STUDIES OF EXCITED STATES IN ^{208}Pb BY INELASTIC PROTON SCATTERING AT 135 AND 100 MeV

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Differential cross sections have been measured for the reaction ^{208}Pb(p,p')^{208}Pb at 135 MeV leading to the following excited states in ^{208}Pb: 3^-(2.615 MeV), 5^-(3.198 MeV), 5^-(3.709 MeV), 2^+(4.086 MeV), 4^+(4.323 MeV), 6^+(4.424 MeV), 8^+(4.608 MeV), 10^+(4.882 ± .015 MeV), 10^+(5.071 ± .007 MeV), 12^+(6.076 ± .023 MeV), 12^-(6.415 ± .013 MeV), 14^-(6.727 ± .015 MeV), and 12^-(7.037 ± .007 MeV). A sample spectrum is shown in Fig. 1. The data on the natural-parity states, together with a collective-model analysis, have been presented in a paper in Physics Letters[1]. Collective model analyses have been performed earlier for (p,p') excitation of several of these states at lower incident energies. At higher beam energies it is found that deformed spin-orbit contributions play a much more important role, that differences in the ratios of the central and spin-orbit coupling parameters are needed for different states of the same spin and parity, and that for the states of highest J the collective model fails to provide a satisfactory description of the differential cross sections. On the other hand, for the states of J $\lesssim$ 6, the deduced central coupling parameters are in good agreement with those found at lower bombarding energy. The collective model calculations are compared with the data in Fig. 2, and the derived coupling parameters are listed in Table I.

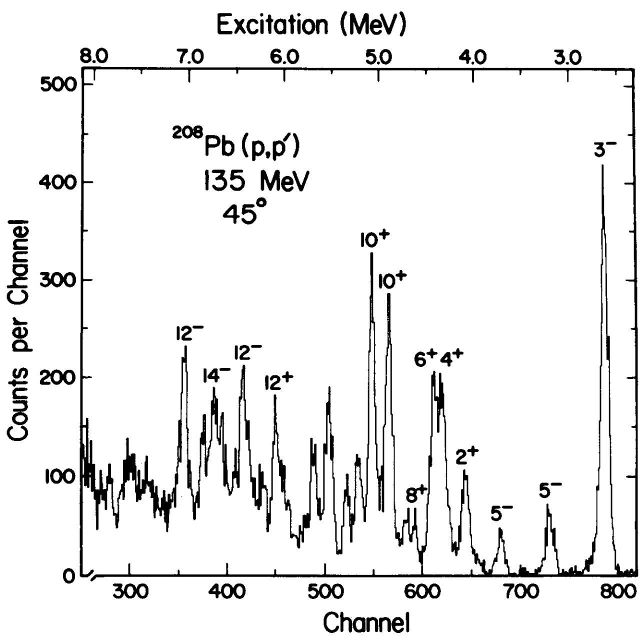

Figure 1. Inelastic proton spectrum at θ_{lab} = 45°. The peaks of interest are labelled by their spins and parities.

In a second paper, also to appear in Physics Letters[2], a microscopic interpretation of the data on the same natural-parity states is presented. A distorted-wave impulse approximation is used, with transition densities taken from electron inelastic scattering results. The t-matrix interaction of Love[3], derived from free nucleon-nucleon scattering at the same energy, is used, and exchange is included in the knock-on approximation. The results of the calculations are in good agreement with the data, even in those high-J cases where the collective model fails, and it is especially noteworthy that the sharp reduction in the central-force contributions to the higher-spin states (and the resulting relative importance of the spin-orbit terms in the t-matrix) comes about naturally

