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I. S. Grant, P. Mismeides, R. Kirchner, O. Klapper, E. Rocek, P. Tiemann-Petersson, A. Prochodzi, J. Zylicz

Cadmium-10-Cesium Region

MASSS OF VERY NEUTRON-DEFICIENT ISOTOPES IN THE

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ABSTRACT: Recently measured 0-values for alpha decays, 0 EC decays and gCPgCP proton decays in the region are used to link the strength of the 2450 MeV shell to the proton drip line. The measured mass-cross sections for 0 EC decays to neutron decays, and difficulties are discussed systematically. In a model-independent way, furthermore, the measured mass-cross sections of semi-empirical formula, for the calcium-oxygen region.

L. Germano, P. Massalesis

51 Darmstadt, 6100 Darmstadt, Fed. Republic of Germany

A. Knobler, O. Klapwert, E. Roos, P. Thielemann-Petersson

University of Darmstadt, 00-668 Darmstadt, FRG

Institute of Experimental Physics
A. Preuss, J. Ziller

In the calcium-oxygen region

Mass of very neutron-deficient isotopes
1. Introduction

The binding energies or mass excess (ME) values of nuclear ground-states represent properties of basic interest, e.g., for testing nuclear-matter calculations. With respect to the applicability of such calculations for predicting properties of yet unknown nuclei very far from the β stability line, it is particularly important to compare calculated with measured ME values of very unstable nuclei in a systematic way. One of the most powerful experimental methods used for this purpose is the determination of mass differences as decay Q-values, establishing thereby links from known to new ME values. This type of nuclear mass measurements represents one of the main goals of studies on very neutron-deficient nuclides in the tin region which are extensively carried out at the GSI on-line mass separator. In a first series of experiments, the electron-capture decay energies $\Delta E_{EC}$ for the decay of $^{104}_{}$Cd and $^{106}_{}$Sn were determined. These results, combined with the mass-difference data from particle spectroscopy studies, have yielded ME values with precisions between 30 and 130 keV for several nuclides from $^{104}_{}$Cd to $^{113}_{}$Xe (ref. 2). In continuing these studies, we determined the ME values for $^{112}_{}$Te and $^{114}_{}$Cs. From the ME of $^{114}_{}$Cs, using α-decay energies, we deduce ME values for $^{110}_{}$I and $^{106}_{}$Sb. A combination of these ME values with those from ref. 2 allows to derive the $\Delta E_{EC}$ proton shell strength and to obtain new information on proton separation energies $S_p$. The latter aspect has been discussed in a separate paper. Furthermore, the results are discussed in terms of current mass formulae, in particular with the droplet model formula in the version of H.T. von Groote and Takahashi (HGT) and with the inhomogeneous-partial-difference equations of Jønnecke and Eynon (JE). Finally, systematics of the mass-differences ($\Delta E_{EC-S_p}$) and Q(4β) are presented.

2. Experimental studies and results

The way of ME determination for $^{112}_{}$Te and $^{114}_{}$Cs, starting-out from the known ME values of $^{113}_{}$Xe (ref. 2) and $^{109}_{}$Sn (ref. 8), is illustrated in fig. 1. The measurement of the $Q_{EC}$ value for $^{109}_{}$Sb ($Q_{EC}=6360\pm36$ keV) was described in ref. 9. In order to obtain ($Q_{EC-S_p}$) for $^{113}_{}$Xe and $^{114}_{}$Cs the endpoint energies of α-delayed proton spectra were determined. The radioactive sources were produced in $^{58}_{}$Ni + $^{14}_{}$N reactions at the GSI on-line mass separator. The proton spectra were measured in singles mode and in coincidence with positrons, using a surface-barrier detector telescope for the proton-energy analysis and a thin plastic scintillator for positron counting. After correcting the measured proton singles spectra for positron-proton summing effects, ($Q_{EC-S_p}$) was deduced by comparing the energy-dependent coincidence-to-singles ratio with theoretical $\beta^+/(\beta^-+\beta^0)$ probability ratios. This was done in a least-squares fitting procedure on the basis of the model assumptions used for interpreting the α-delayed particle decay of $^{116}_{}$Cs (ref. 12), taking proton decay to excited states of the final nucleus into account. The resulting ($Q_{EC-S_p}$) values for $^{113}_{}$Xe and $^{114}_{}$Cs are $7920\pm150$ and $8730\pm150$ keV. More experimental informations were presented in ref. 13 and will be described in details separately.

