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Proposal to the INTC Committee

Coulomb Excitation of neutron-rich $A \sim 140$ Nuclei

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Summary

Investigating the isospin dependence of the product between the $B(E2)(0^+_1 \rightarrow 2^+_1)$-value and the 2^+_1-excitation energy E_{2^+} in even-even nuclei around $A \sim 140$ one observes a rather smooth trend close to the valley of stability but clear indications for a reduction from the extrapolated $B(E2)$-values by one order of magnitude for some very neutron-rich nuclei. While close to the valley of stability the strong neutron-proton interaction results in an equilibration of the neutron and proton deformations with a predominate isoscalar character of the collective 2^+ excitation, it is conceivable that more loosely bound neutrons cannot polarize a close-to-magic proton core that well any more. This might result in a decoupling of the shape of the outer neutrons from the core and in a strong isovector admixture to the lowest lying 2^+ level. In this way the 2^+-energies could be further lowered in neutron-rich nuclei, while the quadrupole moments of the proton core stays small, leading to an unexpectedly small value of the product B(E2)$(0^+ \rightarrow 2^+)\cdot E_{2^+}$. We therefore want to investigate the energy weighted $B(E2)$ values for very neutron rich tellurium, xenon, and barium isotopes, in which first indications for such a reduction have been observed, using the Coulomb excitation process; for these isotopes $B(E2, 0^+ \rightarrow 2^+)$ values can be determined by projectile Coulomb excitation at REX-ISOLDE even with the presently available beam energy of 2.2 MeV/u. As in nuclei very close to double magic nuclei additional deviations from a smooth (Z, N)-dependence of $B(E2)(0^+ \rightarrow 2^+) \cdot E_{2^+}$ are known to occur, we propose

to study also the $B(E2)$ values of 2^+ states in nuclei around $^{132}_{48}$Cd, $^{130}_{50}$Sn to arrive at a more complete picture of the isospin dependence of the energy weighted $B(E2)(0^+ \to 2^+)$ values in this mass region. A total of 21 shifts of beam time with an UC_2-target is requested for Coulomb excitation measurements of $^{124}_{48}$Cd, $^{126}_{48}$Cd, $^{128}_{48}$Cd, $^{130}_{48}$Cd, $^{130}_{50}$Sn, $^{134}_{50}$Sn, $^{136}_{52}$Te, $^{138}_{52}$Te, $^{140}_{54}$Xe, $^{142}_{54}$Xe, $^{144}_{54}$Xe, $^{148}_{56}$Ba and $^{150}_{56}$Ba at 2.2 MeV/u.

1 Introduction

We recently investigated the isospin dependence of the the energy weighted $B(E2, 0^+ \to 2^+)$ values, i. e. of the product $E_{2^+} \cdot B(E2)(0^+ \to 2^+)$ for the first 2^+-states in even-even nuclei around $A \sim 140$ and derived a new simple formula to describe its value for nuclei close to the valley of stability within $\pm 20\,\%$ [10]. A comparison of this description with the few known $B(E2)$ values of nuclei far off stability seems to suggest that systematic strong deviations from this rule might occur for very neutron-rich nuclei. From theory one expects for nuclei around the valley of stability, that the strong ($T = 0$) n-p–force leads to equal neutron and proton deformations and a predominantely isoscalar collective 2^+-excitation. However, a different picture might occur for very neutron-rich nuclei: considering nuclei with a rather inert core of protons and neutrons and adding loosely bound valence neutrons we can expect that these neutrons are less effective in polarizing the core. These valence neutrons may decouple from the core and form a deformed neutron skin, lowering the excitation energy of the first excited 2^+-state by adding a significant amount of a neutron isovector admixture to the usual isoscalar component. At the same time the collectivity of the $E2$ transition strength, governed by the deformation of the proton distribution and accessible Coulomb excitation experiments, may have a rather small value because the core stays rather spherical. In this way a reduction of the energy weighted $B(E2)$ values from those extrapolated from the isoscalar excitations close to the valley of stability might occur. Having observed first indications of such deviations in nuclei around ^{132}Sn, we want to extend our knowledge of $B(E2)$ values towards more neutron-rich isotopes in this mass region to gain a more fundamental understanding of the deformations, interactions, core polarisations and effective charges [11, 15, 16, 17] of even-even nuclei far outside the valley of stability.

We propose to perform these investigations via projectile Coulomb excitation using neutron-rich beams of 2.2 MeV/u delivered by REX-ISOLDE [1], together with the efficient MINIBALL detector array [2] to detect the deexcitation γ-rays and the highly segmented CD detector system [1] to record the scattered particles. The position sensitivity of MINIBALL and the CD detector allows for a precise Dopplershift correction of the measured γ-rays, which is mandatory because of the large velocity of the Coulomb excited projectiles, and the comparison of the projectile excitation to that of the target, whose $E2$-transition strength are known, allows for an easy absolute measurement of the $B(E2)$ value. As, moreover, nuclear excitations can be avoided by a proper choice of the target, low energy Coulomb excitation with radioactive beams — as compared to Coulomb excitation experiments at relativistic energies — offers a very powerful approach to a precise determination of these fundamental quantities.

