Chapter 1

Introduction

Numerous experimental and theoretical studies are currently focused on nuclear shell structure far from the line of stability [1 and references contained therein]. In particular, the evolution of nuclear properties, e.g. the energy of the first excited 2_1^+ state and the reduced transition probabilities across the Z = 50 chain of tin isotopes are the area of great interest for researchers. This constitutes the longest shell-to-shell chain of semi-magic nuclei investigated in nuclear structure to date. Radioactive ion beams yield new experimental results close to the doubly-magic ^{100}Sn and ^{132}Sn, but very accurate data of the stable midshell nuclei are also of great relevance for our understanding of nuclear structure. This thesis presents an experimental study of reduced transition probabilities in the stable isotopes ^{112}Sn and ^{114}Sn, which are poorly known.

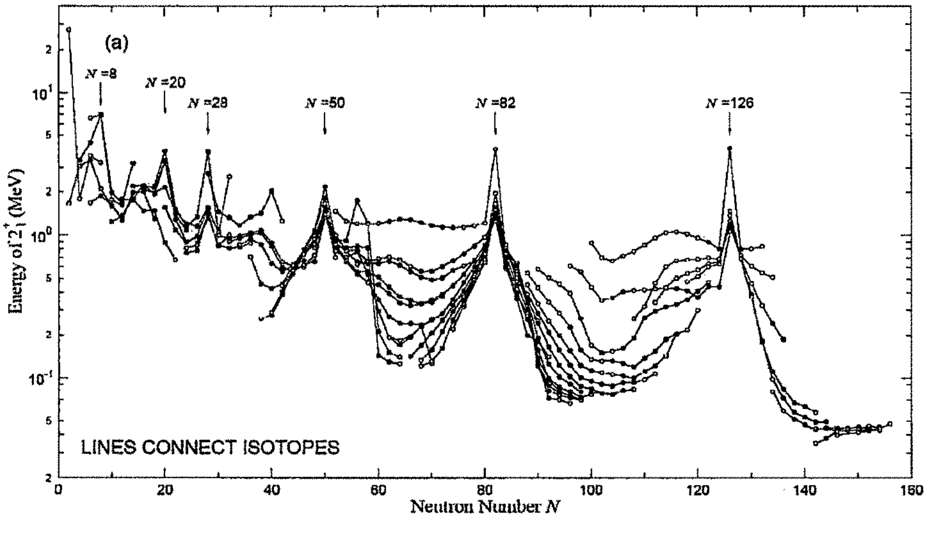

Figure 1.1: Energy of the first excited 2_1^+ state versus the neutron number N [2].

The experimental evidences of the closed shells (magic numbers) are displayed in fig. 1.1 which shows the first excited 2_1^+ states in even-even nuclei through out the periodic table.

Near closed shells the energies $E_{2_1^+}$ are rather high compared to the midshell nuclei. This experimental findings at neutron number 8, 20, 28, 50, 82 and 126 is clearly seen in this figure.

