MASS MEASUREMENT OF SECONDARY IONS OF $A = 100$ IN THE VICINITY OF ^{100}Sn USING THE SECOND CYCLOTRON OF GANIL*

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Two experiments aimed at measuring the masses of secondary ions of $A = 100$ in the vicinity of ^{100}Sn have recently been performed, using the second cyclotron of GANIL (CSS2) as a high resolution spectrometer. The first experiment provided very encouraging preliminary results on the masses of ^{100}Cd and ^{100}In, we reproduced with a precision of ~ 100 keV the known mass excess of ^{100}Cd and we measured for the first time the mass of ^{100}In with a precision of 5×10^{-6}. The relative mass differences between the $A = 100$ secondary ions are less than 3×10^{-4}, and they can thus be simultaneously accelerated in CSS2. In the second experiment — which was run in late July 1995 — we used the same method with a slightly different set-up and it is envisaged that the mass of ^{100}Sn will be determined (we observed very likely about 10 events of $^{100}Sn^{22+}$). The data analysis is in progress.

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1. Introduction

The doubly-magic nucleus ^{100}Sn was recently produced and identified in two independent experiments employing the projectile-fragments separator technique: at GSI with a 1.1 GeV/nucleon ^{124}Xe beam [1] and at GANIL using a 63 MeV/nucleon ^{112}Sn beam [2]. This nucleus is the subject of many searches since longtime, due to its $N = Z$ character at the double shell closure, providing information on the interaction between protons and neutrons occupying the same high lying shell-model orbits and shell-closure near the proton drip-line. It is also the heaviest $N = Z$ doubly-magic nucleus, stable against ground state proton decay, since ^{164}Pb is expected to lie far beyond the proton drip line. One of the fundamental quantities providing information on nuclear binding and structure of ^{100}Sn is its mass. The mass resolution achieved using the direct time-of-flight techniques developed [3–8] mainly with the high precision magnetic spectrometers SPEG [9] at GANIL and TOFI [10] at Los Alamos is limited by the length of the fly path (less than 100 m) to $\sim 3 \times 10^{-4}$. This resolution is insufficient to measure the mass of ^{100}Sn with available countrates. Given the much increased path length when the ions follow a spiral path, we have proposed and tested the use of the second cyclotron of GANIL (CSS2) as a high precision spectrometer. The mass resolution obtained with the simultaneous acceleration of $m/q = 3$ light ions (^{6}He, ^{9}Li) was shown [11, 12] to be 10^{-6}.

We have performed two experiments aimed at measuring with this good resolution the masses of radioactive ions of $A = 100$, produced via the fusion- evaporation reaction ^{50}Cr + ^{58}Ni. All these nuclei are accelerated simultaneously since their relative mass differences are less than 3×10^{-4}, and using the masses of ^{100}Ag^{22+},^{100}Cd^{22+} and ^{50}Cr^{11+} as references, their masses can be determined with a precision of the order of 10^{-6}. The doubly magic nucleus ^{100}Sn has been also produced in our second measurement.

2. Experimental method

The method consists in substituting the existing stripper located between the two cyclotrons by a production target, where the secondary nuclei are produced to be then injected and accelerated in CSS2. In the fundamental cyclotron equation, the mean magnetic induction B, the radio-frequency applied to the cavities f ($\omega = 2\pi f$), the harmonic h (number of radio-frequency periods/turn) are related to the mass-charge ratio m/q , the orbital radius ρ and the velocity v by :

$$\frac{B}{\omega/h} = \gamma \frac{m}{q} = \frac{B\rho}{v}, \qquad (1)$$

where γ is the relativistic factor. Considering that the radio-frequency of the three GANIL cyclotrons (C0, CSS1 and CSS2) is the same, and given the harmonic of CSS1 ($h_1 = 5$), and the ratio between the injection radius of CSS2 and the ejection radius of CSS1 ($\rho_2/\rho_1 = 2/5$), the ratio between the extraction velocity of CSS1, v_1, and the injection velocity in CSS2, v_2, is given by :

