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1.9 Capture of polarized thermal neutrons on polarized target nuclei

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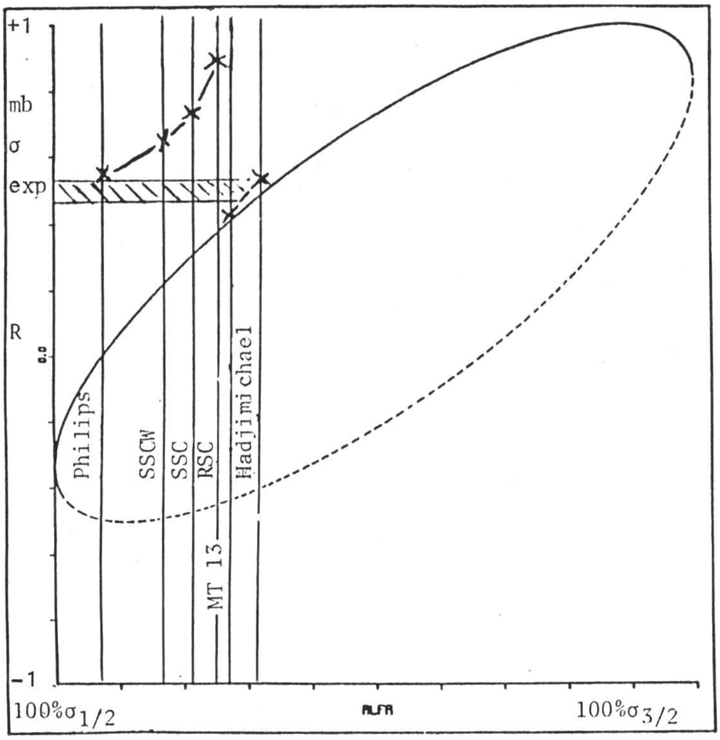
In Petten a unique facility is available for studying the capture of polarized neutrons in polarized target nuclei by means of gamma spectroscopical techniques. During the eighties we have assigned spins to bound states of Na, Ti, V, Cu and Co nuclei in order to test shell model calculations. As a byproduct in this analysis sets of coherent spin admixtures for the unbound s-wave capture states have been obtained [1-5]. As is well known these states may have the spin values $J_t \pm \frac{1}{2}$ (here J_t is the spin of the target nucleus), and the coherent interference for a particular gamma transition is specified by two parameters namely $\alpha = \sigma^+/(\sigma^+ + \sigma^-)$ and the interference sign ρ. For each primary transition f a value for the combination α_f^ρ can be defined, which together with the intensity I_f yields the angular distribution and polarization as well as the partial cross sections σ^+ and σ^- for this transition.

Since for heavy nuclei the s-wave capture states are very complicated, the physics information in α_f^ρ and I_f in general is rather obscure. In the theoretical interpretations, however, levels of increasing sophistication are possible proceeding from heavy to lighter nuclei and reaching closed neutron shells. For heavier nuclei one knows the statistical interpretation, in which a set of gaussian distributed amplitudes exists for each spin value, and the random sign of these amplitudes leads to the relation $\sum_f^N (-)^\rho I_f \sqrt{\alpha_f(1-\alpha_f)} = 0$ if the total number of states N is large enough. Near closed shells, valency capture in single particle s-wave states is found, and the sign and value of α are fixed by the l-s coupling parameters of the bound states. In terms of the shell model ρ is positive for pure $j=\ell+\frac{1}{2}$ states and negative for $j=\ell-\frac{1}{2}$ states. Such relations have served as a spectroscopic tool besides the previously mentioned spin assignments (see ref.[6]). Also in the more complicated case of doorway capture some structural information of the bound levels is hidden in the α_f^ρ values as has been shown in ref.3. Here the wave function of the capture state of ^{52}V could be identified as:

$$\psi_c = 0.44(2)|(f7/2)^3_{7/2}, s\tfrac{1}{2};3\rangle - 0.09(2)|(f7/2)^3_{5/2}, s\tfrac{1}{2};3\rangle +$$
$$-0.15(2)|(f7/2)^3_{7/2}, s\tfrac{1}{2};4\rangle + 0.13(2)|(f7/2)^3_{9/2}, s\tfrac{1}{2};4\rangle.$$

In this wave function the channel spins 3^- and 4^- are coherently mixed and all gamma spectroscopical data a e described in terms of bound state shell model specifications.