2 Systematics of the energy weighted $B(E2, 0^+ \rightarrow 2^+)$ values

A simple formula to estimate the $B(E2, 0^+ \rightarrow 2^+)$ value for nuclei where the 2^+ excitation energy E_{2^+} is known has been given by Grodzin several years ago [6]:

$$E_{2^+}[keV] \cdot B(E2)(0^+ \rightarrow 2^+)[e^2b^2] = 16.3 \cdot Z^2 \cdot A^{-1} \tag{1}$$

An improved version has been published more recently by S. Raman et al. [7]:

$$E_{2^+}[keV] \cdot B(E2)(0^+ \rightarrow 2^+)[e^2b^2] = 2.57 \cdot Z^2 \cdot A^{-2/3} \tag{2}$$

where the Z- and A-dependence has been taken from the energy weighted $E2$-sum rule [16]. Eq. 2 leads to a closer estimate of the $B(E2)$-value than eq. 1, with less than a factor of 2 deviation for 91 % of the 300 known nuclei [7], where both the 2^+-energy and the $B(E2)$ value are known. Investigating the isospin dependence of the energy weighted $B(E2)$ value $E_{2^+} \cdot B(E2)(0^+ \rightarrow 2^+)$ for nuclei with $50 \leq Z \leq 82$ more carefully, we observed a systematic deviation of the measured values from those given by eq. 2, i. e. that for neutron poor isotopes the predictions are too small while they are too large for neutron-rich isotopes. We could take care of this dependence by adding a term in eq. 2 linear in $N - \bar{N}$, where N is the neutron number and $\bar{N}$ denotes the neutron number for which the nuclear mass within an isobaric chain reaches its minimum. Differentiating Weizsäcker's mass formula [5] for fixed mass number A with respect to N one obtains:

$$\bar{N} = \frac{A}{2} \cdot \frac{1.0070 + 0.0128\, A^{2/3}}{1 + 0.0064\, A^{2/3}} \tag{3}$$

Multiplying eq. 2 by $a + b \cdot (N - \bar{N})$ and fitting all experimental $E(2_1^+) \cdot B(E2)(0^+ \rightarrow 2^+)$ values known for nuclei with $48 \leq Z \leq 70$ and excitation energy ratios $R_{4/2} = \frac{E_{4_1^+}}{E_{2_1^+}} \geq 1.8$, we obtain $a = 1.260$ and $b = -0.077$. This leads to the significantly improved description of the energy weighted $B(E2)$ values for nuclei with $48 \leq Z \leq 70$ of

$$E_{2^+}[\mathrm{keV}] \cdot B(E2)(0^+ \rightarrow 2^+)[\mathrm{e}^2\mathrm{b}^2] = 3.242 \cdot Z^2 \cdot A^{-2/3} \cdot \big(1.000 - 0.0608\, \big((A - Z) - \bar{N}\big)\big) \tag{4}$$

The accuracy of eq. 4 is demonstrated in fig. 1.