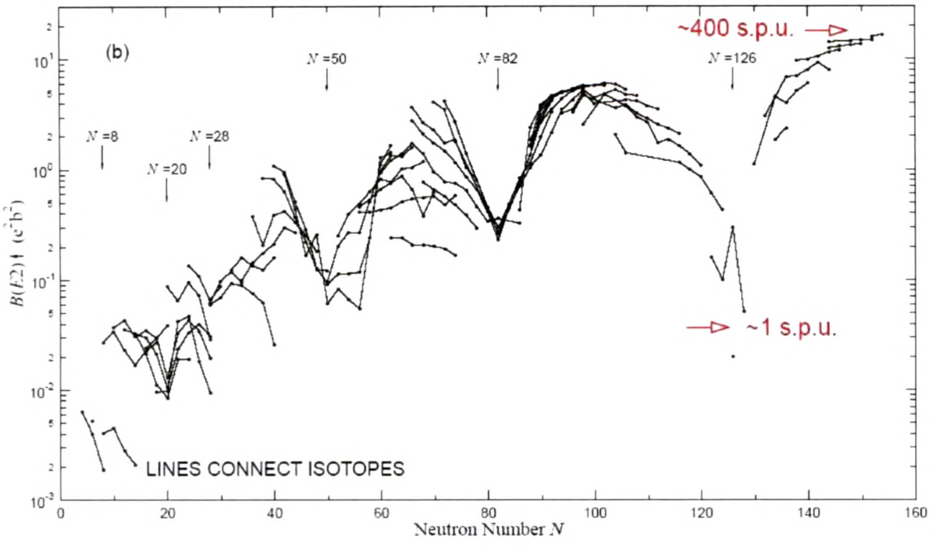

Figure 1.2: B(E2;0$^+$ $\rightarrow$ 2$^+$) values [2] across the nuclear chart for even-even nuclei in units of a single particle value defined as B(E2;0$^+$$\rightarrow$2$^+$)$_{s.p.u.}$ $= 3{\cdot}10^{-5}\ A^{\frac{4}{3}}e^2b^2$ [3].

Another experimental indication yields the B(E2;0$^+$$\rightarrow$2$^+$) values across the nuclear chart (see fig. 1.2). They are rather small for closed shell nuclei. Besides the energies $E_{2_1^+}$ and the reduced transition probabilities B(E2;0$^+$ $\rightarrow$ 2$^+$) one observes the existence of the shell structure also from the investigation of the neutron (proton) separation energy $S_{2n}(S_{2p})$ as discussed in chapter 6.

The nuclear shell-model is the most successful theoretical framework for understanding the atomic nucleus in terms of its constituent nucleons. In the shell-model, the nucleons are moving, to first order, independently in a static potential created by all other nucleons. The residual interaction between nucleons is not considered. This model calculates the energy eigen-values of the nucleons which are grouped in major shells. This result explains the experimental observation that nuclei with so-called magic proton or neutron numbers 2, 8, 20, 28, 50, 82, and 126 are particularly stable. This simple model works extremely well for selected group of nuclei, namely those with one particle outside a doubly magic core.

In nuclei with more than one neutron or proton outside the major shell one has to consider the residual interaction between the valence nucleons. When there are numerous particles outside the closed shells, they can enter different shell model orbits. For example, in the tin isotopes the up to 32 valence neutrons might be in five orbits $1g_{7/2}$, $2d_{5/2}$, $2d_{3/2}$, $3s_{1/2}$, $1h_{11/2}$. Fig. 1.3 shows the partial level schemes of even-A Sn isotopes with the dominating 6^+ and 10^+ yrast isomers resulting from the filling of the $g_{7/2}$ and $h_{11/2}$ neutron subshells in

A = 102-114 and A = 116-130, respectively. These two regions seem to be divided by a soft closed subshell at N = 64. If spectroscopic properties of nuclei with more than six or eight valence neutrons are studied with the shell model, the required model space is, however, already exceedingly large. It is therefore appropriate to resort to further simplifications.

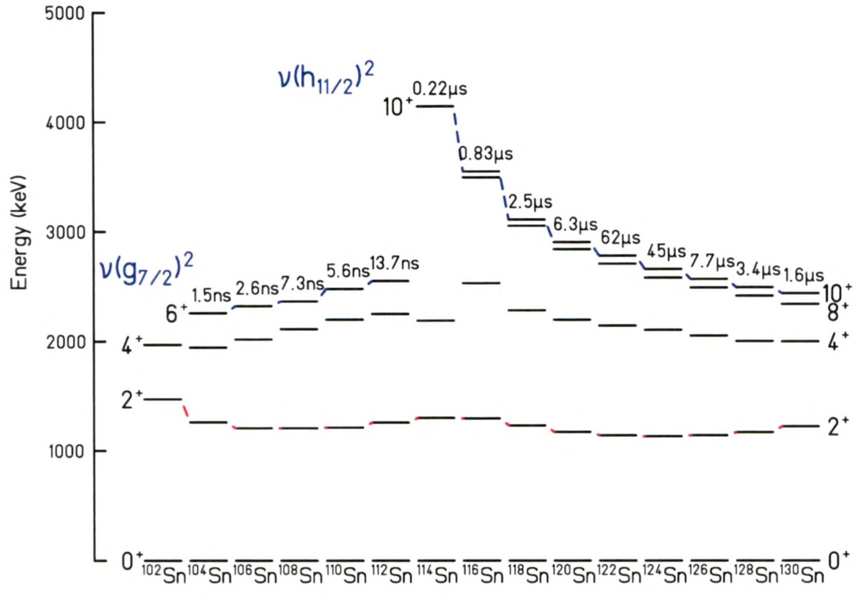

Figure 1.3: Partial level schemes [NNDC] and isomer systematics in the even-A Sn nuclei for mass numbers between A = 102 and A = 130. Levels of the same spin and positive parity are connected by broken lines.

