Probing the isovector transition strength of the low-lying nuclear excitations induced by inverse kinematics proton scattering

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A compact approach based on the folding model is suggested for the determination of the isoscalar and isovector transition strengths of the low-lying ($\Delta S = \Delta T = 0$) excitations induced by inelastic proton scattering measured with exotic beams. Our analysis of the recently measured inelastic $^{18,20}\text{O}+\text{p}$ scattering data at $E_{\text{lab}} = 30$ and 43 MeV/nucleon has given for the first time an accurate estimate of the isoscalar $\beta_0$ and isovector $\beta_1$ deformation parameters (which cannot be determined from the $(p,p')$ data alone by standard methods) for $2^+_1$ and $3^+_1$ excited states in $^{18,20}\text{O}$. Quite strong isovector mixing was found in the $2^+_1$ inelastic $^{20}\text{O}+\text{p}$ scattering channel, where the strength of the isovector form factor $F_1$ (prototype of the Lane potential) corresponds to a $\beta_1$ value almost 3 times larger than $\beta_0$ and a ratio of nuclear transition matrix elements $M_n/M_p \approx 4.2$.

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Although the isospin dependence of the nucleon-nucleus optical potential, known now as Lane potential $[1]$, has been studied since a long time, very few attempts have been made to study the isospin dependence of the transition potential for inelastic scattering. The neutron and proton contributions to the structure of the low-lying nuclear excitations are known to be quite different $[2]$, and the inelastic nuclear form factor contains, therefore, an isospin dependence which determines the degree of the *isovector* mixing in the inelastic scattering channel that induces the excitation.

In general, the isospin-dependent potential is proportional to the product of the projectile and target isospins ($T_pT_t$). For the heavy ions, this term has been shown $[3]$ to be negligible and the scattering cross section is mainly determined by the isoscalar term. Situation is different in the nucleon-nucleus case where the optical potential can be written in terms of the isoscalar ($S$) and isovector ($V$) components $[1]$ as

$$U(R) = U_0(R) \pm \varepsilon U_1(R), \quad \varepsilon = (N-Z)/A, \quad (1)$$

where the + sign pertains to incident neutron and - sign to incident proton. The strength of the Lane potential $U_1$ is known from $(p,p)$ and $(n,n)$ elastic scattering and $(p,n)$ reactions studies, to be around 30-40% of the $U_0$ strength. In many cases, inelastic nucleon-nucleus scattering cross section can be reasonably well described, in the distorted-wave Born approximation (DWBA) or coupled channel formalism by a collective-model prescription, where the inelastic form factor $F$ is obtained by ‘deforming’ the optical potential $[1]$ with a scaling factor $\delta$ known as the nuclear deformation length

$$F(R) = \delta \frac{dU(R)}{dR} = \delta_0 \frac{dU_0(R)}{dR} \pm \varepsilon \delta_1 \frac{dU_1(R)}{dR}, \quad (2)$$

The explicit knowledge of $\delta_0$ and $\delta_1$ would give us vital structure information about the IS and IV transition strengths of the excitation under study. There are only two types of experiment that might allow one to determine $\delta_0$ and $\delta_1$ using prescription $[2]$:

i) $(p,n)$ reaction leading to the excited isobar analog state. It was shown, however, that the two-step mechanism usually dominates this process and the calculated cross sections were insensitive to $\delta_1$ values $[4]$.

ii) Another way is to extract $\delta_0(1)$ from the $(p,p')$ and $(n,n')$ data measured at about the same incident energy and exciting the same state of the target $[3, 4]$. Since $\varepsilon U_1/U_0$ is only about few percent, the uncertainty of such method can be quite large. Moreover, the most interesting data are now being measured with the secondary (unstable) beams and (given the beam intensities much weaker than those of stable beams) it is technically not feasible to perform simultaneously $(p,p')$ and $(n,n')$ measurements (in the inverse kinematics) with those beams.

