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BREATHING MODE EFFECT IN p – ^{4}He ELASTIC SCATTERING AT INTERMEDIATE ENERGIES*

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ABSTRACT

Effect of the coupling between the ground and the first excited monopole state in intermediate energy p-^{4}He elastic scattering has been estimated using the breathing mode model and found to be important beyond the first diffraction minima.

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Elastic scattering of intermediate energy protons on ^{4}He has received great theoretical attention in recent years (Wallace 1980). Following interesting experimental developments the initial theoretical studies using the spin independent NN amplitude and the gaussian or more realistic target densities (Czyz and Lesniak 1967, Bassel and Wilkin 1968) have gradually been replaced by more sophisticated ones employing spin dependent NN amplitudes (e.g. Auger, Gillespie and Lombard 1976), and incorporating intermediate nucleon isobar and other effects (Wallace 1980). However, to the best of our knowledge, no attempt has been made so far to study effects of the long range correlation (other than the centre of mass one) which is strongly indicated to be present in ^{4}He.

The first excited state in ^{4}He is the 20.1 MeV, 0^{+}, T = 0 state, and it occurs only a fraction of MeV above the t-p break up threshold. This state has long been adequately interpreted as the breathing mode (or compressional) state by Werntz and Überall (1966) in terms of a simple collective model which assumes a vibration of the ground state matter density according to a coordinate scale factor. The model gives a reasonably fair description of the $0^{+} \rightarrow 0^{+}$ (20.1 MeV) inelastic electron scattering experiments. Therefore, it seems interesting to apply Werntz-Überall model to see if the coupling between the breathing mode state and the ground state has some effect on p-^{4}He elastic scattering at intermediate energies.

In what follows we work under the adiabatic approximation inherent in the collective model description of a nucleus and following Werntz and Überall (1966), obtain the collective model density $\tilde{\rho}$ (r) by scaling the intrinsic one-body density ρ (r):

$$\tilde{\rho}(r) = N(\xi)\, \rho[r(1-\xi)], \qquad (1)$$

where the collective model operator ξ is defined as

$$\xi = C_s (a^{\dagger} + a). \qquad (2)$$

In eq. (2) a^{+} and a are the creation and annihilation operators and the dimensionless constant C_s which depends on the mass, one phonon excitation frequency and rms radius of the nucleus is a measure of the strength of one phonon excitation (Werntz and Überall 1966).

From eq. (1) it follows that the form factors $\tilde{F}$ (q) and F (q) which correspond respectively to the densities $\tilde{\rho}$ (r) and ρ (r) are related to each other to first order in ξ as

$$\tilde{F}(q) = F(q) + \xi\, q \frac{dF}{dq} \tag{3}$$

Now if it is assumed that the ground state form factor is the renormalized form factor which is measured experimentally, then application of eq. (3) to p-^{4}He elastic scattering will give results correct to second order in ξ (c.f. Friar 1973, Bassichis, Feshbach and Reading 1971).

Since in this work we are interested only in having an estimate of the effect of the coupling we will work with spin independent NN amplitude $f_{NN}(q)$ and neglect the Coulomb and other effects. Under these approximations the usual Glauber model expression for the elastic p-^{4}He scattering amplitude, $F_{N\alpha}(q)$, may be written as

$$F_{N\alpha}(q) = K(q)\frac{ik}{2\pi}\int d^2b\; e^{i\vec{q}.\vec{b}}\left\{1 - [1 - \Gamma_{00}(b)]^4\right\} \tag{4}$$

$$\Gamma_{00}(b) = \frac{1}{ik}\int_0^\infty dq\; q\, J_0(qb)\, f_{NN}(q)\, F(q)/K(q)\;, \tag{5}$$

where q is the momentum transfer, k the incident momentum, F(q) the ground state form factor of ^{4}He and K (q) is the c.m. correlation correction factor:

$$K(q) = e^{\frac{b_0^2 q^2}{16}} \tag{6}$$

with b_o^2 as the oscillation constant.