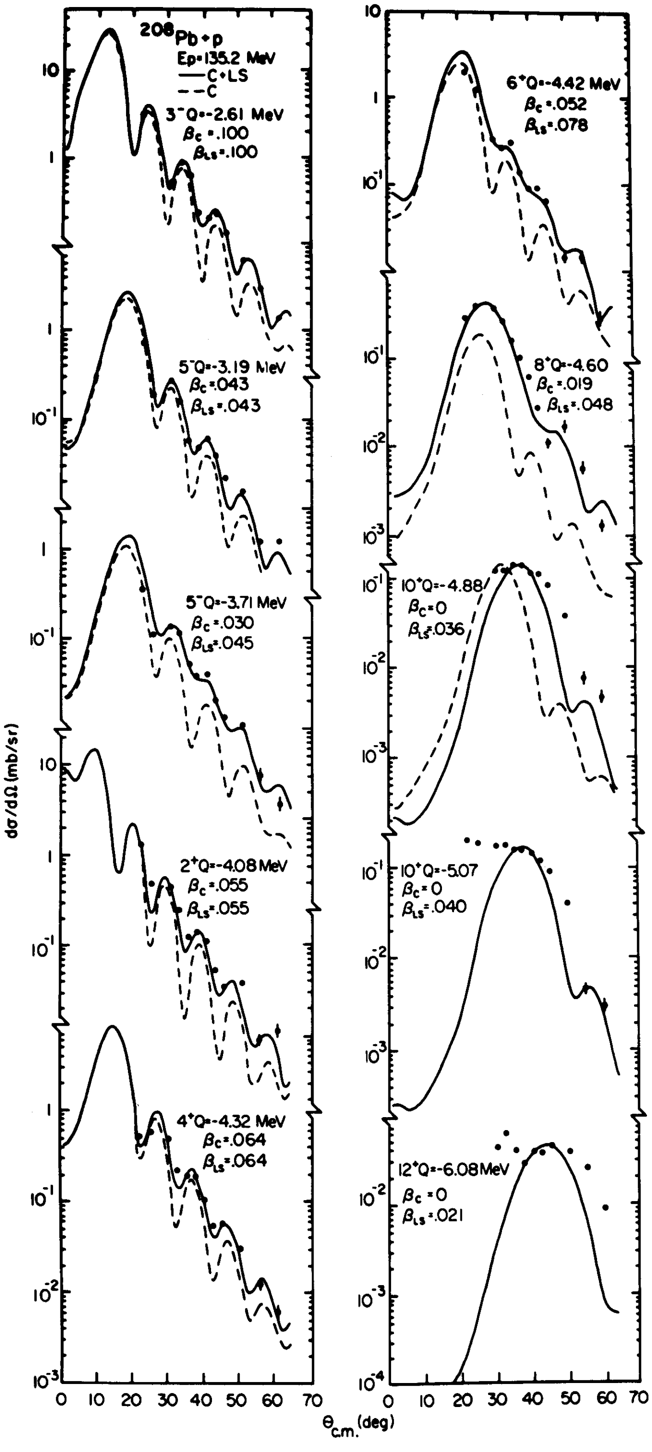

Figure 2. Comparison of experimental cross sections with collective model calculations for excitation of low-lying normal parity levels in ^{208}Pb by 135 MeV protons. C + LS and C are cross sections with and without DSO contributions. β_C and β_{LS} are central and DSO deformation parameters. For the 10_1^+ excitation ($Q= -4.88$ MeV) where β_C has been determined to be 0, the central only curve has been normalized to the peak experimental cross section in order to exhibit the difference in peak angle between the C and LS contributions.