From a theoretical point of view, the form factor $[4]$ has been shown to have inaccurate radial shape which tends to underestimate the transition strength, especially, for high-multipole excitations induced by inelastic heavy-ion scattering $[3, 7]$. Since the nuclear deformation is directly linked to the ‘deformed’ shape of the excited nucleus, instead of ‘deforming’ the optical potential $[2]$, we build up the proton and neutron transition densities of a $2^\lambda$-pole excitation ($\lambda \geq 2$) using Bohr-Mottelson (BM) prescription $[5]$ separately for protons and neutrons

$$\rho^\tau_\text{g.s.}(r) = -\delta_\tau \frac{d\rho^\tau_{\text{g.s.}}(r)}{dr}, \quad \text{with} \quad \tau = p, n. \quad (3)$$

Here $\rho^\tau_{\text{g.s.}}(r)$ are the proton and neutron ground state (g.s.) densities and $\delta_\tau$ are the corresponding deformation lengths. Given the explicit proton and neutron transition densities and an effective isospin-dependent nucleon-nucleon (NN) interaction, one obtains from the folding model $[5]$ the inelastic proton-nucleus form factor (in terms of IS and IV parts) as

$$F(R) = F_0(R) - \varepsilon F_1(R), \quad (4)$$

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where \( F_0(R) = V_{IS}(R) \) and \( F_1(R) = -V_{IV}(R)/\varepsilon \). The explicit formulas of \( V_{IS(IV)} \) are given in Ref. [6]. One can see that \( F_1(R) \) is prototype of the Lane potential for inelastic scattering. In both elastic and inelastic channels, \( V_{IS} \) and \( V_{IV} \) are determined by the sum \((\rho_n + \rho_p)\) and difference \((\rho_n - \rho_p)\) of the neutron and proton densities [4], respectively. It is, therefore, natural to represent the IS and IV parts of the nuclear density as

\[
\rho^{(1)}_{\lambda(g.s.)}(r) = \rho^{\lambda}_{\lambda(g.s.)}(r) \pm \rho^{\lambda}_{\lambda(g.s.)}(r).
\]  

On the other hand, one can generate using the same BM prescription the IS and IV transition densities by deforming the IS and IV parts of the nuclear g.s. density

\[
\rho^{(1)}_{\lambda}(r) = -\delta_{\lambda(1)} \frac{d[\rho^{0}_{\lambda}(r) \pm \rho^{0}_{\lambda}(r)]}{dr}.
\]  

The explicit expressions for the IS and IV deformation lengths are easily obtained from Eqs. [14] and [15], after some integration in parts, as

\[
\delta_0 = \frac{N < r^{\lambda-1} >_n \delta_n + Z < r^{\lambda-1} >_p \delta_p}{A < r^{\lambda-1} >_A},
\]

\[
\delta_1 = \frac{N < r^{\lambda-1} >_n \delta_n - Z < r^{\lambda-1} >_p \delta_p}{N < r^{\lambda-1} >_n - Z < r^{\lambda-1} >_p}.
\]

The radial momenta \(< r^{\lambda-1} >_n,p,A \) are taken over the neutron, proton, and total g.s. densities, respectively,

\[
< r^{\lambda-1} >_x = \int_0^\infty \rho^{x}_{\lambda}(r)r^{\lambda+1}dr/\int_0^\infty \rho^{x}_{\lambda}(r)r^2dr.
\]

The transition matrix element associated with a given component of nuclear transition density is

\[
M_x = \int_0^\infty \rho^{x}_{\lambda}(r)r^{\lambda+2}dr.
\]

Realistic estimate for \( M_n/M_p \) or \( M_1/M_0 \) should give important information on the IS and IV transition strengths

\[
\frac{M_n}{M_p} = \frac{N < r^{\lambda-1} >_n \delta_n}{Z < r^{\lambda-1} >_p \delta_p},
\]

\[
\frac{M_1}{M_0} = \frac{(N < r^{\lambda-1} >_n - Z < r^{\lambda-1} >_p)\delta_1}{(A < r^{\lambda-1} >_A)\delta_0}.
\]

It is useful to note that the ratios of transition matrix elements in the two representations are related by

\[
\frac{M_n}{M_p} = (1 + M_1/M_0)/(1 - M_1/M_0).
\]

If one assumes that the excitation is purely isoscalar and the neutron and proton densities have the same radial shape, scaled by the ratio \( N/Z \), then \( \delta_n = \delta_p = \delta_0 = \delta_1 \),

\[
\frac{M_n}{M_p} = \frac{N}{Z} \quad \text{and} \quad \frac{M_1}{M_0} = \frac{N - Z}{A} = \varepsilon.
\]

Therefore, any significant difference between \( M_n/M_p \) and \( N/Z \) (or between \( M_1/M_0 \) and \( \varepsilon \)) would directly indicate an isovector mixing effect.

