Title

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ABSTRACT

The inelastic scattering of protons from ^{58}Ni and ^{60}Ni is compared with the results of a coupled-channel scattering calculation using a microscopic nuclear description. Comparison with DWBA results shows the necessity for a full coupled-channel treatment. We show that this kind of analysis provides a sensitive test of nuclear wave functions. Suggestions for improving the wave functions of these nuclei are made.

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The main thrust of the theory of nuclear structure in the last years has been directed toward obtaining a detailed understanding of the microscopic structure of nuclei. At this level all nuclear phenomenon, the collective as well as the single-particle aspects, are described in terms of the underlying nucleon motions and their correlations. The theoretical methods developed for this purpose have proven capable of explaining the energy level systematics and some of the prominent features of transition rates. A still more stringent test is provided by the analysis of inelastic nucleon scattering.

The nickel isotopes have been the subject of several of such detailed structure calculations. This note reports the experimental results for the scattering of protons on several of these isotopes, together with a calculation of the cross-sections based on the microscopic wave functions, using the coupled channel method. This method of solving the scattering problem is felt to be sufficiently good that we are testing only the nuclear structure and the effective two-nucleon interaction. Within the subspace chosen, the coupled channel method solves the problem to all orders in the interaction. That is to say, in the calculation of each inelastic cross section, the contribution of all indirect routes as well as the direct transition from the ground are included. We establish first that, in general, it is necessary to treat the problem by this method rather than relying on the distorted wave method, which neglects all save the direct transitions from the ground state. Figure 1 compares cross sections for protons scattered by ^{60}Ni calculated by the two methods. As expected, the DWB does fairly well for the collective 2^+ state since it is strongly coupled to the ground state by the scattered protons. However, for some of the non-collective states, for example the 0_2 and 2_3

levels, the coupling to other excited states is so strong as to fundamentally alter the results that would obtain for a direct transition alone.

We stress that in the cross-section calculation we regard only one parameter as free, the strength of the direct interaction between scattered proton and neutrons in the target. The range of the interaction is roughly known, so a fixed value of 1.85 F was adopted. In principle, the optical model parameters are also free, but except in the case of very strong coupling, they can be fixed by the elastic scattering cross-section. For these parameters we adopt values obtained previously for 17 MeV protons, except that the spin-orbit term is here neglected. The inelastic cross sections are not very sensitive to changes that do not drastically alter the elastic.

Protons of 17.6 and 17.8 MeV were scattered respectively from targets of ^{58}Ni and ^{60}Ni. Energy spectra of scattered particles were measured with Si(Li) detectors at an energy resolution of 45 keV and 30 keV respectively. Some of the experimental angular distributions are shown in Figure 2. The energies of the second and third 2+ levels have not previously been established for ^{58}Ni. The assignments shown in Figure 2 (2+ levels at 3.035 MeV and 3.260 MeV) were made by a study of the scattering of 50 MeV helium ions by ^{58}Ni. The angular distributions of these two levels gave shapes identical with the angular distribution for the first 2+ level. However, the levels at 2.899 and 2.939 MeV were too weakly excited in inelastic scattering of helium ions to permit accurate angular distributions to be measured: it is therefore possible that one or both of these are 2+ levels. Indeed the 2.899 MeV level has been assigned $J\pi = (1,2)+$.[1]

The nuclear structure calculation that we are testing is that of Arvieu, Salusti, and Veneroni.[2] They diagonalize the nuclear Hamiltonian in a subspace of two quasiparticle configurations. This treatment can describe the collective states that would correspond to the one-phonon states of the vibrational model. Comparing the calculated and observed cross sections shown in the figure for the 2_1 state suggests that the microscopic description of this state is fairly good. However the limitation to two-quasiparticle configurations means that there are no states in their calculations that correspond to the two-phonon states of the vibrational model. There does not yet exist very strong evidence for harmonic vibrations in the nickel isotopes although some degree of harmonicity is expected. This being absent in the calculations, there is a problem in deciding to which of the many levels above the collective one, the calculated levels correspond. In Figure 2 we show the most prominent experimental cross sections for levels whose spins are known. The calculated and experimental angular distributions for levels of the same spin are shown superimposed in the order in which they occur in the theoretical and experimental spectra respectively. For ^{58}Ni, the microscopic theory does fairly well in describing the cross-section to the second 2+ level. However the calculated cross section for the third 2+ is much smaller than observed. Evidently there is a good deal more strength going into these 2+ levels than the theory describes. This suggests that there is some two-phonon character in this state, or possibly distributed over several of the 2+ states in this region. Such an admixture would probably enhance the total transition strength to the 2+ states by virtue of the strong coupling between the one and two-phonon states. The calculated 2_3+ level in ^{58}Ni should possibly be identified with one of the weak unresolved levels around 2.9 MeV. The two-quasiparticle description of the 0_2 and 4_1 levels accounts correctly for the observed magnitude of the cross sections, and to some degree, their angular distributions.