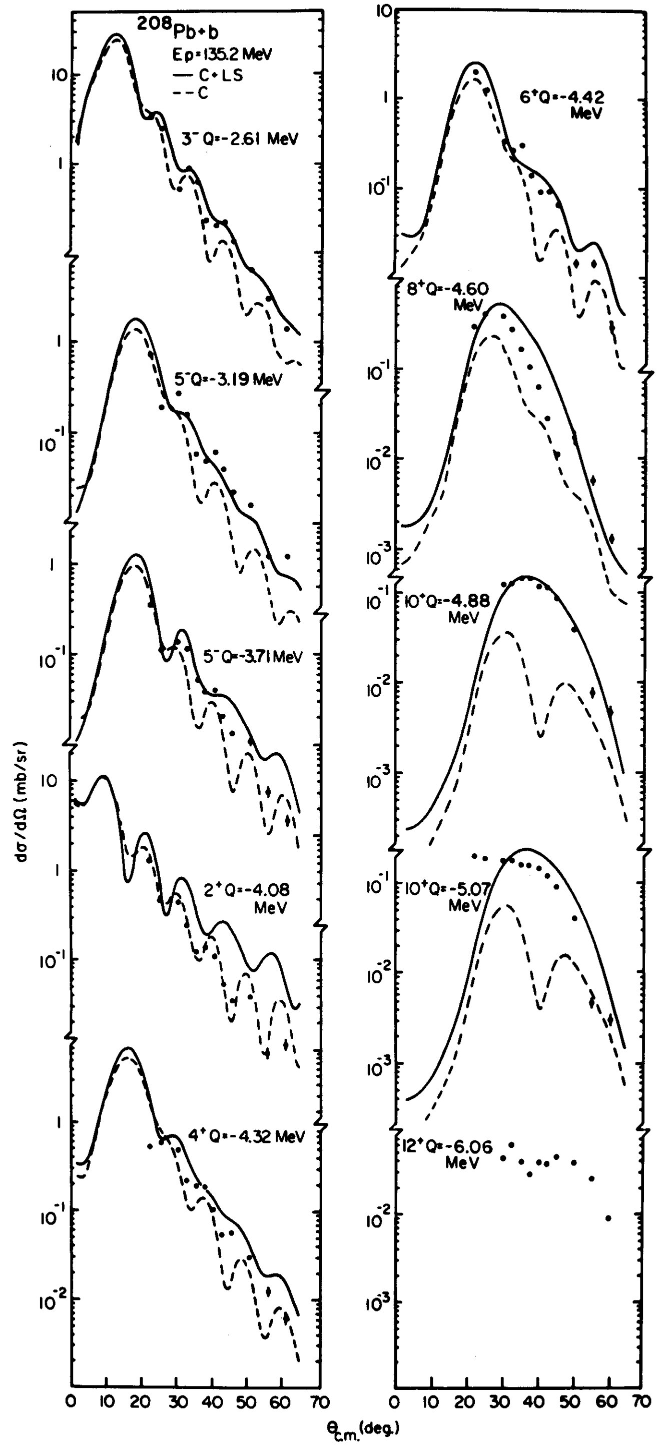

Figure 3. The proton transition densities obtained from electron scattering for the J=2 to 10 normal parity transitions in ^{208}Pb and the moduli of the components of complex t-matrix interaction[6] which contribute with no spin-transfer to the target. Both ρ_p and v are shown in momentum space. C and LS denote central and spin-orbit, respectively. Knockout exchange contributions are included in v.

Table I. Deformation parameters (β) for the $^{208}Pb(p,p')^{208}Pb$ reaction

E_x(keV)	J^π	E_p(MeV) 135.2[a,f]	61.2[b,g]	54[c,g]	35[d,g]	24.5[e,g]
4082 ± 5	2^+	.055(.055)	.055	.058	.058	.050
2610 ± 9	3^-	.100(.100)	.103	.11	.120	.108
4315 ± 10	4^+	.064(.064)	.064	.069	.067	.063
3193 ± 13	5^-	.043(.043)	.044	.055	.058	.074
3709 ± 10	5^-	.030(.045)	.032	.035	.034	.035
4417 ± 9	6^+	.052(.078)	.057	.064	.062	.059
4604 ± 8	8^+	.019(.048)	.040	.039	.040	.045
4882 ± 15	10^+	.000(.036)	--	.022	.027	--
5071 ± 7	10^+	.000(.040)	--	.030	.039	--
6076 ± 23	12^+	.000(.021)	--	--	--	--

a) Present work.