From these $Q_{EC}$ and ($Q_{EC-S_p}$) data and by improving some of the earlier ME results on the basis of remeasured $Q_{4β}$ values, we obtained the 14 new ME values compiled in table 1, including the one for $^{104}_{}$In deduced from the measured endpoint energy.

3. Discussion

3.1. Mass Excess Values

A comparison of the new ME values with predictions from various mass formulae (see table 1) confirms the conclusion drawn in our earlier work: The best overall agreement with the experiment is provided by the HGT and JE calculations, yielding root-mean-square deviations of the order of 0.3 MeV.
In addition to determining the optimum weights of the real and

values 3.4 of $^{33}$S values are determined for

Discussion.

dependence on proton and neutron shell strength (see ref. 2) for a detailed

The $^{33}$S systematics (fig. 4) shows experimental evidence for the inter-

\[ \frac{14}{\nu} \text{H} \text{H}_{\nu+2} = \frac{(\text{I}^{+}\text{H}_{\nu+2})}{(\text{H} \text{H}_{\nu+2})} = (\text{N})^{0} \text{H}_{\nu} \]

approximated by the following difference of square modulae:

}\]

\[ \text{mass difference such as } \nu \text{ cm}^{2} \]

interesting to note that further improvements is most appropriate for discribing

anomalous mass formula with not so strong Pauli and to fit bonding

mass differences well as \nu\%.

For light calcium isotopes, the mass formula with anomaly in absolute mass and

the natural mass formula is examined, the ones of Pauli and

for calcium isotopes. There is, however, a systematical deviation

this formula yields a good approximation of measured mass for fixed-

formula with anomaly in absolute mass for calcium isotopes, shown in fig. 2.

As can be seen from the comparison of predictions from the mass

seems to make this trend.

to mass formula for II-isotopes, for II-C# does not continue for II-C# which

is interesting to consider the model of II-C# as an extension

are discrepancies of up to 10% for certain nuclei in this region.

However, even for the two formula with best overall agreement there
region by the Z=50 shell closure resulting in a large gap between antimony and tellurium precursors. \((Q_{EC-S_P})\) values are of special interest for interpreting the measured energy spectra, intensities and intermediate-nucleus lifetimes for \(\beta\)-delayed particle spectra\(^{13}\). Besides the 4 new endpoint energies determined in this work, the systematics shown in fig. 5 may be used for estimating additional \((Q_{EC-S_P})\) values by extrapolating the smooth linear relationships emerging for the tellurium-to-barium region. In this context it is interesting to note, that proton binding energies are known for \(^{108}\)In (ref. 2, 15), \(^{109}\)Sb (this work and ref. 2), \(^{110}\)Te (this work and ref. 2) and \(^{113}\)I (this work), which represent intermediate nuclei for the \(\beta\)-delayed particle decays of \(^{105}\)Sn, \(^{109}\)Te, \(^{110}\)I and \(^{113}\)Xe, respectively. In these cases, not only the differences \((Q_{EC-S_P})\), but also the two energy parameters themselves are known, which allow more reliable conclusions from \(\beta\)-delayed particle studies.

4. Summary and conclusion

By measuring total decay energies for neutron-deficient isotopes and linking them with known ME values, we succeeded in gaining precise information on the structure of the mass-energy surface in the tin region allowing a systematic discussion of ME values, proton separation energies\(^{4}\), \(\alpha\) decay energies\(^{3}\) and isobaric four-beta-decay energies. These systematics suggest that the mass-spectrometric ME values for very neutron-deficient cesium isotopes, in particular for \(^{117}\)Cs, are somewhat too high. A recent reevaluation\(^{23}\) indeed showed that the original data\(^{19}\) underestimate stability, e.g. for \(^{117}\)Cs by approximately 0.2 MeV. However, this correction cannot fully account for the observed discrepancy. An experiment, which would help to clarify this discrepancy, would be the search for decay of \(^{117}\)Cs, since the corresponding \(Q_\alpha\) value would represent a decay link to \(^{113}\)I. The known ME value of \(^{113}\)I together with the one of \(^{117}\)Cs measured by Epherre et al.\(^{19}\) corresponds to a \(Q_\alpha\) value for \(^{117}\)Cs of about 3.38 MeV and, assuming a reduced width similar to \(^{114}\)Cs (ref. 3, 12), to a branching of \(\approx 4 \times 10^{-3}\). On the other hand, the \(Q_\alpha\) value of about 2.4 MeV expected from systematics of \(\alpha\) decay energies is considerably lower, corresponding to an \(\alpha\) branching ratio as small as \(7 \times 10^{-12}\). Since, under present experimental conditions, the smallest detectable \(\alpha\) branching for \(^{117}\)Cs is of the order of \(10^{-8}\), a negative result of a search experiment would allow to determine an upper limit of \(Q_\alpha\) around 2.7 MeV.