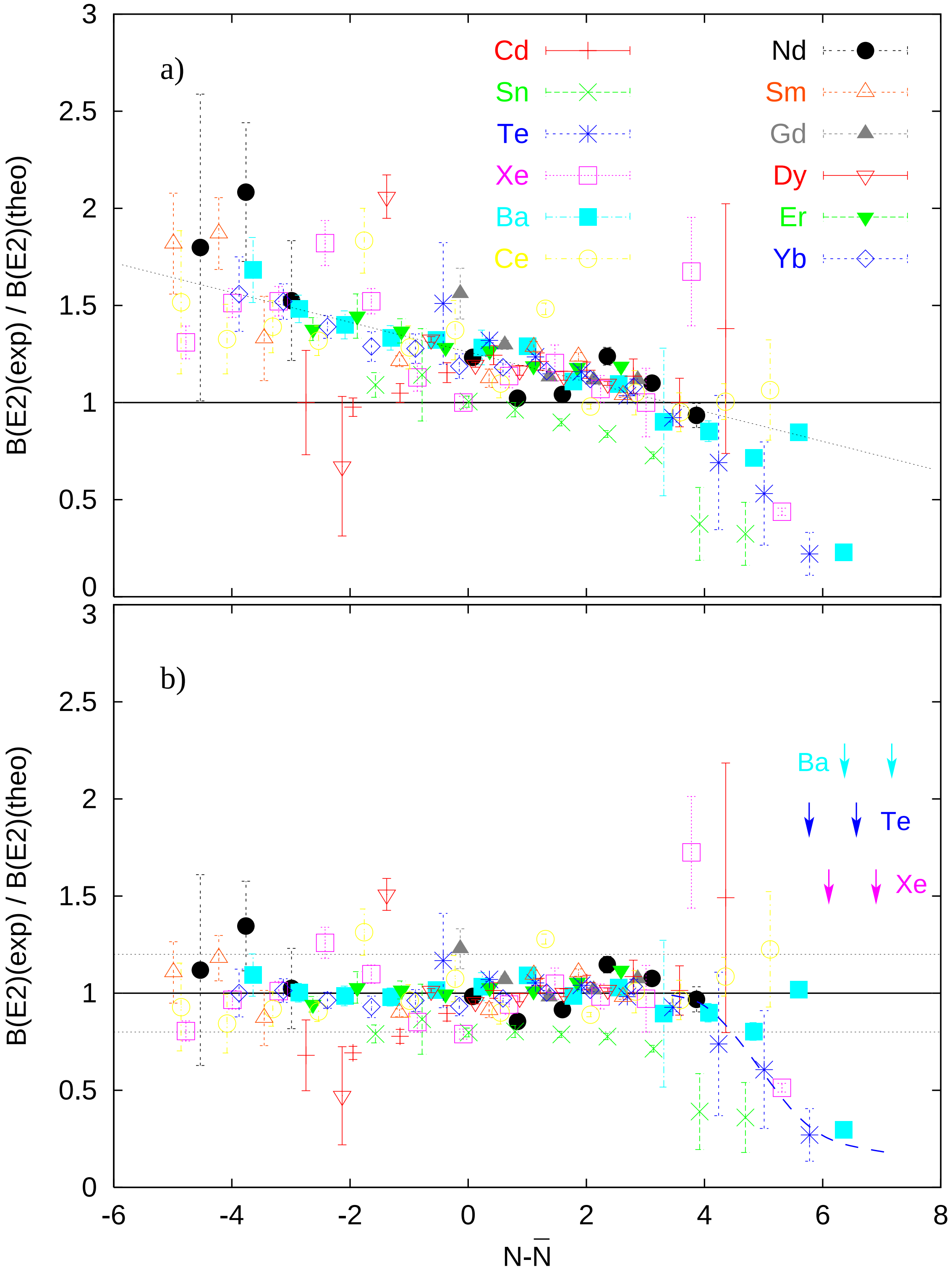

Figure 1: *Ratio of experimental B(E2)-values over theoretical values for nuclei with* $(48 \leq Z \leq 70)$ *as a function of* $(N\text{-}\bar{N})$ *using a) Raman's formula (2) or b) using our improved formula (4). The neutron-rich* ${}^{148,150}_{56}$Ba, ${}^{142,144}_{54}$Xe *and* ${}^{136,138}_{52}$Te, *which are proposed here to be studied experimentally, are indicated by arrows. The dashed line is meant to guide the eye.*

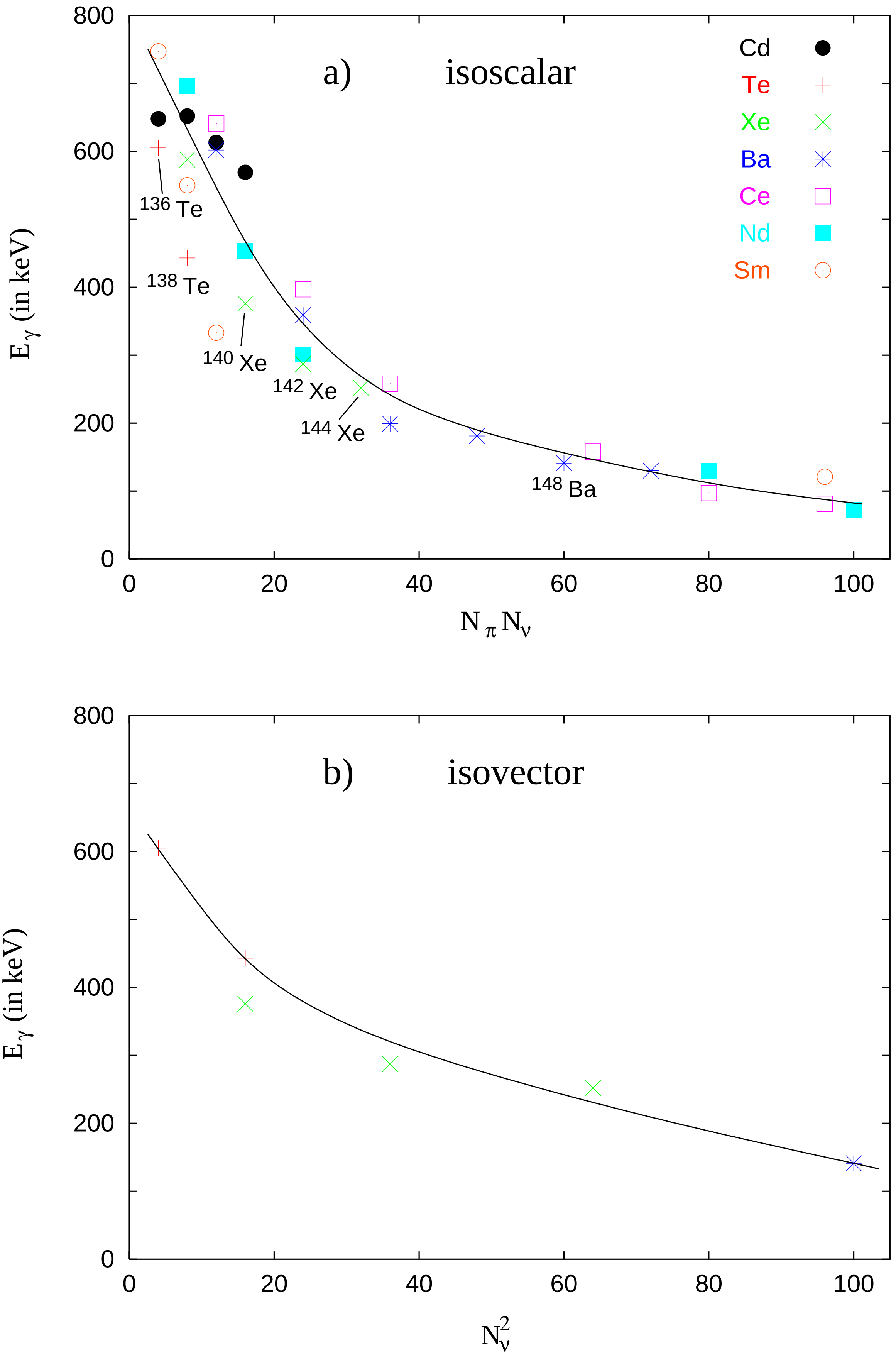

Figure 2: *a) Plot of the 2_1^+-energies versus $N_\pi \cdot N_\nu$ for the $A \sim 140$ region [4, 25]. b) Plot for possible isovector E_{2+} energies versus N_ν^2 for the $A \sim$ 130 region.*