In writing eq. (5) we have used the relation F(q) = K(q) F^M(q), where F^M(q) in the form factor of ^{4}He as given by the independent particle model. Following several authors (e.g. Alkhazov et al. 1978) we will assume that the above relation between the intrinsic form factor and the independent particle model form factor provides a reasonably good approximate means for accounting for the c.m. correlation

even if the independent particle model may not provide a good description of the nucleus concerned.

Now an expression for the elastic scattering amplitude $\tilde{F}_{N\alpha}(q)$ appropriate to the collective model may be obtained under the adiabatic approximation by following the usual approach of replacing the ground state density (form factor) by the collective model density (form factor). Thus we replace F(q) in eq. (5) by $\tilde{F}(q)$ as given by eq. (3) and substitute the resulting $\tilde{\Gamma}_{00}$ (b, ξ) in eq. (4) to obtain the collective model p-^{4}He amplitude $\tilde{F}_{N\alpha}$ (q, ξ) which now depends upon the collective coordinate ξ. Further, for simplicity, we assume the gaussian model for F (q) appearing in eq. (3) and the gaussian parametrization for the NN amplitude:

$$f_{NN}(q) = \frac{k\,\sigma\,(i+\alpha)}{4\pi}\, e^{-\beta^2 q^2/2}\;, \tag{7}$$

where σ in the NN total cross section, α the real-to-imaginary ratio and β^2 the slope parameter.

Now expanding $\tilde{F}_{N\alpha}$(q, ξ) in powers of ξ and going upto second order, the following expression for the p-^{4}He elastic scattering amplitude may easily be obtained:

$$(0|\tilde{F}_{N\alpha}|0) = F^0_{N\alpha}(q) - ik\,\frac{9A^2 b_0^2 C_1^2}{\pi B^2}K(q)\sum_{t=0}^{2}\sum_{r=0}^{2}(-1)^{t+r}\binom{2}{t}\binom{2}{r}A^t B^{-r} J_r\!\left(\frac{2+t}{B}, q^2\right), \tag{8}$$

where $F^0_{N\alpha}$(q) is the same as obtained by Czyz and Lesniak (1967), and Bassel and Wilkin (1968) using the oscillator model and

$$B = b_0^2 + 2\beta^2\;; \qquad A = \frac{\sigma\,(1-i\alpha)}{2\pi B}$$

$$J_0(\mu, q^2) = \frac{\pi}{\mu}\, e^{-\frac{q^2}{4\mu}}$$

$$J_r(\mu, q^2) = (-1)^r \frac{d^r}{d\mu^r} J_0(\mu, q^2)\;; \qquad r = 1, 2\,.$$

The last term in eq. (8) describes the effect of the coupling with the breathing mode state of ^{4}He. The target first excites to the monopole state and then de-excites to the ground state to contribute to the elastic channel.

Naturally the magnitude of the coupling contribution depends upon the inelastic transition strength parameter C_s. Werntz and Überall (1966) find that the value of C_s as given by the model overestimates the electron inelastic scattering differential cross section. Therefore, calculations in this work have been made using a value of C_s^2 which is consistent with electron inelastic scattering experiment and this value is 0.31 times the model value (Werntz and Überall 1966).

The calculated coupling effects on p-^{4}He elastic scattering at 1 and 24 GeV using eq. (8) are shown in fig. 1 (similar results are obtained at lower energies). The calculations have been made using $b_0^2 = 1.87$ fm^2 (Bassel and Wilkin 1968) and taking the NN parameter values at 24 and 1 GeV from the papers of Auger, Gillespie and Lombard (1976) and Bassel and Wilkin (1968) respectively. A comparison of the solid and the dashed curves which are respectively obtained with and without the coupling shows that the coupling effect is quite appreciable beyond the first diffraction minima. In general the coupling enhances the cross section at large momentum transfers, the enhancement being more than 20 % in the region of the first diffraction maxima. Thus we find that the dynamical long range correlation effects are fairly important at intermediate energies.