Note that if one neglects the difference between different radial momenta \(< r^{\lambda-1} >_x >_x \), then expressions [11] and [12] are reduced to those used earlier for the ‘experimental’ determination of \( M_n/M_p \) and \( M_1/M_0 \) ratios

\[
\frac{M_n}{M_p} = \frac{N_0}{Z_0} \delta_p \quad \text{and} \quad \frac{M_1}{M_0} = \frac{(N - Z)_0}{A_0} \delta_0.
\]

We further choose the proton deformation length \( \delta_p \) so that the measured electric transition rate is given by \( B(E\lambda \uparrow) = e^2|\langle M_p \rangle|^2 \). As a result, the only free parameter to be determined from the DWBA fit to the inelastic scattering data is the neutron deformation length \( \delta_n \), which agrees well with the observed trend. To illustrate the radial shape of the Lane potential, given a realistic choice for the effective NN interaction and nuclear g.s. densities, we have plotted in the left panel of Fig. [8] the folded \( U_1 \) and \( U_0 \) potentials for \( ^{18}\text{O} \), and \( ^{20}\text{O} \), respectively. The isovector dependence of the CDMS3Y6 interaction was shown earlier to reproduce the empirical symmetry energy of asymmetric nuclear matter [3] and it gives also a realistic estimate for the folding model in predicting the strength and shape of the Lane potential, given a realistic choice for the effective NN interaction and nuclear g.s. densities.

We discuss now the IS and IV strengths of the inelastic \( ^{18,20}\text{O} \) form factors. Note that \( ^{18}\text{O} \) nucleus is rather well studied and inelastic \( ^{18}\text{O} \) data are, therefore, quite helpful in testing the present Folding approach.
FIG. 1: Real folded optical potential (left panel) and $2^+$-inelastic form factor (right panel) for $^{20}\text{O}+\text{p}$ system. $U_1$ and $F_1$ show strength and shape of the Lane potential in the elastic and $2^+$-inelastic channels, respectively.

By adjusting $M_p$ to the experimental $B(E2 \uparrow \downarrow) = 45.1 \pm 2.0 \text{e}^{-2} \text{fm}^4$ and $B(E3 \uparrow \downarrow) = 1120 \pm 11 \text{e}^{-2} \text{fm}^6$ for the first $2^+$ and $3^-$ states in $^{18}\text{O}$, we obtain $\delta_p = 1.040 \pm 0.020$ and $1.449 \pm 0.008 \text{ fm}$, respectively. The $E2$ transition strength is more fragmented in $^{20}\text{O}$ and the experimental $B(E2 \uparrow \downarrow) = 28.1 \pm 2.0 \text{e}^{-2} \text{fm}^4$ for $2^+_1$ state. There are no $B(E3 \uparrow \downarrow)$ data available for $3^+_1$ state in $^{20}\text{O}$, and we have assumed a value $B(E3 \uparrow \downarrow) = 1200 \pm 12 \text{e}^{-2} \text{fm}^6$ which was estimated from the experimental $B(E3 \uparrow \downarrow)$ for $3^+_1$ state in $^{18}\text{O}$ using the ratio of the $B(E3 \uparrow \downarrow)$ values calculated for these two cases in the Quasiparticle Random Phase Approximation (QRPA) [16]. As a result, we obtain the proton deformation lengths $\delta_p = 0.815 \pm 0.029$ and $1.424 \pm 0.008 \text{ fm}$ for $2^+_1$ and $3^+_1$ states in $^{20}\text{O}$, respectively. Note that the numerical uncertainties of the obtained proton deformation lengths are fully determined by those of the measured $B(E2 \uparrow \downarrow)$ values. Using the best-fit neutron deformation length from the DWBA analysis of the inelastic data under consideration, realistic shape of the Lane potential in an inelastic scattering channel can be obtained. As an example, we have plotted in the right panel of Fig. 1 the $2^+$-inelastic form factor for $^{20}\text{O}+\text{p}$ system, where contributions by the IS and IV components are shown explicitly. We further assign a numerical uncertainty of around 5% to the deduced neutron deformation length which gives a cross-section shift within the experimental errors. The numerical uncertainties of all the deformation parameters and ratios of transition matrix elements given in Table I were deduced directly from those found for the proton and neutron deformation lengths.

Since the CDMS3Y6 interaction is real, only real nuclear, Coulomb and spin-orbit transition form factors for $^{18,20}\text{O}$ are obtained from the folding calculation [8]. The imaginary nuclear form factor is obtained by deforming the imaginary part of the optical potential with $\delta_0$ that is iteratively found from the DWBA fit to the data. Fortunately, nucleon inelastic scattering at low-to-medium energies is not dominated by the imaginary coupling and the DWBA cross section is strongly sensitive to the real form factor which allows an accurate deduction of the (neutron) deformation length.

