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MICROSCOPIC COUPLED - CHANNEL STUDY OF INELASTIC PROTON SCATTERING FROM ^{20}Ne

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TECHNICAL PAPER presented at
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ABSTRACT

An attempt has been made to explain proton inelastic scattering from Ne^{20} using projected Hartree-Fock wave functions. A coupled channel calculation has been carried out with the explicit inclusion of at least the 0^+, 2^+, and 4^+ members of the ground state rotational band. A comparison is made with experiment and with DWBA predictions for the same reaction. Also studied is the effect on the cross sections of truncating the basis space used for the Hartree-Fock states.

INTRODUCTION

Considerable effort has been expended recently in attempts to provide microscopic descriptions of nuclear states which exhibit collective properties. The most detailed investigations, of a microscopic nature, have been made for the light deformed nuclei in the 2s-1d shell. Physical states of interest for these nuclei have been obtained by use of the Hartree-Fock (HF) method of deformed orbitals followed by projection of states of good angular momentum. The use of such wave functions in the prediction of nuclear structure properties, has provided considerable insight into their inadequacies. The prediction of cross sections for inelastic scattering of nucleons also provides a test of the wave functions. Unfortunately the only completely microscopic studies of inelastic scattering have been made using DWBA.[1] Although it is true that the DWBA may be adequate for the lowest, strongly excited states, other studies indicate that the method of coupled channels (CC) is required if one hopes to obtain meaningful results for excited states in the higher energy region. Thus, while the use of CC provides a good test of the reliability of DWBA for scattering to the lowest lying collective states, it also enables one to examine various aspects of the structure problem with greater confidence. Another important aspect of this approach is that it becomes possible to draw more reasonable conclusions with regard to the relation between the macroscopic and microscopic models.

In this article we compare the results of CC and DWBA studies of inelastic proton scattering from ^{20}Ne, using projected HF wave functions. The nuclear structure problem is examined by varying the size of the basis space in the HF problem.

DISCUSSION

The intrinsic HF states were obtained using a six-state H.O. basis ($1s_{1/2}$, $2s_{1/2}$, $1d_{3/2}$, $1d_{5/2}$, $1p_{1/2}$, $1p_{3/2}$) and a fifteen-state H.O. basis, i.e., shell model states up through $1g_{7/2}$. The oscillator parameter is chosen so that the projected RMS radius agrees with experiment. The radius and E2 rate for ^{20}Ne may be found in table I. The CC treatment of inelastic scattering has been made by Glendenning.[2] Essentially, the problem consists of the solution of the set of coupled differential equations

$$\left[\frac{\hbar^2}{2m}\left(\frac{d^2}{dr^2} - \frac{\ell'(\ell'+1)}{r^2}\right) - U_{opt}(r) + E'_c\right] u_{c'}^{C\pi I}(r)$$

$$= \sum_{c'' \neq c'} \left\langle \phi^M_{C'\pi I} \middle| V \middle| \phi^M_{c''\pi I} \right\rangle u_{c''}^{C\pi I}(r)$$

subject to the boundary conditions that there are incoming spherical waves in the elastic channel and outgoing waves in all other channels.[2] If the interaction, V, can be expanded in irreducible tensors, then it can be shown that

$$\left\langle \phi^M_{c'\pi I} \middle| V \middle| \phi^M_{c''\pi I} \right\rangle = \sum_{LSJ} G^{\pi I}_{LSJ}(c', c'')\; V_s \left\langle \alpha_2 J_2 \middle\| \mathcal{J}_{LSJ} \middle\| \alpha_1 J_1 \right\rangle$$

where $(\alpha_1 J_1)$ and $(\alpha_2 J_2)$ refer to the initial and final nuclear states, respectively. The reduced matrix elements of $\mathcal{J}_{LSJ}$ (i.e., nuclear form factors) have been discussed in detail by Braley and Ford for the case in which the nuclear states are represented by projected HF wave functions.[1] The potential $U_{opt}(r)$ is an optical model parameterization of the diagonal elements of an effective interaction.[2] In this study, the proton-nucleus interaction, V, is taken to be

$$V(r) = -52.0\ e^{-(r/1.85)^2}\ (P_{TE} + 0.6\ P_{SE})$$

This interaction has been used previously in microscopic DWBA studies.[1] The CC calculations were made using 12 partial waves. Table II lists the optical model parameters used for this calculation.

