First results of a high precision mass measurement program for very short-lived nuclides

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Abstract

The recent commissioning of the experimental program MISTRAL (Mass Measurements at ISOLDE using a Transmission and RAdiofrequency spectrometer on Line) brought mass measurements of high precision performed on neon, sodium and magnesium isotopes. The shortest half-life of an isotope measured with MISTRAL was 30.5 ms (^{28}Na). Though this first phase of data taking was dedicated to the exploration of MISTRAL performance it has allowed us to reduce the uncertainty in the masses of $^{28-30}$Na by almost one order of magnitude.

Key words: Mass spectrometry, short-lived nuclides, sodium isotopes, ^{32}Mg

Verifying binding energies and minimizing their uncertainties in the neutron rich sodium region of the nuclear chart is important to help clarify the long standing problem of the strength of the N=20 shell closure.

The new experimental program MISTRAL (Mass Measurements at ISOLDE using a Transmission and RAdiofrequency spectrometer on Line) was installed at ISOLDE/CERN during the summer 1997. This spectrometer uses a technique

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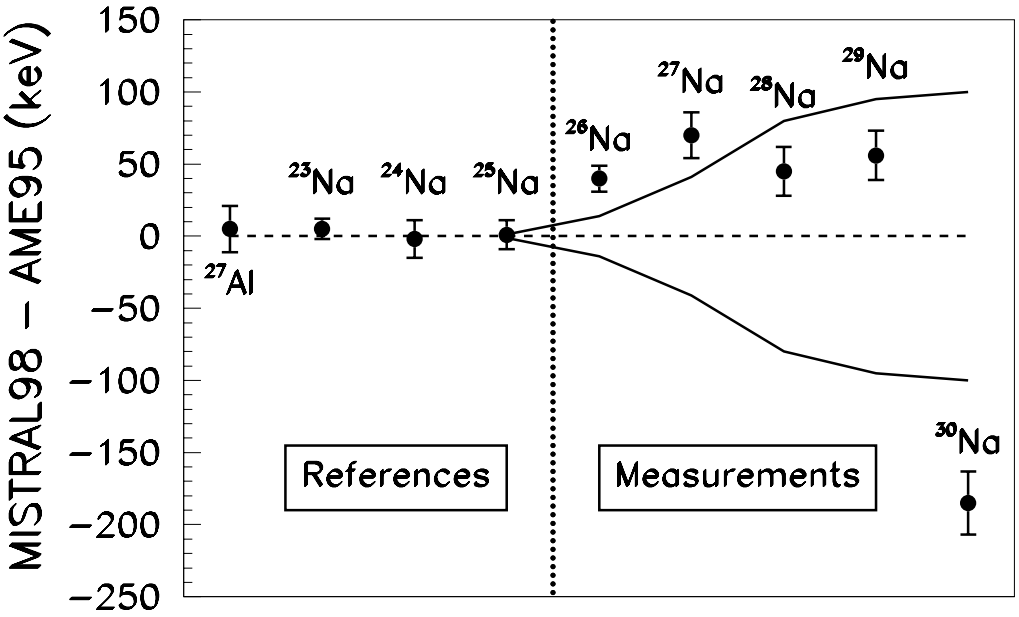

Fig. 1. The MISTRAL results compared to the AME'95 for ^{27}Al and for the sodium isotopes from $A = 23$ to 30. The zero line represents the values from the mass table and the two continuous symmetrical lines represent the table uncertainties.

of radiofrequency excitation of ion kinetic energy in a homogeneous magnetic field. The cyclotron frequency is determined with the help of the radiofrequency field applied at the beginning and at the end of a cyclotron orbit. Ions may only reach the final detector if this radiofrequency f_{RF} is related to their cyclotron frequency f_c by $f_{RF} = (n + \frac{1}{2})\, f_c$ which leads to a"zero" net effect of the two modulations (1, 2, 3) The mass is obtained by the comparison of the cyclotron frequency of the unknown mass to that of a reference mass since the product of their mass by their cyclotron frequency is constant at a given field strength.