Elastic and inelastic $^{18,20}\text{O}+\text{p}$ cross sections (at 43 MeV/nucleon) obtained with the best-fit deformation parameters are plotted in Fig. 2. One can see that the IV contribution is small in the elastic and $3^-$ inelastic channels. We found that $3^+_1$ state is dominantly isoscalar, with the best-fit $M_n/M_p$ ratio slightly above $N/Z$ and $M_1/M_0$ ratio close to $\varepsilon$ (see Table I). This result is well expected because the $3^+_1$ states in $^{18,20}\text{O}$ isotopes were

| $\lambda$ | $\beta_\mu$ | $\beta_\nu$ | $M_\mu/M_\nu$ | $\beta_0$ | $\beta_1$ | $M_1/M_0$ | $J_1/J_0$ | data |
|----------|-------------|-------------|--------------|----------|----------|-----------|---------|------|
| $2^+$    | 0.331 ± 0.006 | 0.455 ± 0.023 | 1.80 ± 0.13  | 0.401 ± 0.016 | 0.861 ± 0.034 | 0.286 ± 0.023 | −0.992 ± 0.089 | 10   |
| $3^+$    | 0.461 ± 0.003 | 0.453 ± 0.022 | 1.35 ± 0.08  | 0.456 ± 0.014 | 0.432 ± 0.016 | 0.149 ± 0.010 | −0.410 ± 0.029 | 10   |

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shown by the QRPA calculation to consist mainly of the $(1p_{1/2}, 1d_{5/2})$ proton configuration. Strong IV effect was found in $2^+_1$ inelastic channel. Structure of $2^+_1$ state in $^{18}$O has been investigated in numerous studies like $(p,p')$ reactions at low and intermediate energies of the $(1p, \pi, \pi')$ reactions, and the weighted average of those results gives $M_n/M_p \approx 2$. This value also agrees fairly with that deduced from a pure isospin-symmetry assumption that $M_p$ obtained for the mirror $^{18}$Ne nucleus would yield $M_n$ for the corresponding excited state in $^{18}$O. $M_n/M_p$ ratios deduced from these studies are compared with our result in Fig. 3.

One can see that our result is in a satisfactory agreement with the empirical data. The obtained IV deformation $\langle \beta_1 \rangle \approx 0.86$ is about twice the IS deformation which indicates a significant IV mixing in this case. Prior to our work, the only attempt to deduce $\beta_1$ for $2^+_1$ state in $^{18}$O that we could find in the literature is the DWBA analysis of $(p,p')$ and $(n,n')$ scattering data at 24 MeV which gives $\beta_0 \approx 0.4$ and $\beta_1 \approx 1.0 \pm 0.5$, using prescription and assuming $\beta_0$ to be the average of the $\beta$ values obtained with $(p,p')$ and $(n,n')$ data. Although the uncertainty associated with $\beta_1$ is large, this result agrees reasonably with $\beta_0(11)$ given by our analysis.

In contrast to the $^{18}$O case, the $(p,p')$ excitation of $2^+_1$ state in radioactive $^{20}$O nucleus has been studied only recently in the inverse kinematics proton scattering measurements at 43 and 30 MeV/nucleon. A simple folding analysis using the microscopic QRPA transition densities and JLM interaction has failed to fit the data at 43 MeV. Khan et al. obtained $M_n/M_p \approx 1.10 \pm 0.24$ and $3.25 \pm 0.80$ for $2^+_1$ excitation in $^{18}$O and $^{20}$O, respectively, after renormalizing the QRPA densities to the best DWBA fit to the data. If one uses a simple (probe-dependent) collective model in the analysis of $(p,p')$ data measured at 24 and 30 MeV for $^{18}$O and $^{20}$O, these values become $M_n/M_p \approx 1.50 \pm 0.17$ and $2.9 \pm 0.4$, respectively. Despite the uncertainty of these data, they do indicate a strong IV mixing in the $2^+_1$ excitation in $^{20}$O. Our result shows even stronger IV transition strength for this state and $M_n/M_p$ ratio obtained with the best-fit neutron deformation length from our folding analysis of 43 MeV and 30 MeV data is around 4.25 and 4.13, respectively. We adopted, therefore, an average value of $M_n/M_p \approx 4.2 \pm 0.3$ from the values obtained in these two cases. The IV deformation, given for the first time for $2^+_1$ state in $^{20}$O ($\beta_1 \approx 1.3$), is nearly three times the IS deformation ($\beta_0 \approx 0.5$) and $M_1/M_0 \approx 0.6 \pm 3\varepsilon$. This leads to a ratio of the volume integrals of $F_1$ and $F_0$ folded form factors $J_1/J_0 \approx -1.25$ which is significantly higher than that found in the elastic channel. The relative IV strength in the inelastic $2^+_1$
channel is, therefore, $\varepsilon |J_1/J_0| \approx 25\%$ with the IV form factor peaked at the surface (see Fig\[1\]). This significant contribution by the Lane potential in the $2_1^+$ inelastic channel of $^{20}$O+p system amounts up to 40-50\% of the total cross section over the whole angular range as shown in Fig\[2\].