b) A. Scott, N.P. Mathur, and F. Petrovich, Nucl. Phys. A285, 222 (1977).

c) M. Lewis, F. Bertrand, and C.B. Fulmer, Phys. Rev. C7, 1966 (1973).

d) W.T. Wagner, G.M. Crawley, G.R. Hammerstein, and H. McManus, Phys. Rev. C12, 757 (1975).

e) J. Saudinos, G. Vallois, O. Beer, M. Gendrot, and P. Lopato, Phys. Lett. 22, 492 (1966).

f) β_C is listed first with β_{LS} given in parenthesis.

g) Only β_C is listed. The DSO contributions were not included in the calculations.

as an effect associated with the short-range repulsion in the central t-matrix. A comparison of the momentum-transfer dependence of the transition densities with that of the various relevant terms in the t-matrix is shown in Fig. 3, and the quality of the agreement between the DWIA calculations and experiment is shown in Fig. 4.

A systematic comparison[4] between the excitation of stretched-spin states using both electron and proton inelastic scattering indicates that while the shapes of the angular distributions are well described by the theory, an overall renormalization factor ($\sim$ 0.3 - 0.5) is required to reproduce the data. The similar magnitude of this factor for both electron and proton probes for a given transition strongly suggests that this factor arises from nuclear structure effects, perhaps from effects such as ground state correlations. The 14^- transition in ^{208}Pb, which corresponds to a stretched neutron particle-hole excitation, exhibits a similar behavior with a common renormalization factor of $\sim$ 0.5 for both electron and proton inelastic scattering. However, it is already apparent that the two 12^- states require quite different renormalization factors from those observed with (e,e'). One possible explanation for this anomaly is that the two 12^- states observed are linear combinations of the two proton and neutron particle-hole configurations available. Such an explanation would require an amplitude mixing parameter of ∿ 0.4. This observation, however, appears to be inconsistent with an analysis of the (e,e') data for the same states which requires very little configuration mixing.

Since many of the excited states of interest occur in a region of high level density in ^{208}Pb, and since the minimum line width obtained in the 135 MeV experiments was about 65 keV, the ^{208}Pb experiments were repeated at a bombarding energy of 100 MeV, where the line width could be reduced to about 40 keV. No qualitative differences in the spectra were observed, increasing our level of confidence in the analyses at 135 MeV. Work has continued at 100 MeV where the improved resolution will enable the study of additional inelastic transitions. A complete set of analyzing power measurements, using the IUCF polarized proton beam, has now been completed at 100 MeV, covering the excitation-energy range 0-8 MeV and the angular range 7.5^o to 75^o. Analysis of these data is in progress. Of particular interest are the analyzing powers for the excitation of the two 12^- states for which calculations indicate a sensitivity to the degree of configuration mixing.

The third-excited state in ^{208}Pb at 3.475 MeV, which is a 4^- state with a well-known (primarily neutron) particle-hole wave function, is weakly excited in all inelastic scattering reactions. This state is of interest since its weak excitation suggests it may be a good case in which to study possible contributions from two-step processes of the (p,d,p') type. Some recent discussions of nuclear critical opalescence[5] have led to predictions that the cross section for this state should be enhanced, possibly by a large factor, near a momentum transfer of about 280 MeV/c. Cross sections are being extracted for the (p,p') excitation of this state at both 100 and 135 MeV. Our preliminary analyses show no evidence for such an enhancement.