Most sophisticated but also most challenging is the description of the capture state by means of accurate nucleon wave functions from realistic calculations. In this case the magnetic dipole strength needs to be explained by the fact that the nucleus also contains virtual mesons and that even excitations of the nucleon e.g. the Δ-isobar can occur. A good test of the meson exchange operator in a few body system is provided by the radiative capture in few nucleon systems. An impressive confirmation of the existence of meson exchange currents were the calculations of Riska and Brown [7]) who could explain the long standing descrepancy between theory and experiments for radiative neutron capture on protons. As it has been argued in refs. [8]) and [9]) a very stringent test of meson exchange currents and nucleon nucleon forces will be provided by measuring the dependence of the capture cross section on the polarization of the incident neutron as well as of the target deuterium. For this system the value of α may range from 0.05 to 0.32 depending on the internucleon force, which has been selected. In the upper left hand corner of fig.1 it is shown how the estimates for different nucleon nucleon forces compare with the measured $\sigma(n,\gamma)$ value and in the ellips how the ratio $\alpha = \sigma^+/\sigma$ can be observed from the γ circular polarization after polarized neutron capture in unpolarized deuterium. This ellips shows the polarization parameter R obtained from the circular polarization after polarized neutron capture in deuterium. For each value of α there are two solutions for R: one for which the matrix elements for $J^\pi = \frac{1}{2}^+, {}^3/_2{}^+$ have the same sign (the full line) and one for which these matrix elements have opposite signs (the broken line). This sign information



should be compared with the model calculations just as the absolute value of α^{ρ}. The latter value can be derived if both the neutrons and the deuterium nuclei are polarized along a common axis but alternatingly parallel and antiparallel. Gamma radiation can be detected along this axis and perpendicular to it, as also is described in refs. [1-5]. The normalized γ-ray angular distribution following capture of polarized neutrons by polarized nuclei can then be written in the form:

$$W(\Theta) = 1 + A_0'' f_n f_N + A_2'' f_n f_N P_2(\cos\Theta)$$

where f_N is the nuclear polarization and Θ is the angle of emission with respect to the common axis of orientation. Experimentally the value of α follows from $A'' = \frac{4}{3}\alpha - 1 = \frac{1}{3}\{\varepsilon(0^{\circ}) + 2\varepsilon(90^{\circ})\}/f_n f_N$ with $\varepsilon(\Theta) = \frac{1}{2}\{W_{\uparrow\uparrow}(\Theta) - W_{\uparrow\downarrow}(\Theta)\}$ where the intensities W are measured with parallel and antiparallel spins. As an extra information the parameter A_2'' is obtained, which shows interference in the same way as illustrated for R in fig.1. For example it allows us to determine the amount of E2 radiation as is described in ref.[11]. An experiment is underway in which we aim at an accuracy of 5% for the value of α in the range $0 \leq \alpha \leq 100\%$. The fact that the flux has been increased by more than an order of magnitude after a recent replacement of the reactor vessel and the circumstance that the 6.3 MeV gamma line takes 100% of the transition strength is essential in the feasibility considerations. This experiment is important to investigate not only meson exchange currents but especially the internucleon forces. Information obtained from these low momentum transfer experiments will provide valuable constraints for the interpretation of the high momentum experiments.

An extension of this work to heavier systems such as ^{3}He and ^{6,7}Li is foreseen, whereas the study of the reaction $^{10}\vec{B}(\vec{n},\alpha\gamma)$ has already been performed (see ref.[10]). It has been shown that the latter reaction almost purely proceeds through the channel $J_t + \frac{1}{2}$.

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