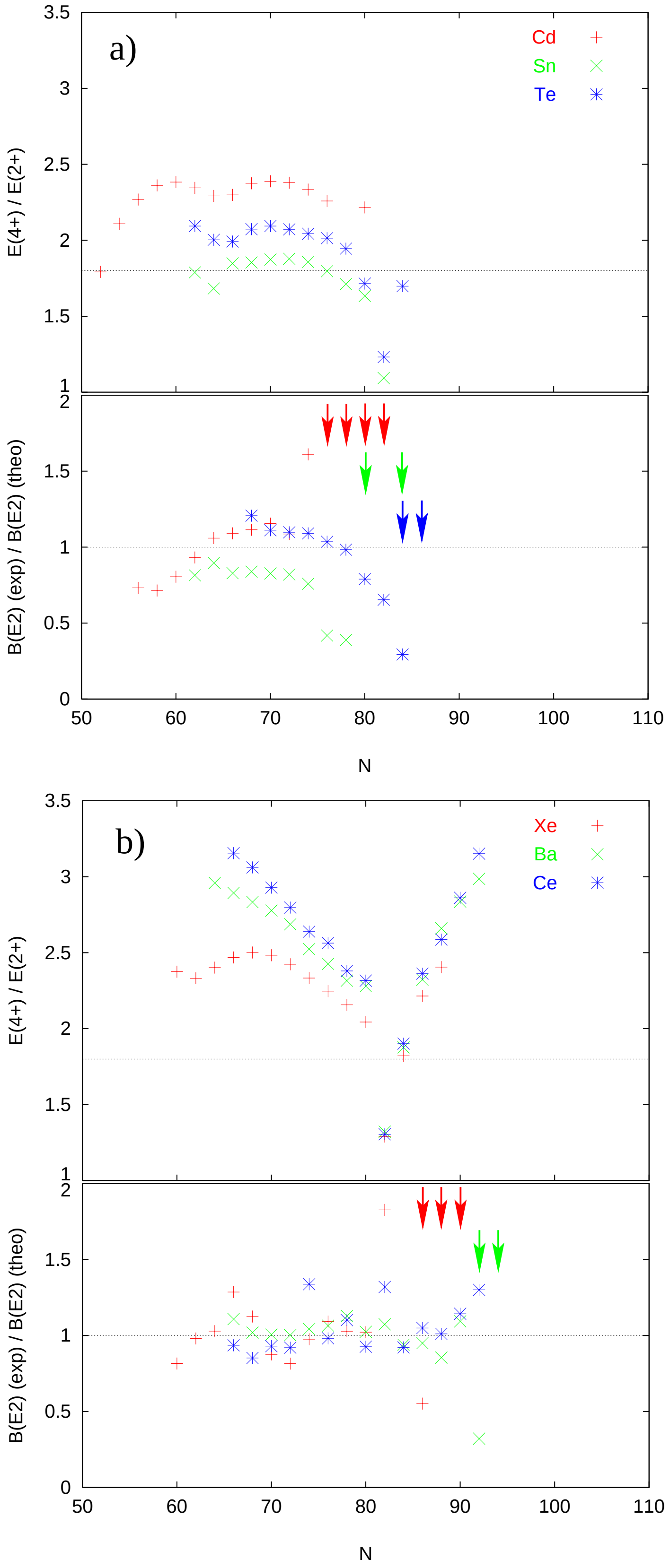

Figure 3: *Ratio $R_{4/2} = E_{4_1^+}/E_{2_1^+}$ in the region of the $N = 82$ shell closure and ratios of experimental and theoretical $B(E2)(0_1^+ \rightarrow 2_1^+)$-values (from eq. 4) as a function of neutron number N a) for Cd, Sn and Te isotopes b) for Xe, Ba and Ce isotopes. The data of ref. 7 are extended by results from recent Coulex measurements at the RIB-facility in Oak Ridge [19]. The arrows indicate nuclei we propose to measure in this proposal.*

While for Raman's formula (2) deviations by a factor of 2 are quite typical, our new description (eq. 4) represents the measured $B(E2)$ values within ±20%.

However, for extreme $(N - \bar{N})$ values of about 6 large systematic deviations of the experimental B(E2)-values from the smooth behaviour of eq. 4 become apparent; the dashed curve drawn in fig. 1 is meant to accentuate this trend suggested by the available data. To improve the data basis and to further support this surprising reduction of the energy weighted $B(E2)$ values at these extreme $N - \bar{N}$ values, which points to exciting new physics in very neutron-rich nuclei, we propose to repeat the $B(E2, 0^+ \rightarrow 2^+)$ measurements for ^{148}Ba and ^{136}Te and to perform new measurements for the very neutron-rich nuclei ^{150}Ba,^{142,144}Xe,^{138}Te. Note that within an isotopic chain ($Z =$ const) a difference of $(N - \bar{N})$ corresponds to a neutron number, which is about $2(N - \bar{N})$ away from those of the most stable isotope.