Turning to ^{60}Ni the collective 2_1^+ state again is fairly well described. However the transition strength to the two higher 2+ states is not correctly shared. The microscopic description accounts reasonably well for the 4_1^+ cross section, but the description of the 0_2 seems faulty.

As mentioned earlier, we regard only one parameter in this calculation as being adjustable, V_0, the strength of the spin independent part of the direct interaction. This parameter has the value 60 MeV and 50 MeV for the mass 58 and 60 isotopes respectively. While the effective interaction that should be used is as yet unknown, it will surely be a strongly renormalized force for a structure calculation made in a highly truncated space. In the structure calculations tested here, the closed shells at 28 were regarded as inert. The degree to which this assumption is valid may of course be different for the two isotopes discussed here and can possibly account for the different strengths of the interactions noted above.

In spite of this uncertainty in our analysis, we believe it raises several implications for the structure theory. First it is highly desirable to remove some of the uncertainty in renormalization effects by including in some way the participation of the core in the correlations of the extra core nucleons. Second the coherent collective states seem to be reasonably well described by the two-quasiparticle approximation, but the inclusion of four-quasiparticle configurations seems high desirable for a more complete description of the higher states.

REFERENCES

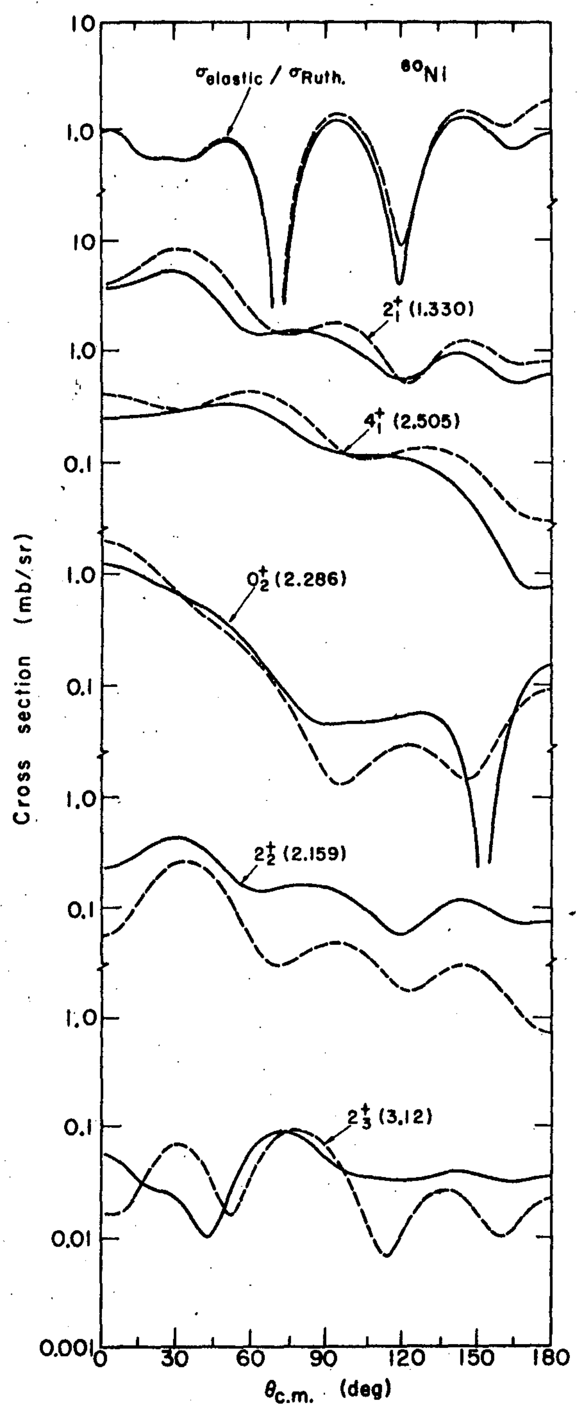
1. D. C. Sutton, H. A. Hill, and R. Shaw, Bull. Am. Phys. Soc. 4, 278 (1959).

2. R. Arvieu, E. Salusti, and M. Veneroni, Phys. Letters 8, 334 (1964).

FIGURE CAPTIONS

Fig. 1. The coupled channel (solid line) and DWB (dashed line) calculations for 17.8 MeV protons on ^{60}Ni are compared.

Fig. 2. Observed proton cross sections for low lying prominent levels of ^{58}Ni and ^{60}Ni are compared with calculations based on a microscopic nuclear description using the coupled channel method.



