NEUTRON INELASTIC SCATTERING IN Pb 206 AND Pb 207

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ABSTRACT. Differential neutron inelastic scattering cross sections for individual states in Pb 206 and Pb 207 have been calculated on the basis of the Statistical theory of Hauser and Feshbach. Calculated excitation functions agree reasonably with experimental data for individual levels, except for the first excited stated of Pb 206. The agreement in general is closer at higher excitation energies as compared to the region nearer threshold. Factors likely to explain the lack of agreement observed are discussed.

INTRODUCTION

The study of neutron inelastic scattering cross sections of nuclei as a function of excitation energy can provide a good test for the Hauser-Feshback (1952) theory of inelastic scattering. It may also provide information regarding the spin and parity of individual states of the nuclei. The present work was undertaken to provide suitable interpretation to the available experimental data for the two lead isotopes.

In an earlier report (Gupta and Nath, 1961) we made similar calculations using the nuclear penetrabilities given by diffuse-edge potential well with only surface absorption (Emmerich, 1958). The calculated cross sections were found to be much larger than the experimental values for the first few levels of Pb 206. Van Patter and Jackiw (1960) and Jackiw *et al* (1961) have obtained much better fit in similar calculations for several even-even nuclei using the penetrabilities given by Bayster *et al* (1957) for a diffuse-edge potential with volume absorption. Beyster *et al* (1957) determined the parameters for their potential by fitting the experimental data on neutron total and differential elastic scattering individually for some twentysix elements from Beyrllium to Uranium over a wide energy range. They permitted much greater variation for the absorption parameter with excitation energy than was done by Emmerich (1958). We have therefore repeated the calculations for lead nuclei using Beyster's penetrabilities.

RESULTS

206*Pb* : Level scheme of 206Pb was adopted in accordance with the one published in Nuclear Data Sheets (Way 1965) and is indicated figure 1. As

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Boyster *et al* (1957) did not specifically fit the data for lead isotopes, we suitably interpolated nuclear penetrabilities given by them for the neighbouring nuclei of Au and Bi to get the ones for Pb. This resulted in a general lowering of the calculated cross section closer in agreement with experimental data.

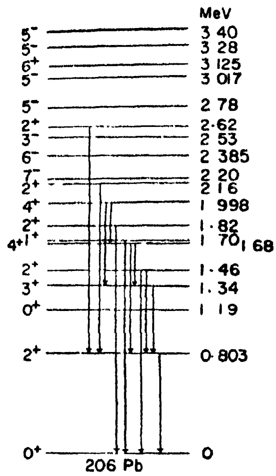

Figure 1. Level scheme adopted for 206 Pb.

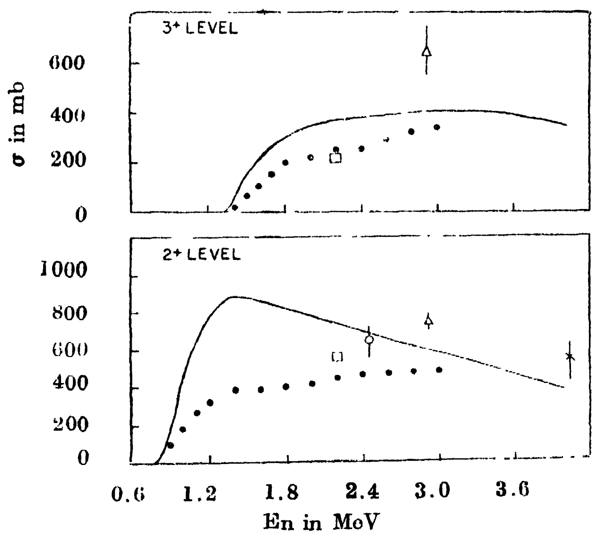

Figure 2. 0.803 and 1.34 MeV level (n, n') cross sections—(Closed circles) Lind and Day, 1961; (open circle) Cranberg *et al*, 1956; (Square) Landon et al, 1958, (Triangle) Boring *et al*, 1961; (Cross) Nellis *et al*, 1962.

