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Deformation and Spin 1 Effects

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Abstract

Elastic scattering measurables for 547 MeV proton scattering from ^{13}C are calculated using a nonrelativistic optical model potential in which deformation of the conventional Woods–Saxon forms of the real and imaginary central potentials is allowed, as well as incorporating spin 1 transfer contributions. The latter are estimated from folding a simple two nucleon *t*-matrix with a 0p-shell model wavefunction.

Microscopic models of optical model potentials for nucleon elastic scattering from nuclei have been made for use both in Schrödinger (nonrelativistic) equations (Rikus *et al.* 1984; Haider *et al.* 1988) and in Dirac (relativistic) equations (Murdock and Horowitz 1987). Both methods of data analysis, given the use of realistic two-nucleon *t*-matrices and nuclear density distributions, give good fits to differential cross sections and to analysing powers. Furthermore, it is possible to relate the scalar and vector potentials of the relativistic formulation to those of the nonrelativistic Schrödinger formalism (von Geramb *et al.* 1988), thereby explaining the strong energy dependences of the latter. The very success of these microscopic model calculations is indicative that, of the many approximations necessary to facilitate evaluations, none are traumatic. It is also evident that the radial variation of the nonrelativistic model potentials vary distinctively from that of the conventional, phenomenological optical potentials, i.e. of Woods–Saxon form.

But, to this day, data analysis made using phenomenological optical model potentials are the most convenient and are almost exclusively used in distorted wave approximation calculations of non-elastic measurables. In nonrelativistic model calculations we thus anticipate a strong energy dependence of the potential strengths and radial variations (to the standard Woods–Saxon forms) and with both due, at least in part, to relativistic effects. The former is a simple matter of adjustment of strengths to give a best fit to data, but the latter is not so easily accommodated within standard programs. Furthermore, the derived potential shapes from microscopic model studies may reflect quite strongly the chosen nuclear density function. Whatever the cause one can tune the usual nonrelativistic Woods–Saxon optical potentials by

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allowing non-spherical (deformation) contributions to the ground state density. With standard collective model prescriptions this leads to coupled equations which can be solved numerically using the program ECIS88 (Raynal 1988). The program incorporates within the elastic channel potential contributions of all orders from deformations. Thus, whatever the actual physical basis underlying the non-standard radial variation of the optical potential, the deformation corrections associated with coupled channels calculations are convenient representations. The size of these effects are studied here for the case of 547 MeV polarised protons scattering from ^{13}C.

The choice of reaction was made partly in anticipation of experiments being made using polarised targets, from which one can obtain data other than the usual differential cross sections and analysing power, and partly because ^{13}C has a spin–parity ground state of $\frac{1}{2}^-$. As a consequence there exist M1 contributions to elastic scattering and recent studies of electron scattering have shown that the M1 form factor is quite unusual and very sensitive to details of nuclear structure (Millener *et al.* 1989; Amos *et al.* 1989).

In an $(LS)J$ representation, there are two M1 contributions to elastic scattering, namely (01)1 and (21)1, and we used a very simple folding model with 0p-shell model wavefunctions (Amos *et al.* 1989) and the Love–Franey (1981) t-matrices to define contributions to the optical potential. For extreme simplicity, by using 0p-shell model wavefunctions, contact (delta function) t-matrices and harmonic oscillator wavefunctions, we have $S=1$ potentials of the form

$$U=-(a+\mathrm{i}\,b)r^2\exp(-0\cdot 39\,r^2)\,,$$

with strengths (a,b) of $(2\cdot 9, 1\cdot 1)$ and $(3\cdot 2, 1\cdot 2)$ for $L=0$ and 2 respectively. We have not sought to define more realistic form factors by using better t-matrices and nuclear density distributions or by accounting properly for antisymmetrisation for example, as our purpose at this stage is simply to suggest whether or not M1 contributions to p–^{13}C scattering ought to be considered in better data analyses.

We have used Woods–Saxon forms for the basic $(S=0)$ undeformed optical potential with parameter values that best fit the cross section and analysing power data.

Specifically, with form factors

$$f(r,R,a)=[1+\exp\{(r-R)/a\}]^{-1}\,,$$

the $U_{(00)0}$ potential for 547 MeV protons scattering from ^{13}C is

$$U_{(00)0}=-9\cdot 2f(r,2\cdot 67,0\cdot 33)-70\cdot 29\mathrm{i}\,f(r,1\cdot 99,0\cdot 55)$$
$$+(\hbar/m_\pi c)\bar{\boldsymbol{l}}\,.\bar{\boldsymbol{\sigma}}\{-1\cdot 76f'(r,2\cdot 36,0\cdot 478)/r+2\cdot 59\mathrm{i}\,f'(r,2\cdot 02,0\cdot 434)/r\}+V_C(r)\,.$$

Here primes denote differentiation with respect to r and $V_C(r)$ is the Coulomb potential of a uniformly charged sphere of radius $2\cdot 67$ fm.