If the first excited 2^+-states of very neutron-rich nuclei acquire an additional strong isovector component as discussed in the introduction, we may observe a lowering of their 2^+-energy with respect to the energy predicted for a pure isoscalar 2^+-state, thus compensating or even over-compensating the possible increase of the isoscalar energy due to the weakened polarization $n-p$ force. Note that for light nuclei close to single or doubly closed shells larger isovector contributions to the first excited 2^+ states have already been observed [12, 13]. R. F. Casten [4, 25] has developed for the first excited 2^+-states of heavier nuclei the $N_\pi \cdot N_\nu$ scheme, which is based on the assumption that their collectivity is due to the long range p-n interaction between valence protons and neutrons and that its magnitude scales with the product $N_\pi \cdot N_\nu$, the number of valence protons (valence proton holes) N_π times the number of valence neutrons (valence neutron holes) N_ν. It is important that N_π and N_ν are always counted to the nearest closed shells, whether these valence nucleons are particles or holes, and to choose the proper magic numbers. For nuclei close to $A \sim 140$ and $N < 90$, the effective proton shells are $Z = 50$ and 64, while for $N \geq 90$ the normal major shell with $Z = 50$ and 82 are considered to be relevant. In Fig. 2a) the experimental 2^+ energies are plotted with respect to the product $N_\pi \cdot N_\nu$ [4]. We may now ask, how the 2^+ energies in those neutron-rich nuclei, where a strong reduction of the B(E2)-value is observed (^{148}Ba, ^{140}Xe, ^{136}Te), or where we might expect to measure a strong reduction (^{142,144}Xe,^{138}Te) compare to those where the usual isoscalar excitation should be dominant. We have marked these nuclei in Fig. 2a) by their isotope assignments, if at all, they have somewhat lower 2_1^+ energies. Using the improved Grodzin's fourmula (5) in a different way we can calculate approximately the isoscalar 2^+-energy from the measured B(E2)-value and we see that the observed 2^+-states are rather pure isovector 2^+-states, because the calculated isoscalar energies are much larger. For a first estimate of this trend for isovector 2^+-states we have plotted their energy in Fig. 2b) versus N_ν^2, which is very different from the product $N_\pi \cdot N_\nu$. On the other hand we can determine from the 2^+-energy predicted via the improved Grodzin's rule and the curve of Fig. 2a) from Casten an effective $N_\pi \cdot N_\nu$-value and deduce in comparison to the $N_\pi \cdot N_\nu$ calculated from N and Z an average reduction of the n-p force for the valence protons and neutrons. E.g. for ^{148}Ba we obtain a reduction of the n-p interaction by a factor of 3. For the Coulomb excitation of these nuclei we expect to observe two 2^+-states one with a dominant isovector component and one with a dominant isoscalar component, which are mixed by some interaction like in usual two-level perturbation theory. This occurance of two 2^+-states is an interesting prediction, which we can check experimentally. If we observe the two level energies and measure the two B(E2)-values we might deduce properties of the unmixed states and their interaction. These discussions should indicate how the measurements of the B(E2)-values proposed here, may change our understanding of first 2^+-states in even-even nuclei.

In Fig. 3 we show the ratio between the experimental and newly predicted $B(E2)$-values together with the energy ratio $R_{4/2} = E_{4^+}/E_{2^+}$ between the energies of the first 4^+ and 2^+ levels for those isotopic chains we want to extend by our proposed measurements (indicated by arrows), as well as for some neighbouring iostopic chains. The ratio $R_{4/2}$ gives an indication of the structure of the nucleus: "shell model configurations" for ($E_4/E_2 < 2$), "vibrational" for ($E_4/E_2 \sim 2 - 2.2$), "transitional" for ($E_4/E_2 \sim 2.7$) and "rotational" for ($E_4/E_2 \sim 3.33$) [4]. As a function of neutron number N both ratios show a smooth dependence with a pronounced dip in the E_4/E_2-ratio for the magic number N = 82. It was already pointed out by Grodzins [6] that for both surface vibrations as well as rotational states a very smooth dependence on A and Z is expected in the irrotational flow model. As can be seen in fig. 3, even if the $R_{4/2}$-value varies strongly the experimental $B(E2)$-values of nuclei being only a few nucleons away from the double magic nucleus ${}^{132}_{50}\mathrm{Sn}_{82}$ are already well described by our improved formula given by eq. 4.

By our proposed measurements of ${}^{148}_{56}\mathrm{Ba}$ and ${}^{150}_{56}\mathrm{Ba}$ we want to extend the chain of $B(E2, 0^+ \to 2^+)$-values for the Ba isotopes. A few years ago the halflife of the 141.7 keV 2^+-state in ${}^{148}\mathrm{Ba}$ was preliminarily measured electronically at OSIRIS to be $T_{1/2} = 1.65 \pm 0.15$ ns, a measurement which will be repeated this year at Studsvik [22]. Surprisingly, the corresponding $B(E2)$-value of $0.47\,e^2\mathrm{b}^2$ is significantly smaller than the expected value $1.46\,e^2\mathrm{b}^2$ obtained with eq. 4. While also the $B(E2)$ values measured for the heaviest Te and Xe isotopes ${}^{136}\mathrm{Te}$ and ${}^{140}\mathrm{Xe}$ show such a reduction of the quadrupole collectivity when going away from the valley of stability, ${}^{148}_{56}\mathrm{Ba}$ is presently the nucleus which reaches furthest out in $(N - \bar{N})$ and it will therefore be of upmost importance to check if this reduction by a factor of 3.1 can be confirmed. This nucleus has an $\mathrm{R}_{4/2}$-ratio of 2.99, very close to a rotor, and it is surprizing that 10 valence neutrons are not strong enough to polarize the proton core significantly. For ${}^{150}_{56}\mathrm{Ba}$ the situation should then be even more extreme; from level systematics one expects a 2^+-energy of about 100 keV, an $R_{4/2}$-ratio of 3.2 and a $B(E2)$-value of only $\sim 0.2\,e^2\mathrm{b}^2$, if the trend indicated in Fig. 1b continues. Within the ISOLDE proposal IS386 an electronic measurement of the 2^+ half life of ${}^{150}\mathrm{Ba}$ is planned after 2002 [22], but it seems more than reasonable to perform also a complementary Coulomb excitation measurement. Also for the $B(E2, 0^+ \to 2^+)$ values in ${}^{138}\mathrm{Te}$ and ${}^{144}\mathrm{Xe}$ proposed to be measured for the first time one could expect a similar reduction by up to a factor of ~ 10.