The predicted cross sections (0^+, 2^+, 4^+, 6^+) using DWBA and CC appear in Figs. I-IV. The fits to the (0^+) elastic scattering are satisfactory but some improvement might be obtained by additional searching on the optical parameters, although this is very time consuming for coupled channels. It is also observed that the elastic results are not affected significantly by enlarging the basis spaces. The predicted cross section for the (2^+) is seen to improve in magnitude as the number of basis states is increased; however, the shape is unaffected. As expected for the (2^+) state, the DWBA predictions are in quite good agreement with CC for such a strongly excited state. The excitation of the (4^+) and (6^+) states is much weaker than (2^+), and we see that the difference in magnitude between throey and experiment increases as the excitation energy becomes greater. For the (4^+) state the effect of increasing the number of basis states is to increase the magnitude of the predicted results. There are no (6^+) results for the 6 orbital basis since no two of the states have large enough angular momenta to couple to $J = 6$. The DWBA results for both of these states differ considerably from CC.

Let us now compare the 15 state coupled channel results with those obtained using the macroscopic model, and which are presented in Fig. 5.[3] We see that the shapes correspond very closely when the macroscopic study is made with $\beta_4 = 0$. However, the macroscopic calculation for which $\beta_4 = 0.28$ (β_4 is the hexadecapole deformation) improves considerably - especially for the 4^+ and 6^+ states. Thus, it would seem that we must find some means by which this effect may be simulated in the microscopic calculation. One very encouraging possibility is suggested by some recent work by Castel and Parikh on ^{28}Si. By a refinement of the usual HF minimization procedure, they were able to find a wave function which had both a lower ground state energy <u>and</u> an increase in hexadecapole deformation. A program to apply this technique to the more complicated wave functions which we employ is not being hotly pursued.

REFERENCES

1. R. C. Braley and W. F. Ford, Phys. Rev. 182, 1174 (1969).

2. N. K. Glendenning, Nucl. Phys. A117, 49 (1968).

3. R. de Swiniarski, et al, Phys. Rev. Letters 23, 317 (1969).

4. B. Castel and J. C. Parikh, private communication.

TABLE I

Basis	$\langle R^2\rangle^{1/2}$ fm.	B(E2; 0^+ - 2^+) $e^2\cdot fm.^4$
6 state	2.94	109.9
15 state	2.73	190.9
Experiment	2.79	286

TABLE II.†

V_o MeV	W_S MeV	V_{LS} MeV	r_o f_m	r_s f_m	r_{LS} f_m	a_o f_m	a_s f_m	a_{LS} f_m	r_c f_m
55.4	7.3	3.58	1.05	1.265	0.95	0.73	0.61	0.33	1.2

†Details regarding $U_{opt}(r)$ may be found in Ref. (1).