Calculations have also been made with the central complex potential components corrected to all orders by allowing a quadrupole deformation in

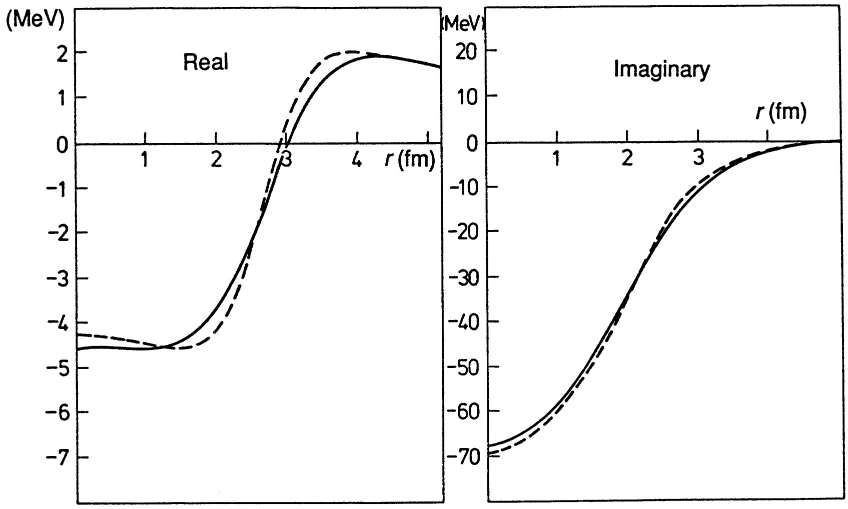

Fig. 1. Central real and imaginary optical potentials for 547 MeV protons on ^{13}C. The real potentials include the Coulomb contribution. The standard (Woods–Saxon) optical potentials are displayed by the dashed curves and when allowance is made for deformation ($\beta_2 = -0 \cdot 6$) the results are given by the solid curves.

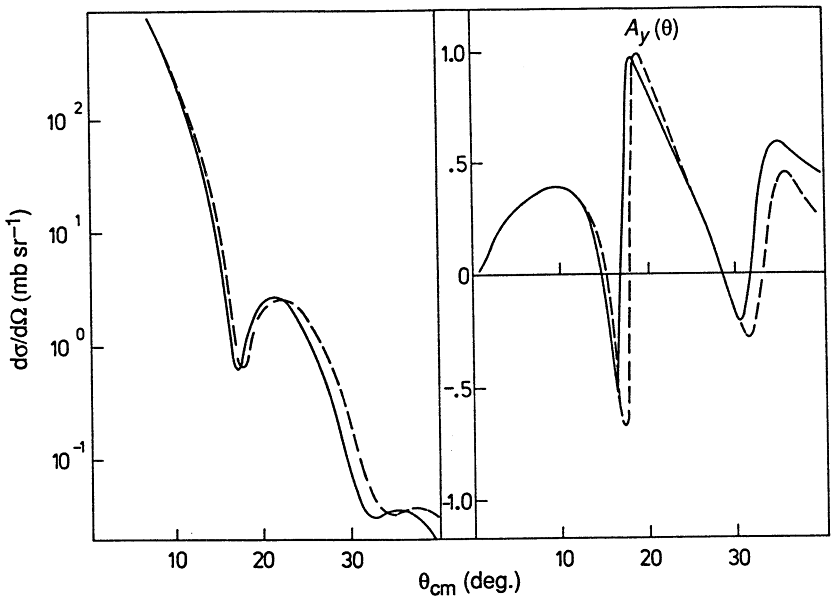

Fig. 2. Differential cross sections and analysing power predictions obtained using the standard $S = 0$ optical model potentials (dashed curves) and with those potentials modified by deformation corrections (solid curves).

the ground state mean field. The deformation parameter was chosen to be $-0 \cdot 6$; a value required in coupled channels calculations of proton scattering from ^{12}C when the elastic and $2_1^+(4 \cdot 44$ MeV) channels are coupled. The resultant central potentials, both real and imaginary, are displayed in Fig. 1. The real potentials include the (repulsive and deformed) Coulomb contribution whence the net refractive field is much reduced at the origin from $-9 \cdot 2$ MeV and, as a consequence, for $r < 3$ fm, the imaginary potential dominates. The dashed curves are the potentials without deformation corrections and the solid curves those with these corrections. Clearly, the adjustment in shapes are slight but are not negligible. By effecting a more diffuse central field, noticeable changes occur in differential cross sections and analysing powers, as shown in Fig. 2. Again the standard potential results are displayed by the dashed curves and the deformation corrected potential results by solid curves. The variation in predictions is quite pronounced with the changes produced by the deformation corrections giving results with momentum transfer characteristics quite similar to those obtained by relativistic (Dirac) optical model calculations. In this case, at least, deformation corrections match the essential shapes of nonrelativistic potentials one would derive by transforming the scalar and vector Dirac potentials (Raynal 1987; von Geramb *et al.* 1988). With this result we do not suggest at all that the relativistic optical model approach using the Dirac equation is inappropriate. Rather, it seems to us that deformation corrections should also be entertained in (phenomenological) relativistic optical model calculations. But attention is drawn to a *caveat emptor*: we have not made an exhaustive search upon the optical potentials to be able to cover uniqueness of the deformation effects in the scattering data analyses.