Figures 2 through 4 show the results of our calculations for the excitation of 0.803, 1.34, 1.45, 1.72, 2.16 and 2.62 Mev levels as solid curves while the experimental results are indicated as explained in the caption for these figures. The 0.803 and 0.538 Mev gamma ray production cross sections corresponding to the excitation of 0.803 and 1.34 MeV levels have been corrected for the known cascades from higher states in order to derive the level cross-sections. The second 2^+ level at 1.46 MeV results in two de-excitation gamma-rays of energies 1.46 and 0.665 MeV. The level cross section is thus obtained by adding the two gamma ray the ground state transition from 1.82 MeV level and the decay of 2.62 MeV level to 0.803 MeV level. Therefore, the cross section for the 2.62 MeV level was obtained from the production cross section of 1.82 MeV gamma ray by subtracting the extrapolated contribution for the 1.82 MeV ground-state transition above the threshold for the 2.62 MeV state. It was found (figure 4) that there is a reasonably good agreement between the experimental data so obtained and the theoretical calculations for the 2.62 MeV level. However, disagreement was obtained for the 1.82 MeV level (excitation function not shown in figure 3) Nellis *et al* (1962) observe a gamma ray of 2.62 MeV in addition to the 1.82 MeV

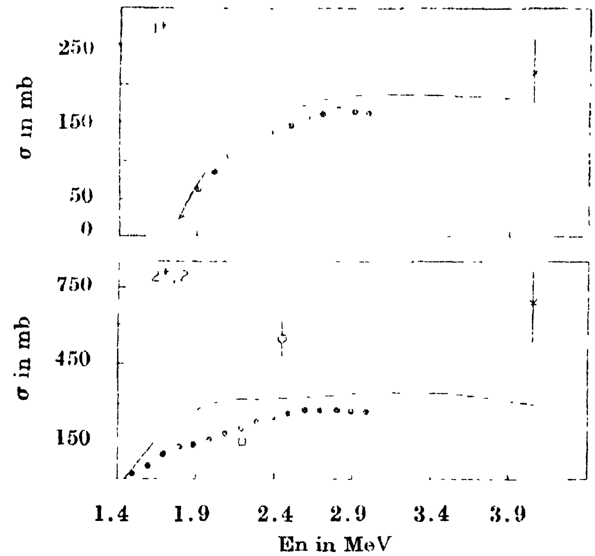

Figure 3. 1.46 and 1.72 MeV level (n, n') cross sections. Experimental data points same as in fig. 1.

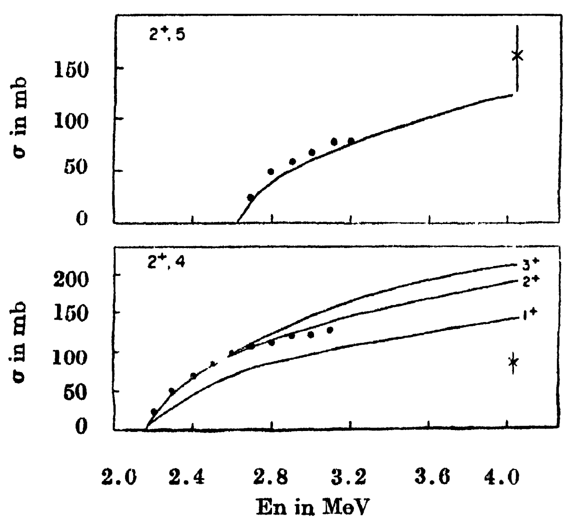

Figure 4. 2.16 and 2.62 MeV level (n, n') cross section (circles) Lind and Day, 1961; (cross) Nellis *et al*, 1962.

one observed earlier by Lind and Day (1961). We find that if we combine the experimental cross section for these two gamma rays, it agrees well with the similarly combined theoretical cross sections for inelastic scattering to the 1.82

and 2.62 MeV levels. No corrections were applied to the experimental data on the corresponding yield of gamma-rays to work out experimental cross sections for the 1.70 MeV and 2.16 MeV levels.

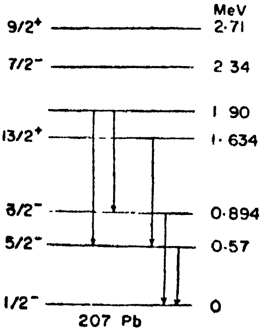

Figure 5. Level scheme for 207 Pb.