In semi-magic nuclei, such as the Sn isotopes, the seniority scheme provides a very valuable tool for describing the low-energy spectra. The nearly constant energy of the first excited 2^+_1 state between N = 52 and N = 80 [2] is one of the well known features of Sn isotopes (see fig. 1.3), and is well explained within the generalized seniority model [5]. It seems to indicate that only one of the two kinds of nucleons contributes to the low energy states. As a consequence, only the isovector (T = 1) interaction plays a leading role outside the doubly-magic core, which cannot generate quadrupole deformation [3]. Furthermore, according to this theory, the electromagnetic transition rates between the 0^+ ground and the first excited 2^+_1 state exhibit a parabolic behaviour as a function of mass number across the Sn isotope chain. Thus, for a seniority changing transition, the $B(E2\uparrow)$ values increase at first, peak at midshell (A = 116) and fall off thereafter.

The experimental $B(E2;\, 0^+_{g.s.} \rightarrow 2^+_1)$ values, henceforth abbreviated as $B(E2\uparrow)$, on the neutron-rich side of the Sn chain follow the theoretical predictions. For the mass range A = 116-130, the first excited 2^+_1 state is generally an admixture of different neutron configurations in contrast to the pure neutron $(h_{11/2})^n$ configuration for the long lived 10^+ isomeric state. For the lighter Sn isotopes, where the neutrons are filling the almost degenerate single-particle $1g_{7/2}$ and $2d_{5/2}$ states, one observes an unexpected asymmetry in E2 strengths with respect to the heavier isotopes. This might indicate that the effective charge values depend on the orbit occupied by the nucleon. Two stable tin isotopes, ^{112}Sn and ^{114}Sn, yield higher $B(E2\uparrow)$ values than expected from shell model calculations, but so far large experimental errors prohibited further theoretical interpretations. One should also note that the $B(E2\uparrow)$ value obtained for the unstable ^{108}Sn [6] in a RISING experiment is based on a measurement relative to ^{112}Sn.

The large uncertainty of the $B(E2\uparrow)$ values in ^{112}Sn and ^{114}Sn motivated two Coulomb excitation experiments to improve these crucial data points. In this technique the nucleus of interest is excited via the well known electromagnetic interaction between the two collision partners. In contrast to other nuclear reactions the excitation can be exactly calculated and the B(E2) values are extracted in the model independent way.

When Coulomb excitation experiments cannot be performed due to the lack of beam intensities, nuclear information are obtained from decay studies. An active stopper for the RISING (Rare Isotope Spectroscopic INvestigation at GSI) project was developed for the β-decay studies and conversion electron spectroscopy following projectile fragmentation/fission reactions. This system employes six double-sided silicon strip detectors in the final focal plane of the GSI FRagment Separator (FRS) to detect both the fragment implantations and their subsequent charged-particles (α, β, p) decays. Its development will be presented in the second part of this thesis.

In this doctoral thesis the less known B(E2) values of ^{112}Sn and ^{114}Sn are measured with higher precision at GSI Helmholtzzentrum and at the Inter University Accelerator Centre. Chapter 2 describes the seniority scheme for the Sn isotopes. The theoretical description of the Coulomb excitation is given in Chapter 3. Details of the performed experiments can be found in Chapter 4. In Chapter 5 the data analysis is described and the results of B(E2) values are given. They are compared in Chapter 6 with the theoritical values of the large scale shell model (LSSM) and the relativistic quasi-particle random phase approximation (RQRPA) calculations. In Chapter 7 the realization of active stopper detector is described. Summary and the outlook can be found in Chapter 8.