$$\frac{v_2}{v_1} = \frac{2}{h_2}, \tag{2}$$

where h_2 is the CSS2 harmonic. The secondary ions must then be degraded to an appropriate velocity to allow their injection in the cyclotron. As harmonics are integer numbers, the ratio v_2/v_1=2/3, 1/2, 2/5, *etc*, constitute a set of permitted solutions. Two ions injected into CSS2 with slightly different masses m and $m + \delta m$ (let call m our reference mass) will have different time-of-flights during their acceleration inside CSS2, the heavier mass will arrive δt later. The cyclotron acceptance for the simultaneous acceleration of different ions is $\sim 10^{-4}$. To first order:

$$\frac{\delta t}{t} = \frac{\delta m}{m} \tag{3}$$

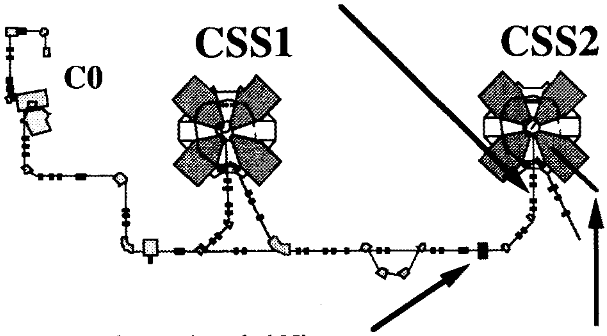
which consists in a calibration procedure : the unknown mass $m + \delta m$ can be determined from the well known reference mass m if the number of turns N_T or the total time-of-flight t are known. If they are not known, the calibration can still be achieved if we have more than one reference mass simultaneously accelerated with the unknown masses, or can be obtained by variation of the magnetic field [11, 12] and/or frequency.

3. Acceleration of $A = 100$ secondary ions

The fusion-evaporation reaction using a ^{50}Cr beam accelerated by the first GANIL cyclotron (CSS1) and incident on a ^{58}Ni target located between the two cyclotrons was used to produce the radioactive nuclei of $A = 100$. This reaction is known to be very favorable to produce nuclei around ^{100}Sn [13]. The optimal energy for the production of ^{100}Sn with this reaction, $E = 255$ MeV, estimated with the Monte-Carlo code PACE, and the ratio v_2/v_1=2/5 determine the incident energy (5.3 MeV/nucleon) and the target thickness (1.3 mg/cm^2) to be used.

Figure 1 shows a schematic diagram of the experimental set-up. The tuning of CSS2 was done with the primary beam $^{50}Cr^{11+}$ degraded to 2/5 of its initial velocity by a 22 mg/cm^2 Ta target. After final corrections for the isochronism and tuning of the injection and initial phase, the individual orbits are perfectly separated and the phase is constant with the radius.

Si-detector to analyse
injected beams



Rotating and cooled Ni target
Production of secondary beams

Stop detector : ΔE(30μm)-E(300μm) Si-telescope, mounted on movable probe SDRC

Fig. 1. Schematic diagram of the experimental set-up.

Both Ni and Ta targets, located between the two cyclotrons, were rotated and cooled to dissipate the heat and allow the use of an intense beam (i = 300–500 nAe). To conserve the same settings in the transport line and in the CSS2, the $A = 100$ secondary ions were selected in the 22^+ charge state. The accelerated ions were detected and identified inside the cyclotron using a Silicon detector telescope (ΔE 30μm, E_{xy} 300μm) mounted on a radial probe which can be moved from the injection radius 1.25 m up to the extraction radius 3.0 m, and with a radial dead zone of 2 mm, much less than the distance between the orbits (14 mm). The time-of-flight (phase) of the detected ions was measured relative to the radiofrequency HF signal of the CSS2 cyclotron. From the phases of the different isobars we can determine their masses.

4. Preliminary results

In the first experiment (october 1994), the masses of $^{50}Cr^{11+}$ and $^{100}Ag^{22+}$ were our references and we could calculate the masses of $^{100}Cd^{22+}$ and $^{100}In^{22+}$ from the experimental spectrum. We obtained the following preliminary results for the Mass Excesses :

$$\text{M.E.}(^{100}\text{Cd}) = -74.413 \pm 0.100(\text{stat.}) \pm 0.300(\text{syst.})\ \text{MeV}$$
$$\text{M.E.}(^{100}\text{In}) = -64.033 \pm 0.300(\text{stat.}) \pm 0.300(\text{syst.})\ \text{MeV}$$

These masses are to be compared with results presented in the Audi–Wapstra mass tables [14]: experimental result [15] for ^{100}Cd (-74.263 ± 0.108 MeV) and estimations [14, 16] for ^{100}In, which are -63.733 ± 0.401

MeV and -63.364 ± 0.936 MeV, respectively. Our masses agree well within the error bars with the previous result and we have measured the mass of ^{100}In.