Strong deviations between experimental $B(E2)$-values and those predicted by Grodzin-like rules are known to occur systematically very close to doubly magic nuclei, which are expected due to the extreme single particle character of these nuclei. To obtain a more complete picture of the validity of eq. 4 in this mass region and the obviously different nature of the observed deviations for $(N - \bar{N}) \geq 5$ and around $(Z, N) \sim (50, 82)$, it seems mandatory to investigate also the latter region in more detail. We therefore propose to perform Coulomb excitation measurements on ${}^{130}_{50}\mathrm{Sn}$, ${}^{134}_{50}\mathrm{Sn}$ and the neutron-rich Cd nuclei ${}^{124}_{48}\mathrm{Cd}$, ${}^{126}_{48}\mathrm{Cd}$, ${}^{128}_{48}\mathrm{Cd}$, and ${}^{130}_{48}\mathrm{Cd}$ (see Fig. 3a). For the Cd-isotopes close to ${}^{132}\mathrm{Sn}$ spectroscopy was performed at ISOLDE by K.L. Kratz et al. [20], but the $B(E2)$-values of the 2^+-states were not measured. Note that the Cd-isotopes are not available as beams at the competing RIB-facility in Oak Ridge, where only negative ions can be accelerated at the tandem accelerator.

3 Coulomb excitation

As we propose Coulomb excitation experiments of radioactive projectiles with mass numbers between $A = 120$ and 150, we discuss some general properties of the excitation process. All calculations are performed with the program COULEX from the LMU Munich [18]. Fig. 4 displays typical projectile Coulomb excitation cross sections at two different beam energies. For not too high excitation energies there is no large difference in the cross sections between beams with 2.2 MeV/u and 3.1 MeV/u, the latter being planned in a proposed upgrade of REX-ISOLDE.

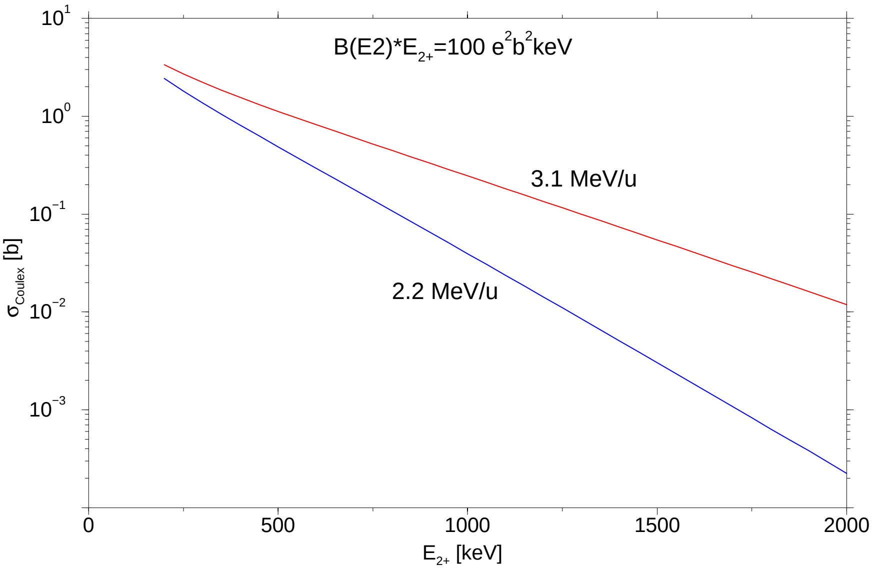

Figure 4: *Coulomb excitation cross sections for a projectile with* $(A = 132, Z = 50)$ *impinging on a Ni target assuming a fixed energy weighted* $B(E2)$ *value. Note that the total cross section is proportional to the* $B(E2)$ *value while it depends approximately exponentially on the excitation energy.*

In Fig. 5 we compare the cross sections for projectile excitation on carbon, nickel and lead targets. At 2.2 MeV/u the Ni target is more favourable than the Pb target, although the differences are small. The lighter targets, however, would have the additional advantage that the target excitation is sizable and can be used as normalisation. The planned energy upgrade to 3.1 MeV/u of REX-ISOLDE leads to an improvement of a factor of 10, but measurements at 2.2 MeV/u will lead already to sufficient counting rates (see table 1).

Fig. 6 shows the differential cross section dependence on the projectile scattering angle. While the Rutherford cross section strongly increases for small scattering angles the Coulomb excitation probability decreases at the same time. The folding of both functions results in a rather narrow scattering angle range with the dominant yield between 7° and 40° in the laboratory frame. This angular range is well covered by the CD particle detector to be used in the set-up.