In conclusion, a compact folding approach is developed for a consistent study of strength and shape of the Lane potential in both elastic and inelastic proton-nucleus scattering, and to deduce from the analysis of (p,p') data the IS and IV deformation parameters which, otherwise, can be deduced only if there are (p,p') and (n,n') data available at the same energy for the same target. With more data being measured with the unstable beams, our model should be helpful for the determination of the isospin distribution in the low-lying excited states of exotic nuclei which can be used as important ‘data base’ for further nuclear structure studies. The use of microscopic nuclear densities in our approach should be encouraged to test the nuclear structure model ingredients by studying the known excitations and, consequently, to predict the isospin character of those not yet measured.

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[1] A.M. Lane, Phys. Rev. Lett. 8, 171 (1962).
[2] A.M. Bernstein, V.R. Brown, and V.A. Madsen, Comments Nucl. Part. Phys., 11, 203 (1983).
[3] Dao T. Khoa, W. von Oertzen and A. A. Ogloblin, Nucl. Phys. A602, 98 (1996).
[4] R.W. Finlay, J. Rapaport, V.R. Brown, V.A. Madsen, and J.R. Comfort, Phys. Lett. 84B, 169 (1979).
[5] P. Grabmayr, J. Rapaport, and R.W. Finlay, Nucl. Phys. A350, 167 (1980).
[6] J.R. Beene, D.J. Horen, and G.R. Satchler, Phys. Lett. B 344, 67 (1995); Nucl. Phys. A596, 137 (1996).
[7] Dao T. Khoa and G.R. Satchler, Nucl. Phys. A668, 3 (2000).
[8] A. Bohr and B.R. Mottelson, Nuclear Structure (Benjamin, New York, 1975), Vol.2.
[9] Dao T. Khoa, E. Khan, G. Colò, and N. Van Giai, Nucl. Phys. A706, 61 (2002).
[10] E. Khan et al., Phys. Lett. B 490, 45 (2000).
[11] J.K. Jewell et al., Phys. Lett. B 454, 181 (1999).
[12] Dao T. Khoa, G.R. Satchler, and W. von Oertzen, Phys. Rev. C 56, 954 (1997).
[13] M. Grasso, N. Sandulescu, N. Van Giai, and R.J. Liotta, Phys. Rev. C 64, 064321 (2001).
[14] R.L. Varner, W.J. Thompson, T.L. McBee, E.J. Ludwig, and T.B. Clegg, Phys. Rep. 201, 57 (1991).
[15] S. Raman, C. W. Nestor, Jr., and P. Tikkanen, At. Data and Nucl. Data Tables 78, 1 (2001).
[16] R.H. Spear, At. Data and Nucl. Data Tables 42, 55 (1989).
[17] G.R. Satchler, Direct Nuclear Reactions, Clarendon Press, Oxford, 1983.
[18] J. Kelly et al., Phys. Lett. 169B, 157 (1986).
[19] J. Jansen et al., Phys. Lett. 77B, 359 (1978).
[20] S. Iversen et al., Phys. Rev. Lett. 40, 17 (1978); Phys. Lett. 82B, 51 (1979).
[21] S.J. Seestrom-Morris, D. Dehnhard, M.A. Franey, D.B. Holtkamp, C.L. Bilie, C.L. Morris, J.D. Zumbo, and H.T. Fortune, Phys. Rev. C 37, 2057 (1988).
[22] A.M. Bernstein, V.R. Brown, and V.A. Madsen, Phys. Rev. Lett. 42, 425 (1979).