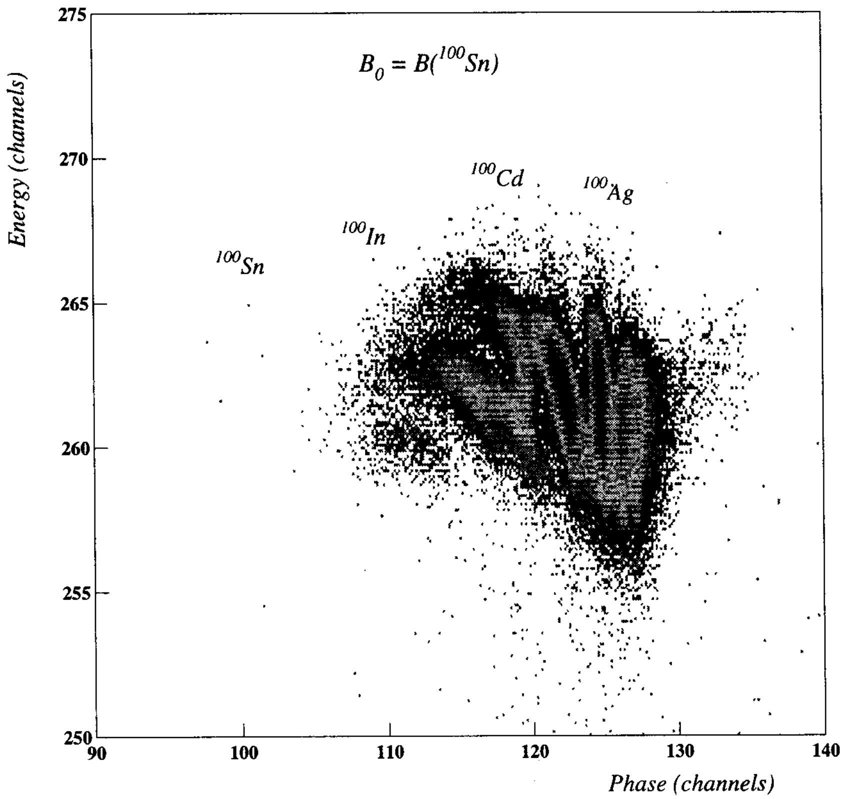


Fig. 2. "Energy vs Time-of-Flight" spectrum of the nuclides with $A = 100$ and $q = 22^+$ obtained with the magnetic field set to put ^{100}Sn at central phase (not full statistics).

In the second experiment (July 1995), the magnetic field was changed in order to put $^{100}Sn^{22+}$ at the central phase. Figure 2 shows one "Energy vs Time-of-Flight" spectrum of the nuclides with $A = 100$ and $q = 22^+$ that we obtained with this setting (not full statistics). A simulation calculating the trajectories of the ions throughout the cyclotron to the detector can help us to understand this spectrum and clearly identify the different nuclei. On this spectrum, 4 counts of $^{100}Sn^{22+}$ can be seen at the position of central phase, previous position occupied by $^{50}Cr^{11+}$ during the tuning of isochronism before changing the magnetic field in the ratio of their mass/charge difference (4.7×10^{-4}). Lighter nuclei are detected at different phases, proportional to their mass/charge differences and several orbits can be intercepted by the detector. The data analysis is in progress, it is envisaged that the mass of ^{100}Sn will be determined since we very likely observed a total of about 10 counts in the whole experiment.

5. Conclusion

We have shown that the method of using the CSS2 cyclotron as a high precision spectrometer works well also for heavy $A = 100$ secondary ions. Results on the masses of ^{100}Cd and ^{100}In are very encouraging, we reproduced with a precision of 100 keV the known mass excess of ^{100}Cd and we measured the mass of ^{100}In with a precision of 5×10^{-6}. The new data which are currently under analysis should allow us to determine the mass of the doubly magic nucleus ^{100}Sn with an uncertainty of a few hundreds of keV.

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