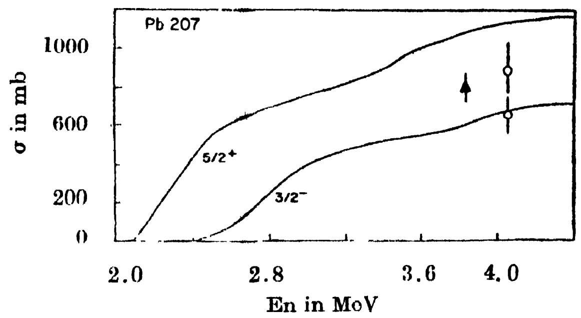

Figure 6. 0.57 and 0.894 MeV level (n, n') cross sections. (circle) Day, 1956; (triangle) Salnikov, 1958.

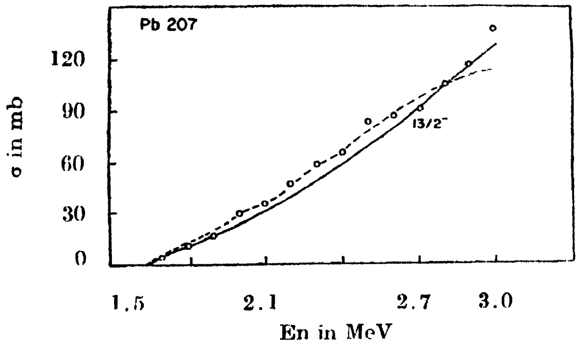

Figure 7. 1.63 MeV level (n, n') cross sections. (circles) Stellson and Cambell, 1955; (dashed curve) Rothman and Van Patter, (1957), theoretical.

207 Pb : The individual level cross sections for this isotope were also calculated using penetrabilities given by Beyster *et al*, (1957). The level scheme adopted is shown in figure 5. The (n, n') cross section thus calculated are much lower than those obtained earlier using Emmerich's potential with only surface absorption (Gupta and Nath, 1961), especially near the threshold. The new results for the first three excited states are shown as solid curves in figures 6 and 7 along with the experimental values. For the first two levels at 0.57 and 0.90 MeV, the experimental values of gamma ray production cross section obtained by Day (1956) following neutron scattering at incident energy of 2.56 MeV indicate good agreement. Another isolated measurement due to Salnikov (1958) at incident energy of 2.34 MeV for the 0.57 MeV state is also in reasonable agreement with the present calculations. Unfortunately, data for complete excitation function for 0.57 and 0.90 MeV states does not exist. Stollson and Campbell

(1955) have measured the $(n, n' \gamma)$ cross section with $\pm 40\%$ error for the 1.63 MeV isomeric state upto incident neutron energy of 3.2 MeV. The agreement of their data with our calculation is good as shown in figure 7. It is an improvement over our earlier calculations (Gupta and Nath, 1961). Rothman and Van Patter (1957) also obtained closer agreement with Stellson's data on the assumption of a strong interaction potential model. However, in their calculation the parameters of the potential-well were chosen on the basis of Stellson's data itself. The close agreement obtained here considering that the penetrabilities were obtained through interpolation of the values for neighbouring nuclei, indicates reliability for Beyster's parameters even for lead.

DISCUSSION

In the case of Pb 206 close agreement is obtained between the calculated and the experimental values of level cross sections for the 1.72 and 2.62 MeV levels. For the 2.16 MeV level the agreement is better with a 2^+ spin as compared to either 1^+ or 3^+, indicating there-by that this is most probably a 2^+ level. The agreement for the 1.46 and 1.34 MeV levels is not quite satisfactory. The 2^+ level at 0.803 MeV Still shows a marked disagreement at lower incident energies.

Lind and Day (1961) had indicated close agreement between their experimental results and the theoretical calculations they made by making an arbitrary choice for the imaginary part W of the Optical potential. However, their comparison indicates that the best fit to the excitation function for the 0.803 MeV level do not provide as good an agreement for the other levels. Towle and Gilboy (1965) used similar arbitrary value for W to fit their results of inelastic scattering on Pb208. However, Auerbach and Moore (1964) obtained satisfactory fit to the Pb 208 data without any need for an arbitrarily low value of W.

We feel that the discreponcies still left especially the ones for lowlying states at incident energies closer to their thresholds may be substantially reduced if level-width fluctuations as proposed by Moldauer (1961) are taken into account. Also, disagreements for levels with low spin values, e.g. 0^+ and 2^+ states at 1.19 and 1.46 MeV, may get reduced if corrections due to anisotropy in the angular distribution of gamma-rays from these states are considered. Any uncertainties about the nuclear level schemes can also cause ambiguities in the comparisons between the experimental data and theoretical values.

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