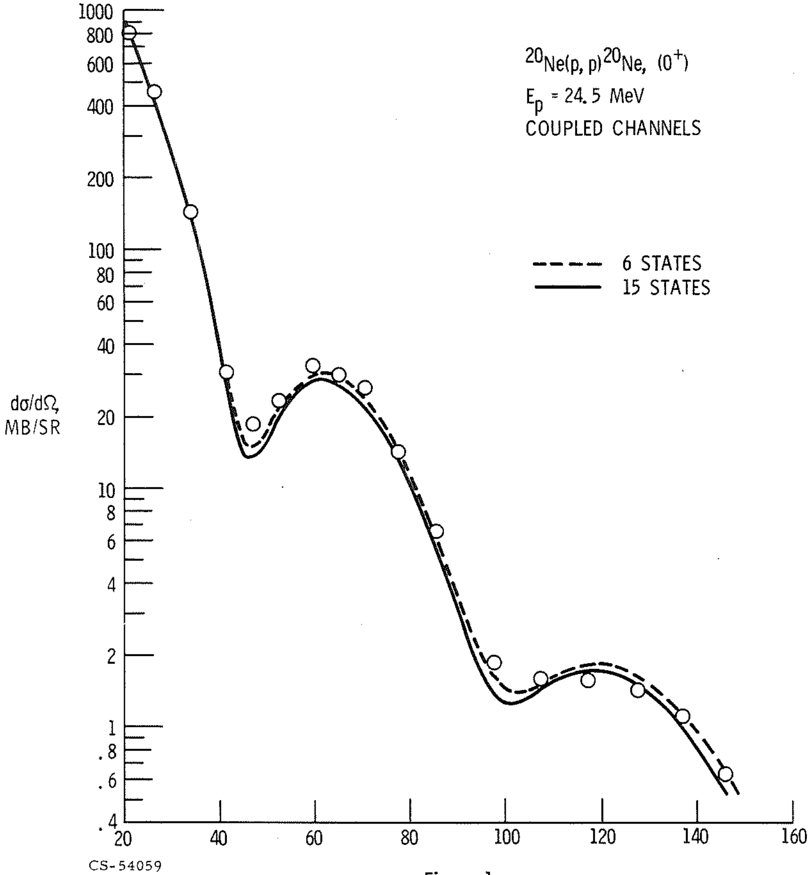

Figure 1

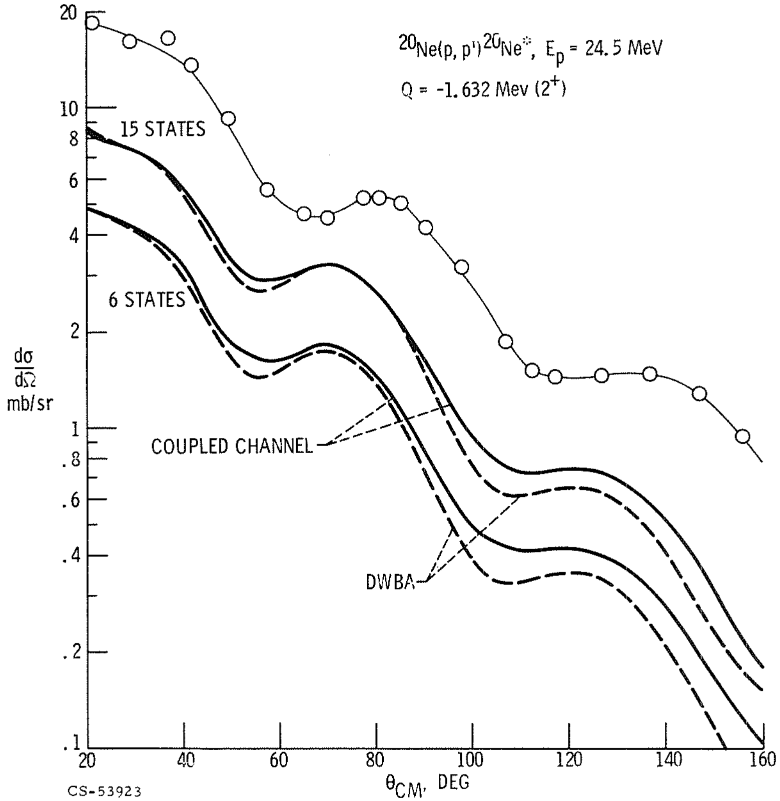

Figure 2

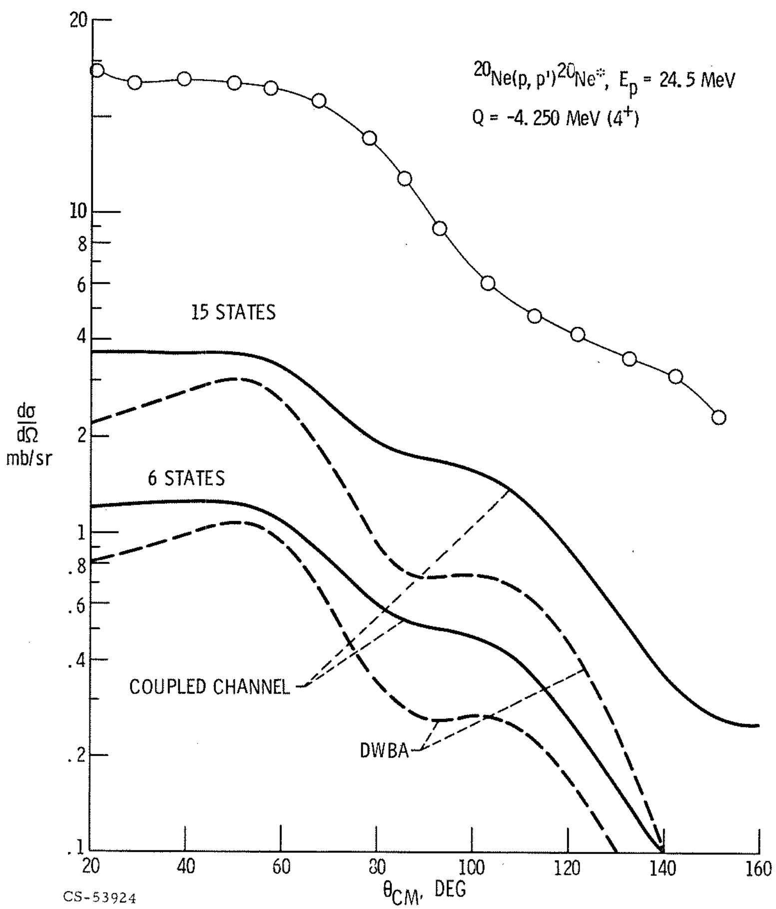

Figure 3

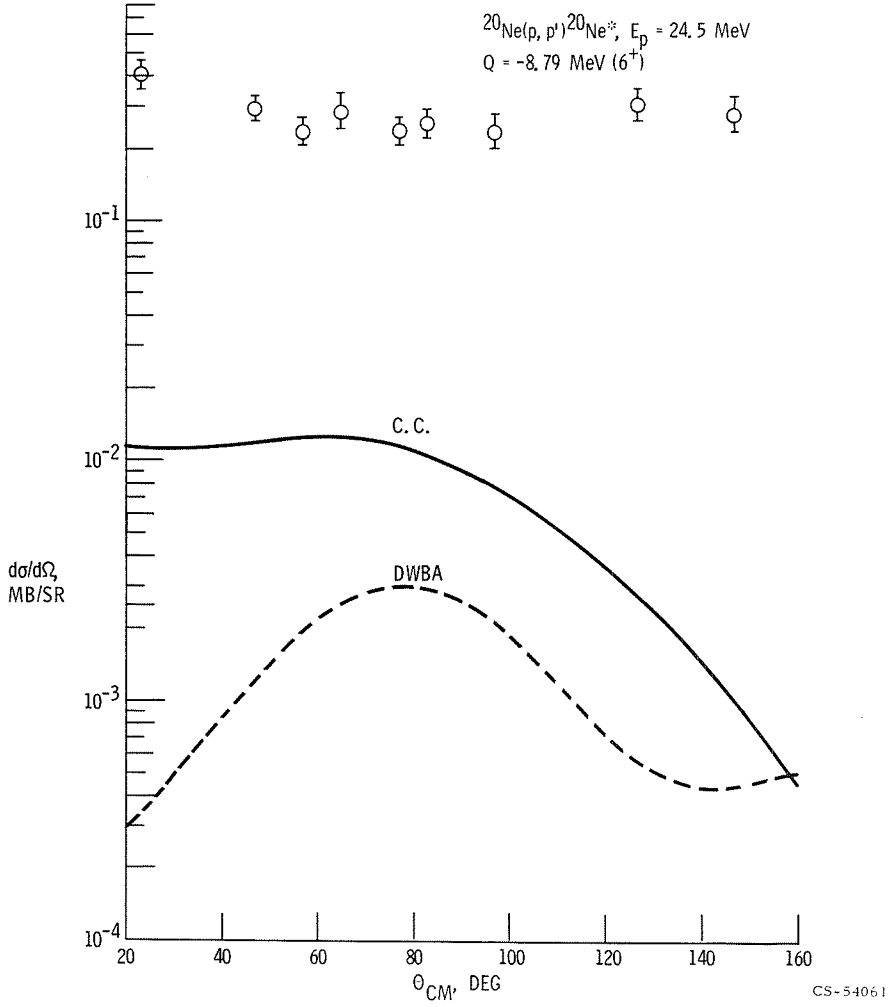

Figure 4

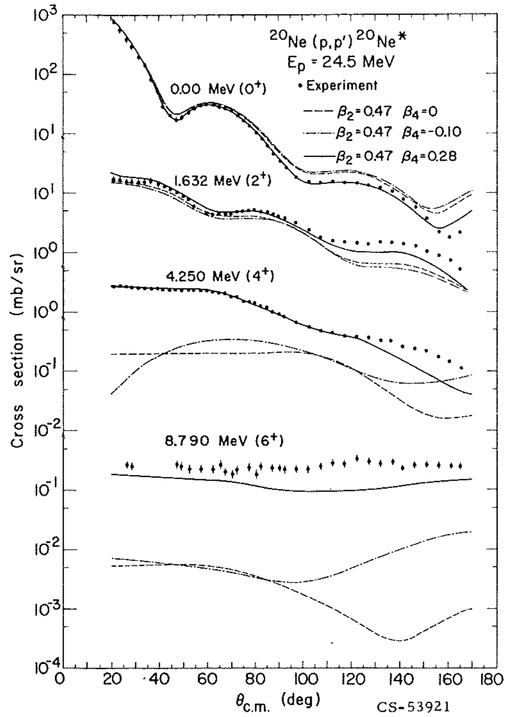
$^{20}Ne\ (p,p')\ ^{20}Ne^*$
$E_p = 24.5$ MeV
• Experiment
$\beta_2 = 0.47$ $\beta_4 = 0$
$\beta_2 = 0.47$ $\beta_4 = -0.10$
$\beta_2 = 0.47$ $\beta_4 = 0.28$
0.00 MeV (0^+)
1.632 MeV (2^+)
4.250 MeV (4^+)
8.790 MeV (6^+)
Cross section (mb/sr)
$\theta_{c.m.}$ (deg)
CS-53921

Figure 5