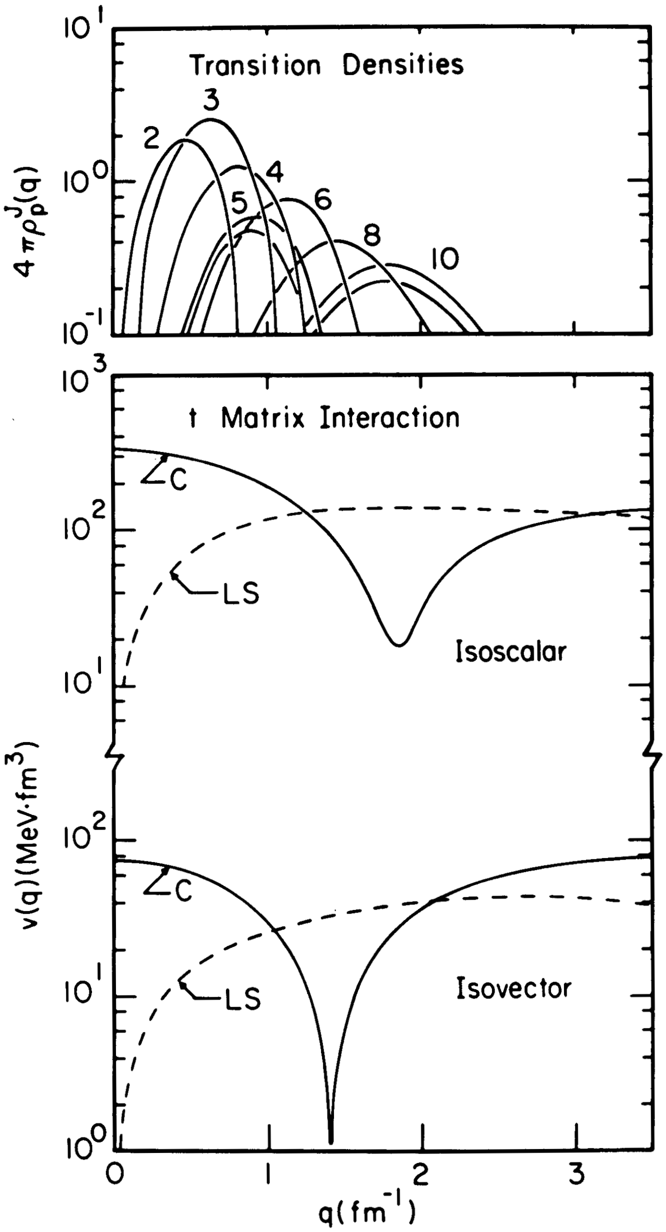

Figure 4. The results of DWIA calculations for normal parity transitions in ^{208}Pb. Results with (C+LS) and without (C) the spin-orbit interaction are shown separately. Note the decrease in the central contributions to the cross sections for transitions with $J \geq 8$.

1) G.S. Adams, A.D. Bacher, G.T. Emery, W.P. Jones, D.W. Miller, W.G. Love, and F. Petrovich, to be published in Phys. Lett. (1980).

2) F. Petrovich, W.G. Love, G.S. Adams, A.D. Bacher, G.T. Emery, W.P. Jones, and D.W. Miller, to be published in Phys. Lett. (1980).

3) W.G. Love, A. Scott, F.T. Baker, W.P. Jones, and J.D. Wiggins, Phys. Lett. 73B, 277 (1978); W.G. Love,

in The (p,n) Reaction and the Nucleon-Nucleon Force, ed. by C. Goodman. S. Austin, S. Bloom, J. Rapaport, and G. Satchler (Plenum, New York, 1980), p. 23; F. Petrovich, ibid, p. 115.

4) R.A. Lindgren, W.J. Gerace, A.D. Bacher, W.G. Love, and F. Petrovich, Phys. Rev. Lett. 42, 1524 (1979).

5) S. Fayans, E.E. Saperstein, and S.V. Tolokonnikov, Nucl. Phys. A326, 463 (1979); I.V. Kurchatov Atomic Energy Inst. Report IAE-3254 (Moscow, 1980).

6) A. Scott, N.P. Mathur and F. Petrovich, Nucl. Phys. A285, 222 (1977).

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