1/2+ PARTICLE-VIBRATION DOORWAYS IN COMPOUND NUCLEI Pb$^{209}$ AND Pb$^{207}$* 

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The doorway state concept has become important in recent years. Such states are composed of simple excitations and might be observed as single resonances or as several narrow resonances. The well known$^{(1)}$ Pb$^{209}$ 1/2+ state at 500 keV neutron energy with a width of 58 keV is an example of the former type. Some similar doorways are found in neutron scattering experiments on target nuclei Y$^{89}$, and Ca$^{48}(2)$, while fragmented doorways have been identified in compound nuclei, Sr$^{89}$, Pb$^{207}$ and Pb$^{208}$. The dissolution of a doorway into narrow resonances implies a width for spreading into more complex states. We have attempted to study doorway states in terms of two different models: 1) 2p-1h configurations and 2) particle-vibration configurations. Reference 2 treats the former approach for compound nuclei Ca$^{49}$, Sr$^{89}$, and Zr$^{91}$. However the latter mode of excitation seems to be preferable in the case of Pb isotopes. In this paper we demonstrate the applicability of the particle-vibration model for interpreting the neutron resonances observed in Pb$^{208}$ and Pb$^{206}$ neutron scattering experiments.

The coupling of an odd particle to a nuclear vibration is a very general and important problem in nuclear physics. The particle-vibration weak-coupling model$^{(3,4)}$ has been successfully applied to study nuclear level structure. In particular the almost pure single particle nature of pertinent neutron and proton states and the collective behavior of the excited states of Pb isotopes facilitate the application of this model for Pb and Bi isotopes. Usually the particle-vibration** states considered are located in the bound region.

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** Both the terms "particle-vibration" and "core-particle" are used in this paper.
However, some of these states could be above particle threshold and observable as resonances. (Incidentally Motelson\(^3\) has pointed out the need for the evaluation of radial matrix elements when the single particle state is at a known energy in the continuum.) We will refer to such resonances as particle-vibration doorways.

As pointed out earlier a very wide \(1/2^+\) resonance in \(\text{Pb}^{209}\) was observed in a neutron scattering experiment at \(E_n = 500\) keV with a width of 58 keV. The experimental cross sections for the \(\text{Pb}^{207}\) and \(\text{Pb}^{206}\) compound nuclei exhibit much fine structure \((J^\pi = 1/2^+)\) in the vicinity of 500 keV neutron energy. The individual sum of the \(\text{Pb}^{207}\) and \(\text{Pb}^{208}\) \(1/2^+\) neutron reduced widths is approximately equal to the \(\text{Pb}^{209}\) \(1/2^+\) reduced width\(^1,5\). This fact lead Newson and his collaborators to conjecture that a common doorway (in \(\text{Pb}^{209}\)) is responsible for the fine structure observed in the other two lead isotopes.

Arguments were given in ref.\(^6\) as to why the \(2p-1h\) picture could not account for the 500 keV \(\text{Pb}^{209}\) \(1/2^+\) resonance. Similar conclusions may be drawn from the results of Vergados\(^7\). Following a suggestion* by Shakin\(^8\) we have shown in an earlier paper\(^6\) that the \(\{4^+ \otimes 2g_9/2\}_{1/2^+}\) state located nearly at the experimental energy has a width of about 1 to 2 times the observed resonance width. Here we report an extension of our particle-vibration model calculation to the other possible \(1/2^+\) doorway states in \(\text{Pb}^{209}\) and \(\text{Pb}^{207}\). The conjecture that the \(\text{Pb}^{209}\) and \(\text{Pb}^{207}\) doorways have similar structure is also verified. An extension of the present model for the \(\text{Pb}^{208}\) (\(\text{Pb}^{207} + n\)) case is expected to give similar results. The Hamiltonian in the weak-coupling model is

\[
H = H_{\text{core}} + H_{\text{part.}} + V_c
\]

Here \(H_{\text{core}}\) and \(H_{\text{part.}}\) are the vibrational core and single particle parts of the total Hamiltonian and \(V_c\) is the coupling interaction chosen to be of the following form:\(^6\)

\[
V_c = k(r) (2\lambda + 1)^{1/2} (\alpha_\lambda Y_\lambda)_0
\]

Where \(\lambda\) is the vibrational quantum number and \(k(r)\) a form factor given by

\[
k(r) = -r \frac{dV(r)}{dr}
\]

The potential \(V(r)\) is taken as a Woods-Saxon well. The magnitude of the vibrational amplitude \(\alpha_\lambda\) can be determined from the cross section for excitation of one vibrational quantum. The matrix element of the coupling interaction \(V_c\) is completely determined by the properties of the single particle motion and the vibration, and is of the form\(^3\)

* A similar suggestion was made by G. E. Brown at the time of publication of the paper quoted in ref. 1.