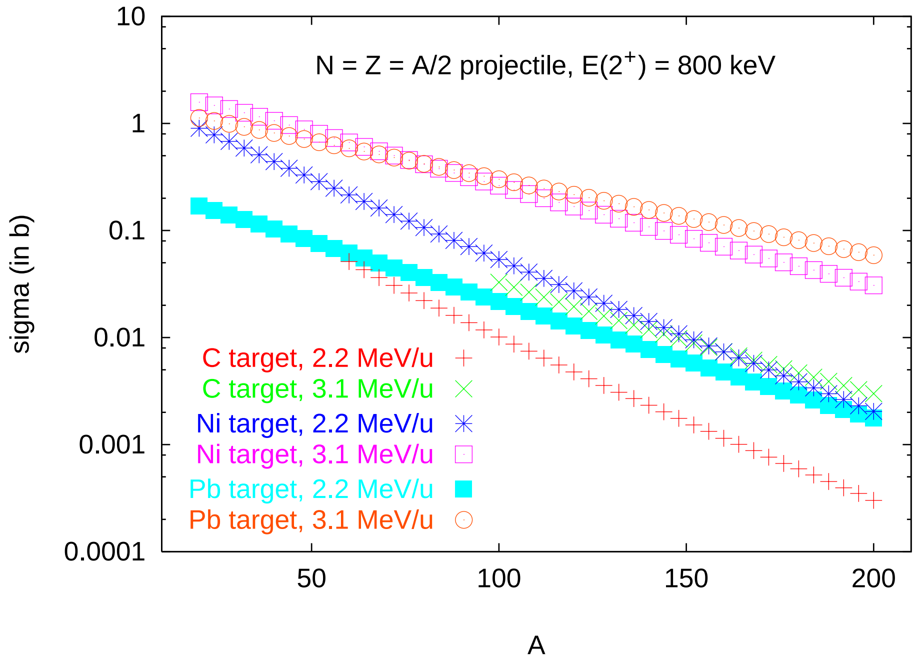

Figure 5: *Mass dependence for Coulomb excitation of* $Z = A$ *projectiles impinging on carbon, nickel and lead targets, assuming* $B(E2, 0^+ \rightarrow 2^+) = 0.1 e^2 b^2$ *and a* 4^+*-energy of 2000 keV with an identical* $B(E2)$ *value.*

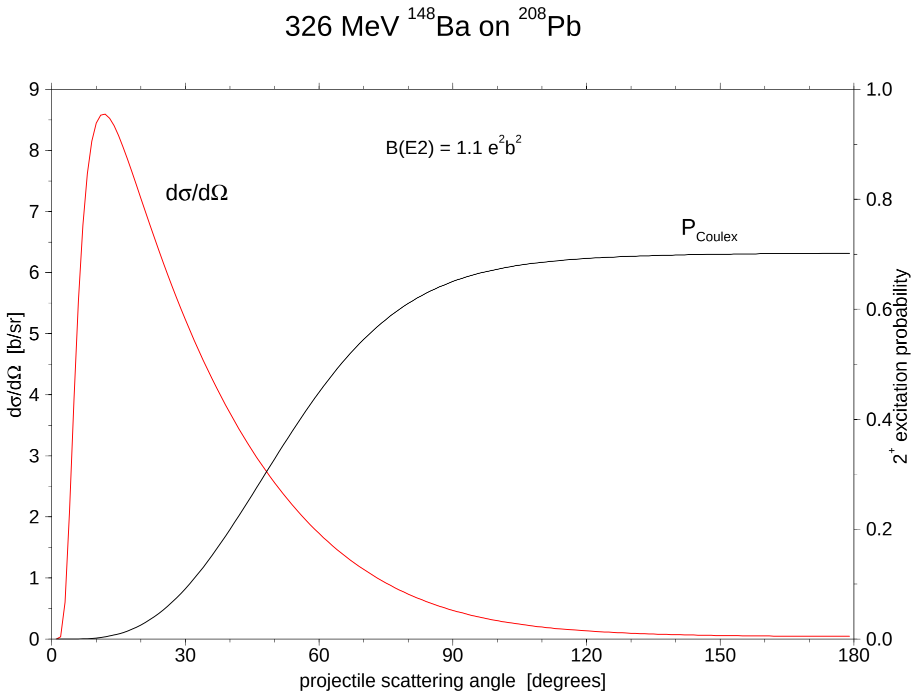

Figure 6: *Differential Coulomb excitation cross section for exciting the* 2^+ *state of* ^{148}*Ba and the corresponding excitation probability as a function of lab angle.*

Table 1 gives a compilation of the main properties of the nuclei we propose to study. For most of them the 2^+ excitation energy is known. If it is not known, the smooth A and Z dependence of E_{2^+} allows a rather reliable prediction by systematics. For most of the nuclei we used the $B(E2)$-value resulting from eq. 4. For the nuclei close to ^{132}Sn this probably leads to an overestimation of the $B(E2)$-value by a factor of up to 10. From the 2^+-energy are estimated the 4^+-2^+ energy ratios by systematics from neighbouring nuclei in case the 4^+-energy was not known. The table uses recent ISOLDE 1^+-yields at 60 keV for the various isotopes [23]. We note that a 1^+ intensity of 10^4/s is marginal for the proposed experiments. We furthermore give the total Coulomb excitation cross sections for the Ni- and Pb-target at the two bombarding energies. It is obvious that the high 2^+-energy in ^{132}Sn of $E_{2^+} = 4.0$ MeV results in a very small Coulomb excitation cross section, which does not allow an experimental investigation at this beam energy. The same is true for ^{130}Cd, for beam intensity reasons.