σelastic / σRuth.
60Ni
2_1^+ (1.330)
4_1^+ (2.505)
0_2^+ (2.286)
2_2^+ (2.159)
2_3^+ (3.12)
Cross section (mb/sr)
θc.m. (deg)
10
1.0
10
1.0
0.1
1.0
0.1
1.0
0.1
1.0
0.1
0.01
0.001
0
30
60
90
120
150
180

Fig. 1

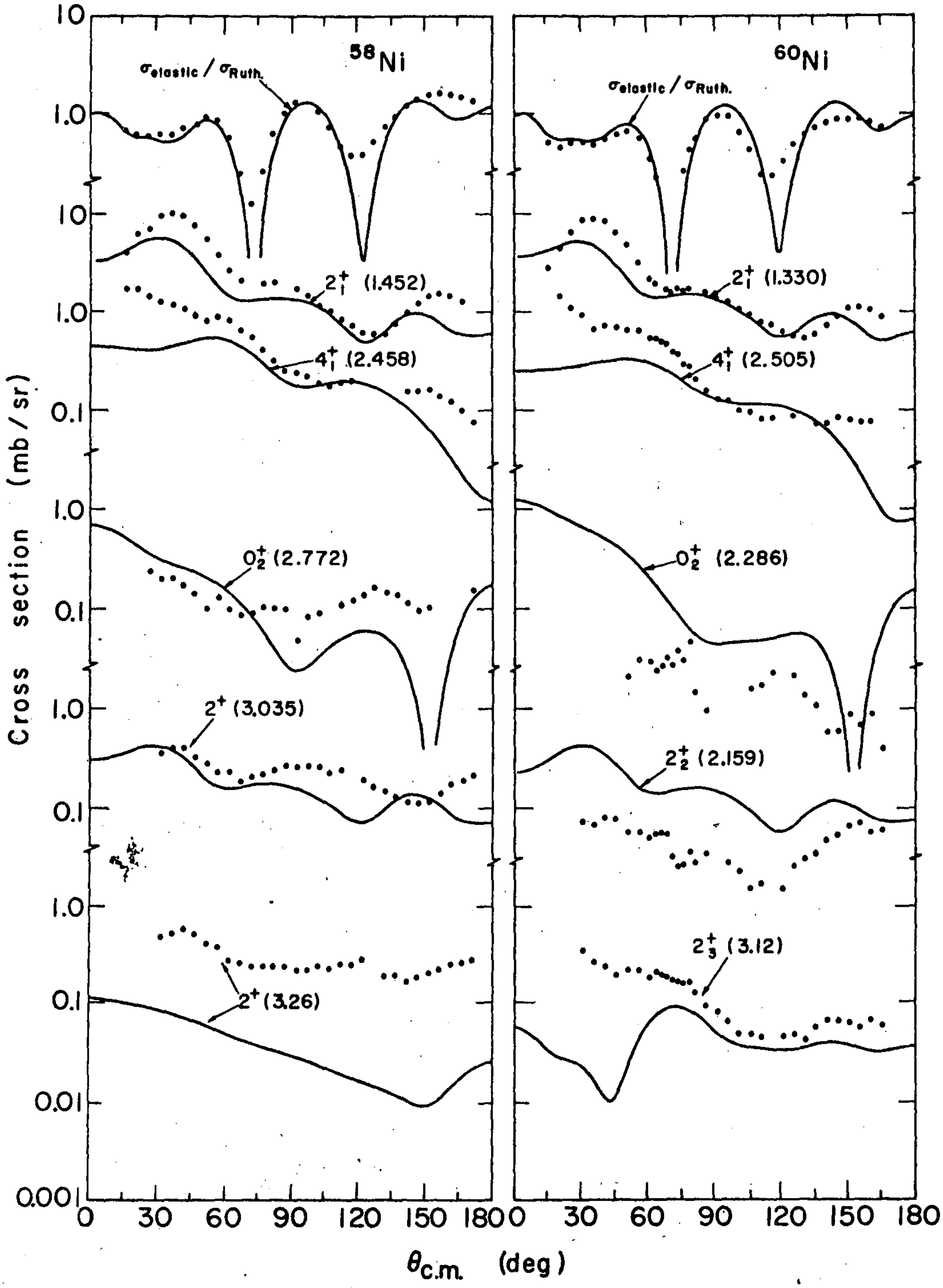

^{58}Ni
^{60}Ni
$\sigma_{elastic}/\sigma_{Ruth.}$
2_1^+ (1.452)
4_1^+ (2.458)
0_2^+ (2.772)
2^+ (3.035)
2^+ (3.26)
2_1^+ (1.330)
4_1^+ (2.505)
0_2^+ (2.286)
2_2^+ (2.159)
2_3^+ (3.12)
Cross section (mb / sr)
$\theta_{c.m.}$ (deg)

Fig. 2