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A Residual Interaction and Low Energy Spectra in the Lead Region

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Abstract. Energy levels and transition probabilities of some nuclei in the lead region can be understood in detail if a residual interaction is introduced. The angular dependence of this interaction is assumed to be a delta function. A Gaussian function is chosen for the radial dependence. No nuclear core excitation has been considered.

In the last few years several shell model calculations including various residual nuclear interactions have been performed [1–6]. In the following we present calculations of single closed nuclei in the lead region. Only nuclei containing two nucleons in the open shell or two holes in a closed shell have been considered. Nuclear core excitations have not been taken into account. Thus, an exact diagonalization of the Hamiltonian can be performed. The positions and properties of the low lying energy levels of the three nuclei Pb^{206}, Pb^{210}, Po^{210} are well described by this model.

We have chosen for the residual interaction the simple form:

$$V(\boldsymbol{r}_1, \boldsymbol{r}_2) = V_0 \, V_R(r_1, r_2) \, \delta(\Omega_{12}) \tag{1a}$$

where

$$V_R(r_1, r_2) = \frac{1}{r_1 r_2} \, e^{-\alpha (r_1 - r_2)^2}. \tag{1b}$$

This Gaussian radial dependence takes into account the short range of the nuclear forces. The delta force of the angular part gives a strong correlation between the nucleons, especially in the lowest state of spin J and parity $(-)^J$. Pairs of nucleons of spin J and parity $-(-)^J$ are much less affected by this residual interaction.

We determine the potential depth parameter V_0 by the energy difference between ground state and first excited state. The radial parameter α is chosen to obtain the best agreement with the experimentally found values of other energy levels. These two parameters can be compared with those obtained by nucleon-nucleon scattering [7]. The range of the residual interaction is almost equal with the value of the scattering experiments and the potential depth V_0 deviates only by 20%.

The single particle energies are taken from the experimental positions of neighbouring nuclei [8–10]. For the computation of the transition probabilities the effective charge of the nucleon is chosen to be one electron charge.

In Figure 1 the experimental values [11] for the energy levels of Po^{210} are compared to the calculated levels. Reduced transition probabilities for the same nucleus are computed and compared with experimental data (see Tab. I). In our shell model

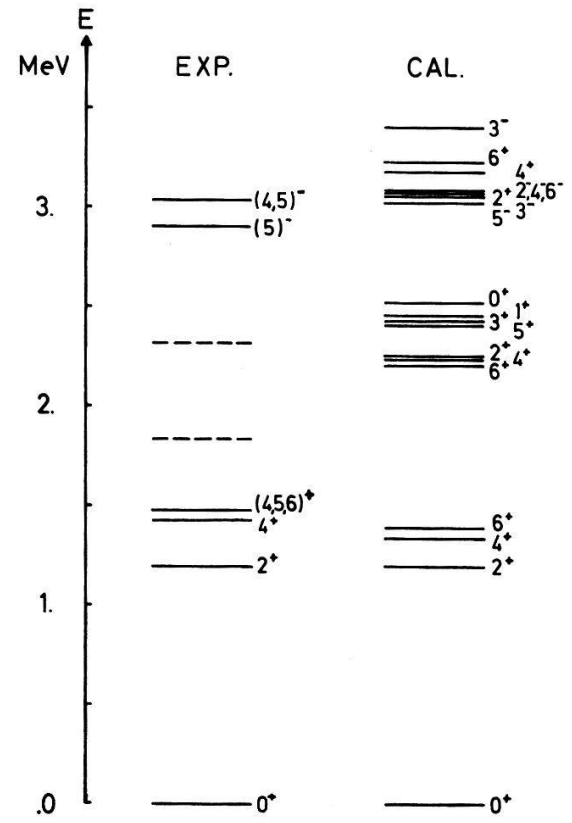

Figure 1

The calculated energy levels of Po^{210} are compared with experimental data.
The parameters are $\alpha = 2$ and $V_0 = .128$.