The present investigation should be taken as providing simply an estimate of the effect of the coupling with the breathing mode state. This is mainly because of the inherent limitations of the adiabatic approximation to describe states of large excitation energies and the approximations involved in the treatment of the c.m. correlation (hence the possibility of some double counting), and also the application of the gaussian model form factor for ^{4}He. However, since the breathing mode model that forms the basis of the present study gives a fair description of the electron inelastic scattering experiment with the gaussian model which also reproduces the gross feature of p-^{4}He elastic scattering, it is rather unlikely that our conclusion as regards the importance of the dynamical long range correlation in p-^{4}He elastic scattering would be affected much by more realistic studies.

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REFERENCES

Alkhazov G.D., Belostotsky S.L. and Vorobyov A.A., 1978, Phys. Reports 42, 89.

Auger J.P., Gillespie J. and Lombard R.J., 1976, Nucl. Phys. A262 372.

Bassel R. and Wilkin C., 1968, Phys. Rev. 174, 1179.

Bassichis W.H., Feshbach H. and Reading J.F., 1971, Ann. Phys. NY 68, 462.

Czyz W. Lesniak L. , 1967, Phys. lett. 25B, 319.

Friar J.L., 1973, Particles and Nuclei 5, 45.

Werntz C. and Überall H. , 1966, Phys. Rev. 149, 762.

Wallace S.J., 1980, Advances in Nuclear Physics, eds. J. Negele and E. Vogt (New York: Plenum) vol. 12 p. 135 and references therein.

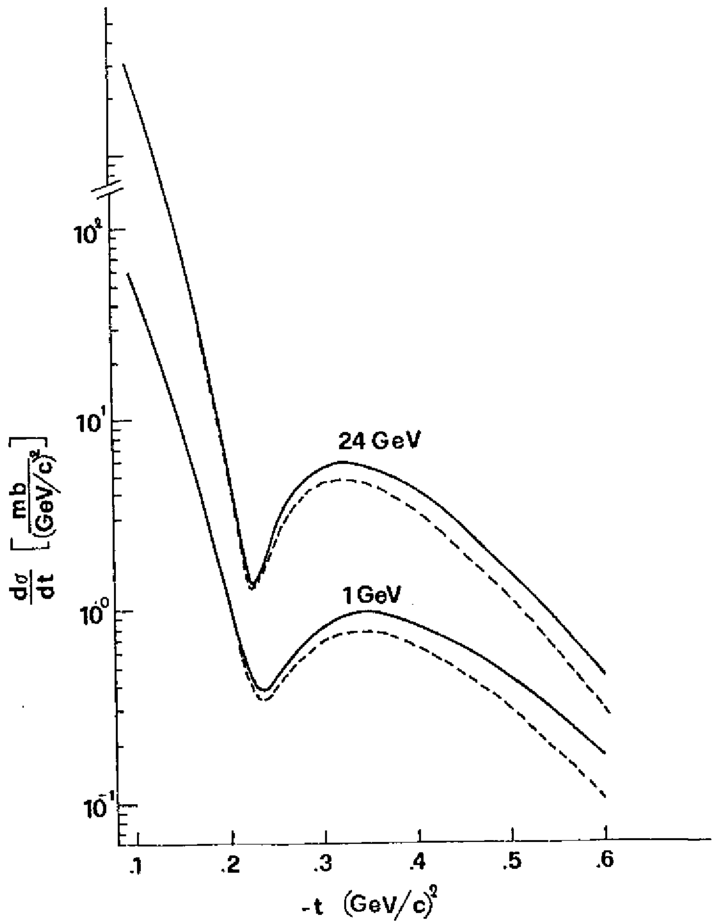

Fig. 1. Elastic scattering of protons on ^4He at 1 and 24 GeV. Dashed curve: without coupling. Solid curve: with coupling.