u.

In October 2001 the first radioactive beam was accelerated by REX to an energy of 2 MeV/u. After performing commissioning runs in 2002, several production runs with beam energies of 2.25 MeV/u were carried out in 2003 including experiments on the neutron-rich Mg isotopes. In 2004, the maximum beam energy was increased to 3.0 MeV/u and for the near future a further energy upgrade to 4.3 MeV/u is planned which will lead to a significant extension of the accessible region of nuclei towards heavier isotopes. In the end of 2003 the REX-ISOLDE accelerator became a dedicated CERN user facility.

2. The MINIBALL-setup

The main experimental device which is currently used in conjunction with the REX accelerator is the modern HPGe array MINBALL [5,6]. It consists of eight triple cluster detectors each of them containing three 6-fold segmented individually encapsulated HPGe detectors. To adjust the MINIBALL array to specific experimental requirements the cluster detectors are mounted on an adjustable frame. In the most dense arrangement of the clusters (target-detector distance $\sim$ 9 cm) the total MINIBALL efficiency is about 10 % at $E_\gamma = 1$ MeV.

The readout of the Ge channels of the MINIBALL array is performed with fully digital electronics. Here, the current signals of the central core and six segment electrodes of each detector are first integrated by preamplifiers and subsequentially digitized (40 MHz, 12 bit) and analyzed online onboard the DGF-4C CAMAC module produced by XIA [7]. The user specific pulse shape analysis (PSA) algorithms which are implemented on the card [6–9] allow (besides energy and timing information) to determine the first interaction point of each γ ray with a position resolution of 7-8 mm. Using the pulse shape analysis the granularity of the HPGe detectors can thus be increased by a factor of about 100 as compared to non-segmented detectors.

The MINIBALL-setup is complemented by a silicon telescope consisting of a $\sim$ 500 μm thick annular double-sided silicon strip detector (dE) of CD type [10] and an additional $\sim$ 500 μm unsegmented silicon detector (E) (covering laboratory angles from 16° to 53°) which allows to identify the reaction products and their energy and direction of flight. For monitoring the radioactive beam a parallel plate avalanche counter (PPAC) [11] with a spatial resolution of 1.6 mm was used at beam currents up to 10^9 particles/s.

3. First Experiments

The REX-ISOLDE facility together with the γ spectrometer MINIBALL offers unique possibilities to study collective and single-particle properties of exotic nuclei far from stability with standard nuclear physics techniques such as “safe” Coulomb excitation (below the Coulomb barrier) and single-nucleon transfer reactions in inverse kinematics as well as other experimental methods. During the measuring campaigns in 2003 these investigations focussed on the neutron-rich Mg isotopes in the vicinity of the “island of inversion”.

Since the discovery in 1975 [12] that the neutron rich ^{31,32}Na isotopes are more tightly bound than expected, the unusual properties of the neutron-rich Na and Mg isotopes in this region near the $N = 20$ shell closure are subject of intense theoretical and experimental investigations. Nevertheless, the knowledge on these nuclei is sparse and some of the existing experimental data are not consistent, e.g. the $B(E2;\ 0^+_{\rm gs} \rightarrow 2^+_1)$ values for ^{30,32}Mg measured by different groups (mainly by intermediate-energy Coulomb excitation at projectile fragmentation facilities) differ from each other by as much as a factor of two [13–16] indicating that systematic errors in these experiments are not completely understood. In contrast the Coulomb excitation studies at REX-ISOLDE are performed at beam energies well below the Coulomb barrier allowing to determine $B(E2)\uparrow$ values in a model-independent way.

In the following first results from the Coulomb excitation of ^{30}Mg with a half-life of only 335 ms, containing four more neutrons than the heaviest stable Mg isotope ^{26}Mg, are presented.

To Coulomb excite the lowest lying 2^+ level of ^{30}Mg at 1482 keV, a 1.0 $\frac{\rm mg}{\rm cm^2}$ natural Ni target was bombarded with a beam of 2.25 MeV/u ^{30}Mg nuclei of an intensity of about 2×10^4 particles per second. A Doppler corrected γ spectrum, taken during a 3 days run, is shown in Fig. 1.

The spectra shown only contain events where the recoiling ^{30}Mg projectiles were scattered in the Si detector corresponding to surface distances between the two colliding nuclei of more than 7 fm. These events can well be separated from those with recoiling Ni nuclei scattered into the particle detector because of the higher kinetic energy of the former at the same laboratory scattering angle. If the Doppler correction is performed for the detected ^{30}Mg ions the first excited 2^+ state in ^{30}Mg at 1482 keV can be seen (upper panel), whereas a Doppler correction for the kinematically reconstructed recoiling Ni nuclei results in the appearance of the two gamma lines at 1454 keV and 1333 keV originating from transitions of the first 2^+ states in ^{58}Ni and ^{60}Ni, respectively (lower panel). In the shown Mg (Ni) spectrum the contributions from the Ni (Mg) peaks were suppressed. From the intensity of the Mg and Ni peaks the $B(E2)\uparrow$ value of ^{30}Mg can be determined relative to the well known $B(E2)\uparrow$ values of the Ni isotopes [17,18] using established Coulomb excitation codes. The analysis results in a $B(E2)\uparrow$ value for ^{30}Mg of 241(31) $e^2{\rm fm}^4$ [19]. The quoted value contains a correction for isobaric beam contaminations, which mainly result from the decay of ^{30}Mg to ^{30}Al during trapping and charge breeding, and of ^{30}Al directly released from and ionized at the primary ISOLDE target. To determine the total beam contamination several tests were performed including LASER-on/off measurements, measuring the time dependences of the γ yield in the ^{30}Mg and ^{58,60}Ni peaks with respect