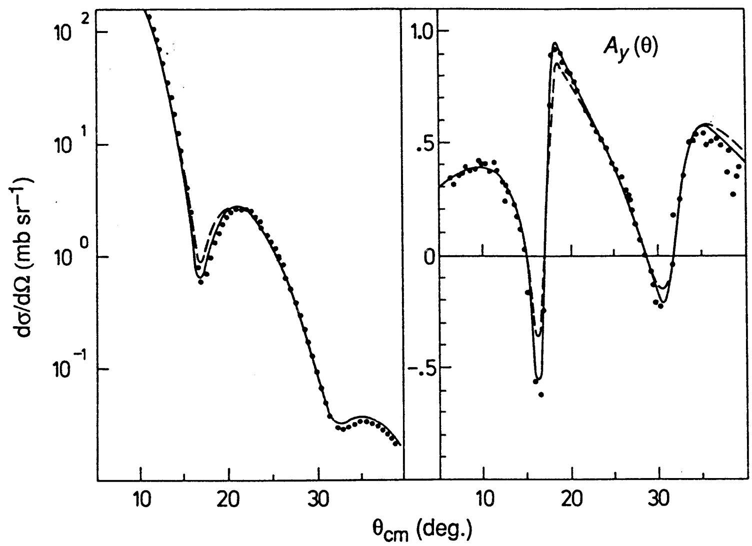

Fig. 3. Differential cross sections and analysing power results obtained using the $S = 0$ deformation corrected optical model potentials (solid curves) and with $S = 1$ contributions included (dashed curves). The data are those of Seestrom-Morris *et al.* (1984).

In contrast the spin 1 components have little effect upon scattering. Indeed, while the real parts are not negligible in comparison with the $S = 0$ contributions, they are of significance at radii where the absorption potential dominates. Even boosting the $S = 1$ distribution by an arbitrary factor of 5 had little effect on the measurable data. The results of including fivefold $S = 1$ components (dashed curves) are compared with those of the underlying $S = 0$ optical model with deformation corrections calculations (solid curves) in Figs 3 and 4. In Fig. 3,

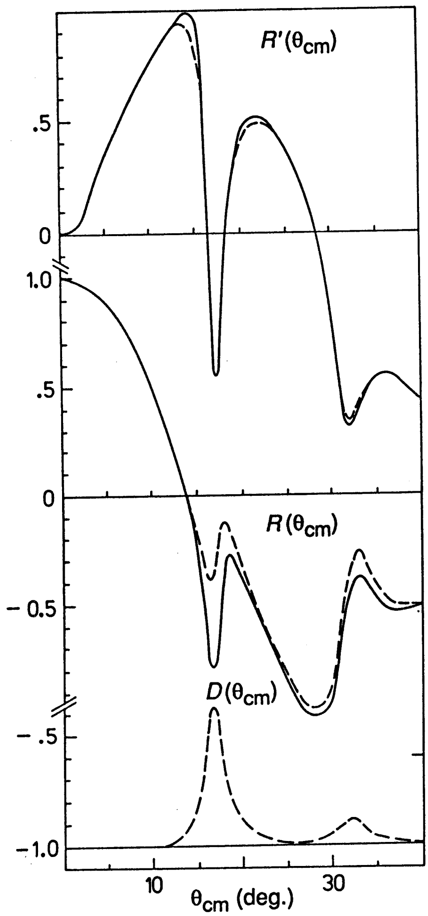

Fig. 4. Rotation and depolarisation parameters obtained from the same calculations giving the cross section and analysing powers displayed in Fig. 3.

the cross sections and analysing power results are compared with the data of Seestrom-Morris *et al.* (1984). Clearly the $S = 1$ components have only a minor effect upon predictions of these measurable properties and the deformation corrected, nonrelativistic optical model calculations are in very good agreement with the data. But there are other measurables and of the complete set, the rotation parameters $R(\theta)$ and $R'(\theta)$ and the depolarisation parameter $D(\theta)$ are likely candidates to show spin transfer effects. The predictions of these three parameters are shown in Fig. 4. For these results only the depolarisation parameter shows any sizeable variation with spin character since only the $S = 1$ components give a variation with momentum transfer from the value -1. It does so noticeably only at momentum transfer values for which the differential cross sections have minima and so a measurement of the required accuracy may be quite difficult. However, the largest variation occurs at the very first minimum of the cross section and careful measurements of such data are feasible.

In summary, there appears to be a definite need to vary the radial distributions of the conventional nonrelativistic optical model potential, which can be attributed to relativistic corrections and/or deformation of the ground state density. But it seems unlikely that nonzero spin transfer contributions will have much influence in analyses of measurable data (at least if the target is unpolarised). Nevertheless, one may entertain hope that the depolarisation parameter will directly reflect the spin 1 attributes in ^{13}C scattering.

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