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1.82 Single-Particle Properties of Protons in the Zirconium Region

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From a number of single particle transfer reactions with polarized projectiles we know[1)] the detailed strength distribution of protons in the $1f_{7/2}$, $1f_{5/2}$, $2p_{3/2}$ and $2p_{1/2}$ shells of nuclei in the mass region of ^{90}Zr. We discuss here global quantities, as are given by the lowest moments of the strength distributions, i.e., spectroscopic strengths, single-particle energies and spreading widths which can be deduced, for example, from proton transfer reactions. The evaluation requires a complete set of data, i.e., the complete spectroscopic strength $G^- = \Sigma C^2S^-$ for pickup and $G^+ = \Sigma(2I + 1)C^2S^+$ for stripping must have been observed. In order to minimize the absolute errors of these strengths determined from different experiments, the data were normalized such that they fulfill the requirement $G^- + G^+ = 2j + 1$ for the different orbits j simultaneously.

Following the ideas of Baranger[2)] we calculated single-particle energies $E_j(A)$ of protons in the orbit with quantum numbers n, l, j of a nucleus A from the first moments E^-, E^+ of the strength distributions according to

$$E_j(A) = (E^-G^- + E^+G^+)/(G^- + G^+) \quad . \tag{1}$$

We applied the prescription to single-particle energies of protons in the $1f_{7/2}$, $2p_{3/2}$, $2p_{1/2}$, $1f_{5/2}$ and $1g_{9/2}$ shells in Kr, Sr, Zr and Mo isotopes. When plotted versus mass number A, the energy values $E_j(A)$ exhibit a pattern which can be interpolated linearly. Connecting the data points for isotopes (isotones) we see a constant increase (decrease) of $E_j(A)$ with increasing neutron (proton) number. This linear system can be parametrized by

$$E_j(A) = E_j(C) + pa + T_o\, b/2 \tag{2}$$

where A is a nucleus with isospin T_o and p particles outside a "core" C with $T_o = 0$. $E_j(C)$, a and b were calculated via linear regression. Experimental values of $E_j(A)$ and the deduced interpolation are presented in fig. 1 for $1g_{9/2}$ protons.

The remarkably simple result can be interpreted in the framework of the Bansal-French model[3)]. If a particle-hole interaction of type $V_{ph} = a + b(\vec{t}_p \cdot \vec{t}_h)$ is assumed, the difference of single-particle energies $E_j(A)$ in a nucleus $A = C + p - h$ with p particles and h holes with respect to core C, and single-particle energies $E_j(C)$ is given merely by a sum of particle-hole interactions $E_j(A) - E_j(C) = \Sigma V_{ph}$. For proton pickup reactions we obtain

$$E_j(A) - E_j(C) = p\cdot a + T_o\cdot b/2 \tag{3}$$

and for proton stripping reactions

$$E_j(A) - E_j(C) = -h\cdot a + T_o\cdot b/2 \tag{4}$$

or, if we introduce a smaller core C' defined by $C = C' + p + h$

$$E_j(A) - E_j(C') = p \cdot a + T_o \cdot b/2. \qquad (5)$$

The comparison shows that the same dependence is obtained for pure hole state and for pure particle states; hence the same is true for mixed configurations, where single-particle energies are determined from both pickup and stripping reactions weighted with the respective spectroscopic strengths G^-, G^+.

We conclude that our empirical parametrization of the single-particle energies $E_j(A)$ can be understood in terms of the Bansal-French model, if a constant residual interaction between protons in the orbit j and surrounding nucleons is assumed. This is true for the considered values of j in the Zr region and is also true for $1f_{7/2}$ protons in nuclei with $46 \leq A \leq 92$.

In a next step we combine the information on the 0^{th} and 1^{st} moments of the proton strength distributions, and plot the proton occupation probabilities $\langle p_j \rangle/(2j + 1)$ as a function of $E_j(A)$; see fig. 2 for N = 50 isotones. A fit to the data points with the BCS occupation probability $v_j^2 = (1/2)\ (1-[E_j-\lambda]/\varepsilon_j)$ with $\varepsilon_j = ([E_j-\lambda]^2 + \Delta^2)^{1/2}$ reveals details of the Fermi surface in these nuclei. The best shell closure among all Kr, Sr, Zr and Mo isotopes is found for ^{88}Sr. The values λ, which define the energetic position of the Fermi surface, were used to test the dependence of the spreading widths $\Gamma\downarrow$ on the distance to the Fermi surface, where $\Gamma\downarrow$ is proportional to the second moment M_2 of the strength distribution $\Gamma\downarrow = 2.35\ M_2$. For deeply bound $1f_{7/2}$ protons hole states as observed in the $(\vec{d}, {}^3He)$ reaction on $^{84,86}Kr$, $^{90,92}Zr$ and ^{92}Mo the data follow the relation $\Gamma\downarrow = a \cdot (E_j - \lambda)^2$ with $a = 0.06\ MeV^{-1}$ as predicted by Bertsch[4] for infinite Fermi systems (fig. 3).

1) G. Seegert et al., Journal de Physique 45, C4 (1984) 85
2) M. Baranger, Nucl. Phys, A149 (1970) 225
3) R.K. Bansal, J.B. French, Phys. Lett. 11 (1964) 145; 19 (1965) 223
4) G.F. Bertsch et al., Rev. Mod. Phys. 55 (1983) 287

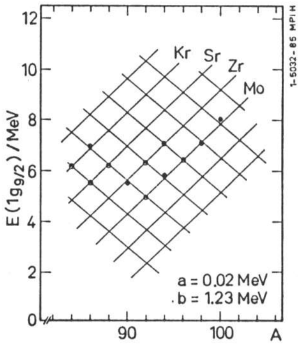

Fig. 1. Single particle energies of $1g_{9/2}$ protons.

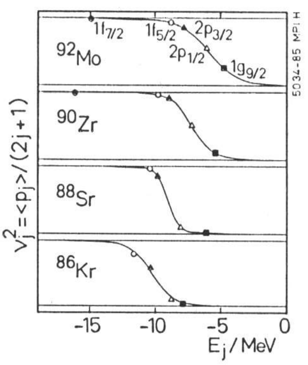

Fig. 2. Proton occupation probabilities in N = 50 isotones.

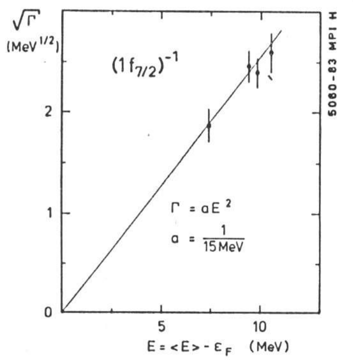

Fig. 3. Spreading widths of $1f_{7/2}$ proton hole states.