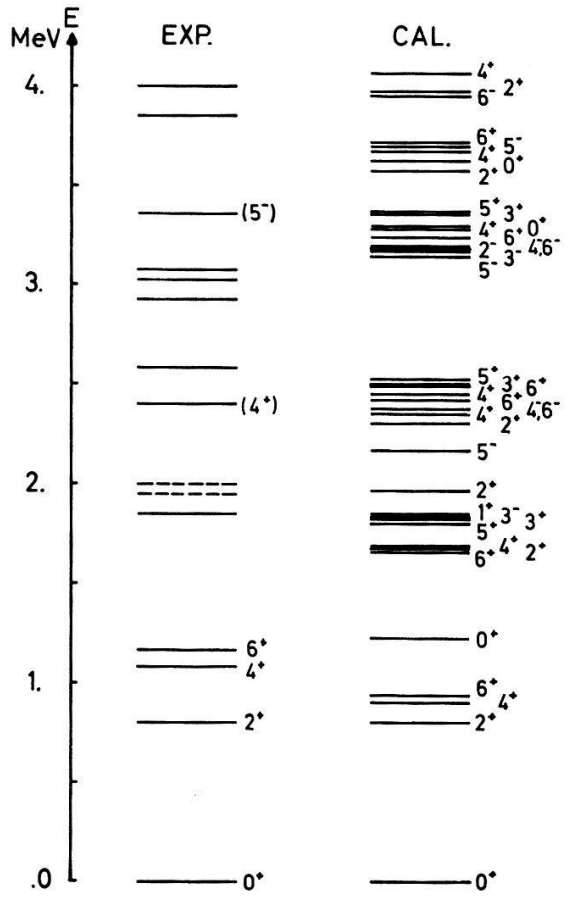

Figure 2

The calculated energy levels of Pb^{210} are compared with experimental data.
The parameters are $\alpha = 2$ and $V_0 = .117$.

Table I

Some calculated reduced transition probabilities are compared with existing experiments

Nucleus	Transition	Reduced transition probability	
		Calculation	Experiment
Po^{210}	$4_0^+ \to 2_0^+$	$1.34 \cdot 10^{-2}$ b^2	$(1.92 \pm .25) \cdot 10^{-2}$ b^2 [a]
	$6_0^+ \to 4_0^+$	$.93 \cdot 10^{-2}$ b^2	$(1.28 \pm .16) \cdot 10^{-2}$ b^2 [a]
Pb^{210}	$4_0^+ \to 2_0^+$	$1.66 \cdot 10^{-2}$ b^2	$3.28 \cdot 10^{-2}$ b^2 [b]
	$6_0^+ \to 4_0^+$	$1.17 \cdot 10^{-2}$ b^2	$3.02 \cdot 10^{-2}$ b^2 [b]
Pb^{206}	$2_0^+ \to 0_0^+$	$.93 \cdot 10^{-2}$ b^2	$\left(2.70 \pm \begin{matrix}.05\\.09\end{matrix}\right) \cdot 10^{-2}$ b^2 [c]

[a]) Ref. [11] [b]) Ref. [12] [c]) Ref. [14].

picture electric dipole transitions are strongly forbidden. This can be deduced experimentally from the branching ratio of the 3.03 MeV level. It follows that the $E1$ transition to the 1.43 MeV level is strongly forbidden.

Figure 2 shows experimental [12] and calculated values for the energy levels of Pb^{210}. Probably due to the neglect of the core excitations, the calculated values of the first 4^+ and 6^+ levels are too low. Reduced transition probabilities from our calculation and from existing experiments are also given in Table I.

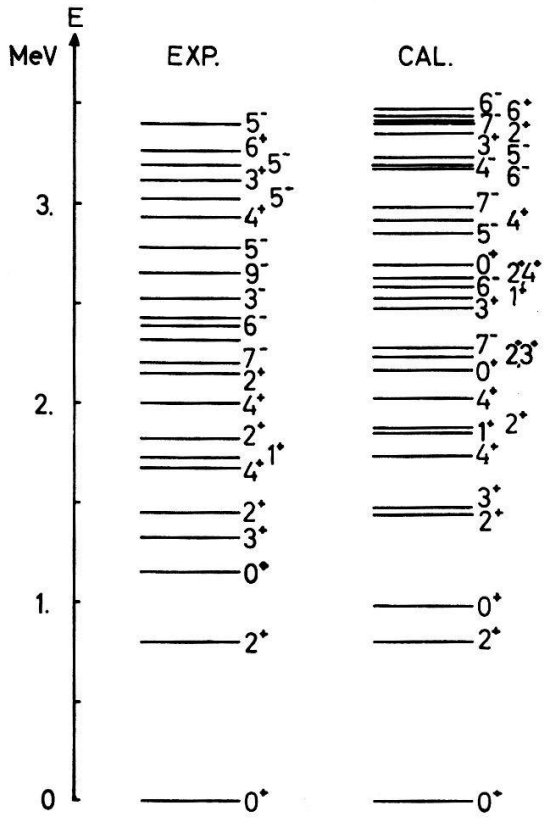

Figure 3

The calculated energy levels of Pb^{206} are compared with experimental data. The parameters are $\alpha = 2$ and $V_0 = .183$.

The data of the calculated and of the experimentally [13] determined values for the energy levels of Pb^{206} are shown in Figure 3, and a very good agreement, even for the negative parity states is found. Again in Table I the measured and calculated transition probability between ground state and first excited state is compared. A calculation of the quadrupole moment of the first excited state gives the value $Q = -3.65 \cdot 10^{-2}$ b.

It is thus seen that the simple residual interaction of Equation (1) reproduces position and properties of the low lying states in three nuclei of the lead region. The coupling of the two nucleons to the nuclear core plays essentially a minor role with the possible exception of Pb^{210}.

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