Nucleus	$E(2^+)$ [keV]	B(E2) [e^2b^2]	$E(4^+)$ [keV]	Yield (ISOLDE) [$1/\mu$C]	σ_{Coul} (mb) Ni target 2.2 MeV/u		Pb target 2.2 MeV/u		counts [1/h]
					2.2 MeV/u	3.1 MeV/u	2.2 MeV/u	3.1 MeV/u	
$^{122}_{48}$Cd$_{74}$	569.45	0.58	1329.15	$6.0 \cdot 10^8$	1159.	2741.	1612.	6099.	$2.0 \cdot 10^5$
$^{124}_{48}$Cd$_{76}$	613.33	0.418	(1530)	$4.0 \cdot 10^7$	751.0	1980.	980.2	4337.	$8.4 \cdot 10^3$
$^{126}_{48}$Cd$_{78}$	652.2	(0.376)	1467.	$3.0 \cdot 10^6$	607.5	1719.	751.0	3669.	$5.3 \cdot 10^2$
$^{128}_{48}$Cd$_{80}$	645.	(0.370)	1429.	$2.0 \cdot 10^5$	618.6	1726.	798.6	3767.	$3.6 \cdot 10^1$
$^{130}_{48}$Cd$_{82}$	957.	(0.25)	(2140)	$\approx 10^4$	141.8	730.0	94.42	1124.	0.5
$^{128}_{50}$Sn$_{78}$	1168.83	0.07	2000.37	$3.4 \cdot 10^8$	12.82	116.4	4.55	127.5	$1.2 \cdot 10^3$
$^{130}_{50}$Sn$_{80}$	1221.26	0.03	1995.65	$4 \cdot 10^8$	4.55	45.9	1.52	48.9	$5.3 \cdot 10^2$
$^{132}_{50}$Sn$_{82}$	4041.1	(0.010)	4415.6	$3 \cdot 10^8$	0.0266	0.0219	0.0792	0.0215	2.2
$^{134}_{50}$Sn$_{84}$	725.	(0.05)	(1600)	$2 \cdot 10^6$	58.9	211.8	68.2	462.8	$3.6 \cdot 10^1$
$^{136}_{52}$Te$_{84}$	605.9	0.097	1029.	$4.0 \cdot 10^7$	150.	444.	221.2	1099.	$1.7 \cdot 10^3$
$^{138}_{52}$Te$_{86}$	443.1	(0.13)	(750)	$2.0 \cdot 10^6$	348.2	753.7	751.7	2269.	$2.0 \cdot 10^2$
$^{138}_{54}$Xe$_{84}$	588.825	(0.21)	1072.53	$\sim 9 \cdot 10^8$	298.5	873.3	445.1	2147.	$\sim 8 \cdot 10^4$
$^{140}_{54}$Xe$_{84}$	376.66	0.324	834.287	$\sim 4 \cdot 10^8$	935.2	1790.	2269.	5566.	$\sim 1 \cdot 10^5$
$^{142}_{54}$Xe$_{88}$	287.1	(0.70)	690.7	$\sim 4 \cdot 10^7$	2499.	3861.	7158.	12220.	$\sim 3 \cdot 10^4$
$^{144}_{54}$Xe$_{90}$	252.6	(0.72)	644.3	$\sim 6 \cdot 10^5$	2798.	4081.	8619.	13260.	$\sim 5 \cdot 10^2$
$^{148}_{56}$Ba$_{92}$	141.7	1.1	423.1	$5 \cdot 10^5$	4694.	5775.	16790.	19100.	$6.6 \cdot 10^2$
$^{150}_{56}$Ba$_{92}$	(≈ 95)	(1.6)	(315)	$2 \cdot 10^4$	6841.	7574.	24630.	24120.	$4.5 \cdot 10^1$

Table 1: *For nuclei to be investigated in the present proposal the 2^+ energies, $B(E2)$-values, 4^+ energies, the new ISOLDE yields [23] as well as the Coulomb excitation cross sections for Ni- and Pb-targets are given. Extrapolated values are given in brackets. The counting rates were estimated for a 2 μA proton current at ISOLDE, an overall transmission of 4 % through REX-ISOLDE, 1 mg/cm^2 thick targets and a 10 % photopeak efficiency of MINIBALL.*

4 Experimental setup, count rates and requested beam time

We propose to study the Coulomb excitation of $A \sim 140$ even-even nuclei extracted from a UC_2-ISOLDE target and accelerated by REX-ISOLDE up to 2.2 MeV/u. The primary ISOLDE yield is reduced by a factor of 1/25 due to the efficiency of the different stages of REX-ISOLDE. The measurements willl be performed using the MINIBALL set-up [2], which presently consists of 24 six-fold segmented Ge-detectors to detect the de-excitation γ-rays. Moreover, the scattered projectiles will be registered in coincidence with the CD-detector [1], a highly segmented double sided silicon strip detector covering an angular range of $5^\circ \leq \theta_{\mathrm{lab}} \leq 50^\circ$ thus covering the relevant phase space. The total γ efficiency of the set-up amounts to 10 % at 1 MeV. The set-up allows for a detailed Doppler shift correction of the detected γ-rays. For a 1 mg/cm^2 Ni-target and a typical Coulomb excitation cross section of 1.0 barn we obtain a reaction probability of $1.0 \cdot 10^{-5}$ and expect counting rates as given in table 1. We typically need to detect 10^3 counts for a $2^+ \rightarrow 0^+$-transition for an accurate determination of the $B(E2)$-value, but also 10^2 counts are sufficient to reveal new trends in $B(E2)$-values. Note, that because of the low excitation energies the predicted cross sections — and thus the count rates — do depend only very weakly on the projectile energy (see tab. 1). It is therefore not necessary for this kind of experiments to wait for the proposed upgrade of REX-ISOLDE to 3.1 MeV/u. Taking the different counting rates of table 1 into account and that some of the most interesting isotopes like ^{150}Ba, ^{144}Xe, ^{138}Te or Cd may have a factor of up to 10 smaller $B(E2)$-values than assumed, we **request a beam time of 21 shifts with radioactive beams using a UC_2 target plasma ion source**.

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