During three data taking periods, we measured masses of isotopes of Ne, Na, Mg, Al, K, Ca and Ti. These measurements extend from the valley of stability to ^{26}Ne, ^{30}Na and ^{32}Mg. Eight of these nuclides have a half-life under 1s, the shortest half-life being 31ms for ^{28}Na. The sodium results are compared in Fig. 1 to the accepted mass values from the 1995 "Atomic Mass Evaluation" (AME'95) (4). The average standard deviation (difference in masses divided by the experimental precision) for the reference masses is extremely good (0.34) showing that the quoted precisions (ranging from 3 to 7×10^{-7}) are certainly not overestimated. Furthermore, the masses of $^{23-30}$Na were measured during two separate runs yielding consistent results.

The MISTRAL masses for ^{26}Na to ^{29}Na are in reasonable agreement with AME'95 but more precise by a factor of five. However, the mass we derive for ^{30}Na strongly disagrees with the mass table. A closer examination locates

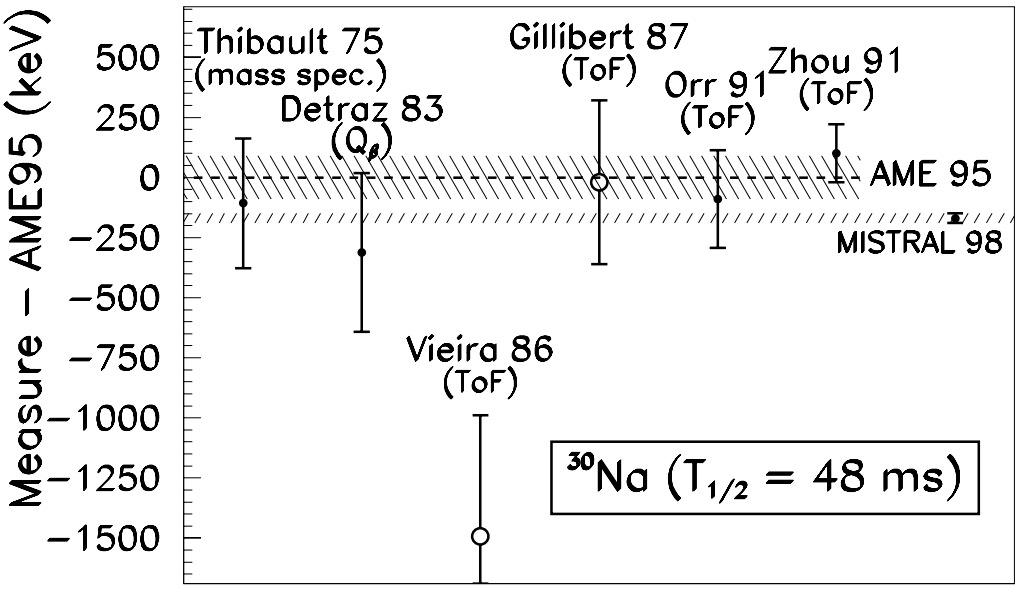

Fig. 2. Comparison of the results of all experiments in which the mass of ^{30}Na has been determined. The dashed area represents the 1σ limit of the AME'95 value, based on the four data represented by full symbols. The measurements represented here were obtained, from left to right, by: mass spectrometry (5) and β end-point energy (6) by the Orsay group at CERN; four time-of-flight technique (TOF) mass determinations by two groups at LAMPF (7), GANIL (8), GANIL (9) and LAMPF (10); and by RF mass spectrometry.

the disagreement (see Fig. 2) to only one experiment (10) in which the mass of ^{30}Na was derived from a time-of-flight (TOF) measurement at LAMPF. One can notice in Fig. 2 that this discrepant result superseded an earlier TOF measurement of the same group (7) which is also at strong variance with our result, but in the opposite direction. Fig. 2 shows that the MISTRAL result agrees nicely with all other data, but is at least one order of magnitude more precise.