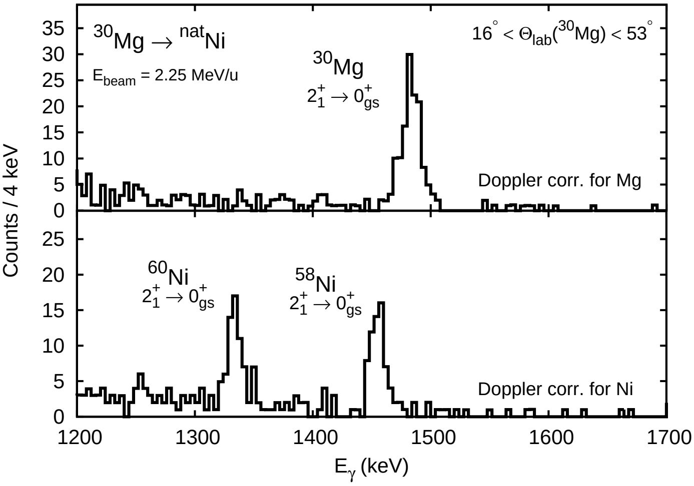

Figure 1. Doppler corrected γ spectra in coincidence with scattered ^{30}Mg in the particle detector. For the spectrum in the upper panel the Doppler correction is performed for magnesium, the lower panel shows the Doppler correction for the recoiling Ni nuclei (see also main text).

to the proton pulse impact on the ISOLDE target, as well as investigating the time structure of the REX-EBIS pulse and analyzing the γ yield due to β decay of ^{30}Mg and ^{30}Al. The total beam contamination by ^{30}Al determined from this analysis was 6.5% (see [19] for details).

In Fig. 2 the $B(E2;\, 0_{gs}^+ \rightarrow 2_1^+)$ value of ^{30}Mg determined at REX-ISOLDE/MINIBALL is shown together with theoretical and experimental $B(E2;\, 0_{gs}^+ \rightarrow 2_1^+)$ values for the neutron-rich even-even Mg isotopes.

It stands out that the ^{30}Mg $B(E2)\!\uparrow$ values measured at MSU and GANIL via the intermediate-energy Coulomb excitation technique are larger than the present value by about 20% and 80%, respectively. It should be noted that in intermediate-energy measurements several effects can influence the deduced $B(E2)\!\uparrow$ values such as feeding from higher lying states and nuclear contributions to the excitation of the 2^+ states which have to be corrected for. In contrast, the present result is based on the well established nuclear physics technique of “safe” Coulomb excitation. In addition, our result is rather insensitive to systematic experimental errors due to the relative measurement of the projectile to target excitation. This consideration is supported by a test measurement performed by replacing the ^{30}Mg by a stable ^{22}Ne beam at 2.25 MeV/u; the deduced $B(E2)\!\uparrow$ value for the first 2^+ state of ^{22}Ne at 1275 keV of 243(27) e^2fm^4 is in excellent agreement with the literature value [20] of 230(10) e^2fm^4.

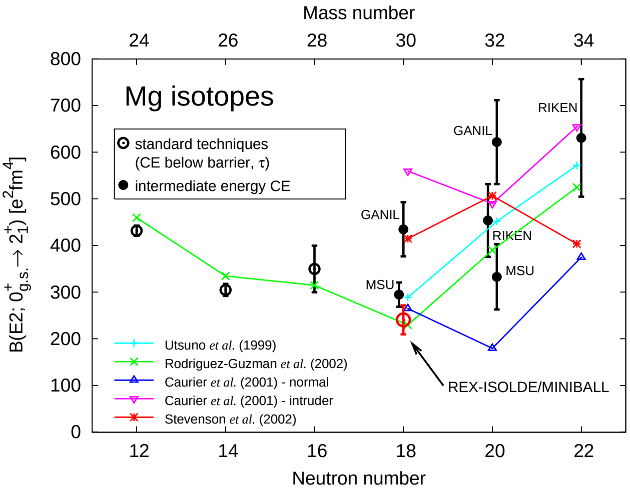

Figure 2. Experimental and theoretical $B(E2)\uparrow$ values for the neutron-rich Mg isotopes. The experimental values for ^{24,26,28}Mg were taken from [20], the values for ^{30,32,34}Mg from [13–16]. The theoretical predictions were taken from [21–24].

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