It is interesting to note that there are two decay paths from \(^{113}\)Xe to \(^{108}\)Sn, namely \(^{113}\)Xe \(\rightarrow\) \(^{109}\)Te \(\rightarrow\) \(^{108}\)Sn and \(^{113}\)Xe \(\rightarrow\) \(^{112}\)Te \(\rightarrow\) \(^{108}\)Sn (see fig. 1). Since three decay energies involved in this closed loop are known, the fourth one can be deduced to be \(Q_\alpha\) of \(^{112}\)Te = 2.31 \pm 0.18 MeV. This result is in accordance with the non-observation of \(\alpha\) decay of \(^{112}\)Te, since even the upper limit of the corresponding \(\alpha\) energy is lying more than 150 keV below the lower limit of the smallest \(\alpha\)-energy observed\(^{3}\) in this region, \(E_\alpha\) of \(^{113}\)I = 2610 \pm 40 keV. From \(Q_\alpha\) systematics of the lighter tellurium isotopes, however, one would expect a \(Q_\alpha\)-value for \(^{116}\)Te close to 2.15 MeV, thus suggesting that the actual ME of \(^{112}\)Te is near the lower experimental limit, an argument which becomes additional support from the \(Q(4\beta)\) value of \(^{112}\)Te (see fig. 3).

The results of the present work, e.g. the information gained of the Z=50 proton shell strength, might be incorporated into future improvements of nuclear mass calculations. So far, taking into account experimental results on mass-excess, \(Q_\alpha\), \(Q_{EC-S_P}\) and \(S_P\) values, the droplet mass formula in the version of Hils et al.\(^{6}\) seems to offer a good overall description. Although such an agreement for a subset of nuclear masses far from stability is quite satisfactory in general, even more reliable predictions of certain mass differences are desired for interpreting the related decay phenomena or for estimating properties of yet unknown nuclei. Alpha decay\(^{3}\), \(\beta\)-delayed particle emission\(^{13}\) and more recently also direct proton decay\(^{24,25}\) may serve as examples for the application of measured (or extrapolated) \(Q\)-values.

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References (continued)


Figure Captions

Fig. 1 Section of the chart of nuclides illustrating the determination of decay energies and masses. The decay links of interest are indicated by arrows. Nuclei with known ME values are marked due to the to the 1977 mass evaluation7) and ref. 8, new ME data are taken from ref. 2 and from the present work. In the first case we consider the 113Xe113I112Te+p decay chain. The ME value of 113Xe is known2), Hence, in order to get the ME of 112Te one has to measure the endpoint energy (QEC-Sp) of the β-delayed proton spectrum, Sp being the proton separation energy in 113I. The second case we start with the ME value obtained for 109Sn from transfer-reaction studies8). In order to get the ME of 114Cs one has to measure QEC for the 109Sn decay and QEC-Sp for the 114Cs114Xe113I+p decay. The missing link between the ME values of 112I and 109Sn is provided by the known1) Qα value of 112I.

Fig. 2 Differences between predictions from the Jänecke-Eynon mass formulae and measured mass-excess values. Experimental results are from this work and ref. 2 (open circles), from the 1977 mass evaluation7) (full circles) and from recent mass-spectrometric measurements19) (open squares). The value for 109Sn is taken from ref. 8.

Fig. 3 Q(46) systematics: Data are taken from this work and ref. 2 (open circles), from the 1977 mass evaluation7) (full circles), from experimental data not accepted in ref. 7 (open circles within brackets), from systematic extrapolations7), from recent mass-spectrometric measurements19) (open squares) and from other recent experiments8,16) (open triangles). The lines are drawn in order to guide the eye.