The resulting value confirms and even slightly enhances the overbinding of Na at $N = 19$ (Fig. 3). Our exploratory experiment on Mg isotopes shows the same type of result for ^{32}Mg which appears some 200 keV more bound than in AME'95(11). However, the measurement of that particular nuclide requires a confirmation. These tendencies for ^{30}Na ($N = 19$) and for ^{32}Mg ($N = 20$) contradict even more $N = 20$ being a magic number at Z =11 and 12, and reinforce the strength of the deformation starting at $N = 19$. This enhancement compared to AME'95 is closer to the Hartree-Fock calculations of Campi et al. (12) (Fig. 3) where strong deformations were considered.

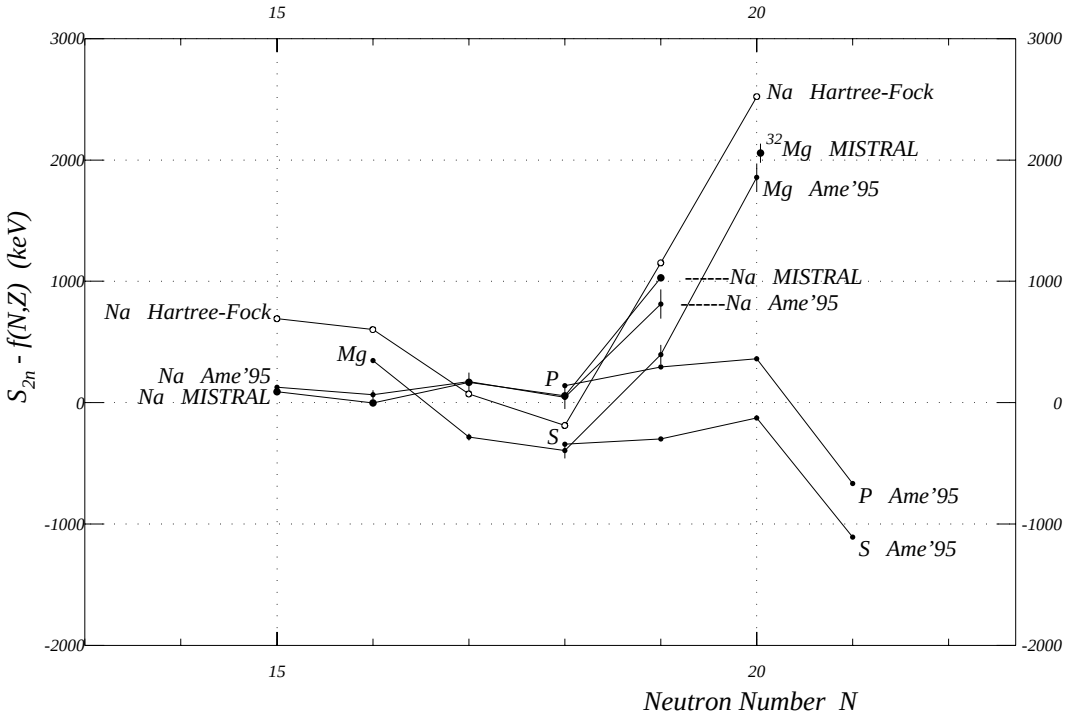

Fig. 3. Two-neutron separation energies S_{2n} for the very neutron-rich sodium isotopes. The following simple function of N and Z has been subtracted from S_{2n} to show more clearly its fine structure: $f = -3300N + 100NZ + 700Z + 39800$. The lines corresponding to Phosphorus (P) and Sulfur (S) show the tendency observed for higher Z where $N = 20$ is still considered magic. The strong increase at $N = 19$ and $N = 20$ in the Hartree-Fock predictions is clearly closer to the MISTRAL result than it was to the AME'95 table.

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