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A study of the ^{7}Li (p, n) reaction in the impulse approximation

J. MAHALANABIS
Saha Institute of Nuclear Physics, Calcutta, India
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Abstract. The (p, n) reaction in ^{7}Li at 94 MeV is studied in the impulse approximation. The differential cross sections for exciting the isobaric analogue state and the 0·431 MeV state in ^{7}Be are obtained using LS-coupled shell-model wave functions. Fairly good shape agreement with the available experimental results is obtained. These results are discussed, together with the inelastic proton scattering to the 0·478 MeV state in ^{7}Li, as a mode of investigating the model wave functions used; where the small-angle results as predicted by the theory appear to be in conflict with the experimental data. Need for more experimental data at small angles for these reactions is stressed.

1. Introduction

The study of (p, n) reactions has been of considerable interest in recent years (Bloom *et al.* 1959, Anderson 1966). Recently several experiments have been performed at different energies to study the (p, n) reactions over a wide range of mass number (Anderson *et al.* 1964, Batty *et al.* 1966, Saltmarsh 1965, Langsford *et al.* 1962 a, b). At lower energies there is a clear excitation of the isobaric analogue states, as well as some excitation of isobaric configuration states (Anderson and Wong 1962). The reaction mechanism has been discussed by Lane and Soper (1962). The isobaric analogue states are states in the final nucleus which have the same configuration and total isotopic spin as the ground state of the target nucleus. For nuclei with isotopic spin $T = \frac{1}{2}$, the isobaric analogue state is the ground state of the resulting nuclei. Isobaric configuration states are states which have similar configuration to the ground state of the target nucleus, but the isotopic spin can be different. Lane has included an isotopic spin dependent term in the real part of the optical potential (Lane 1962 a, b) and it has been shown (Lane and Soper 1962) that the (p, n) reaction cross section can be calculated within the framework of the optical model.

For high energy (p, n) reactions the isobaric analogue state is still clearly excited. Experimental results (Langsford *et al.* 1962, 1963) show that the direct (p, n) reaction preferentially excites the isobaric analogue state. The direct (p, n) reaction is assumed to take place in the following manner: the incoming proton reacts with a neutron in the outer shell, exchanges its charge and is finally emitted as a neutron. As a result, the possibility of exciting the analogue state of the target ground state becomes considerable, because, for this, least rearrangement of the nucleons within the nucleus is needed. This process may be described as the 'quasi-elastic' process and has been studied by Lane and Soper (1962). Another type of transition may occur in addition to the ground state transitions due to the direct (p, n) reactions, which may be described as 'quasi-inelastic' scattering. This reaction may excite states in the final nuclei which are the analogues of the low-lying excited states in the target nucleus. These should be strong when the corresponding inelastic scattering from the target is strong, namely when the states are collective in character (Bassel *et al.* 1963). However, the possibility of 'quasi-elastic' scattering is greater than that of the 'quasi-inelastic' case as in the latter type of reaction the nucleons undergo some rearrangement to give the proper description of the final state, besides the charge-exchange process. These simple pictures may be considered to be valid at high energies, since at lower energies we will have to worry about such things as Coulomb effects (Lane 1962 a, b). Another process may become quite important at higher energies; this is the 'knock-out' process, but it may not excite the isobaric state.

We wish to study the high energy (p, n) reactions in ^{7}Li. We use an impulse approximation and shell-model wave functions with oscillator radial functions. In the impulse approximation the (p, p′) and (p, n) reactions may be described in similar terms (Clegg

1965), and the (p, p′) reaction excites levels which have a large radiative matrix element to the ground state. The importance of impulse approximation for the study of inelastic and charge-exchange scattering of different projectiles by nuclei has been discussed by Satchler (1966) as a method of investigating the structure of nuclei when the nucleon–nucleon interaction is known. The (p, n) and (n, p) reactions may then be described as special cases of inelastic nucleon scattering where the isotopic spin has been flipped. In ^{7}Li, the (p, n) transitions exciting the ground state ($J = \frac{3}{2}^-$) and the 0·431 MeV state ($J = \frac{1}{2}^-$) of ^{7}Be are studied in this work. The (p, p′) reaction exciting the 0·478 MeV state ($J = \frac{1}{2}^-$) has been studied (Mahalanabis 1964, Mahalanabis and Jackson 1966) where the nuclear structure effects have been discussed. We wish to study the (p, n) reactions in ^{7}Li and obtain further information regarding the structure effects in $A = 7$ nuclei.

2. The transition matrix in the impulse approximation

At high energies the transition amplitude for transition from an initial state Ψ_i to a final state Ψ_f may be described by the two-body scattering amplitude $M(q)$ appropriate to a free nucleon–nucleon scattering (Kerman *et al.* 1959). The matrix element for the transition is given by

$$T_{if} = \langle \Psi_f \chi^-(\boldsymbol{r}) | \sum_j M_j(q) | \chi^+(\boldsymbol{r}) \Psi_i \rangle \tag{2.1}$$

where the summation is over the target nucleons participating in the transition. The two-nucleon scattering amplitude $M(q)$ in the centre-of-mass system is related to the two-body scattering matrix $t(q)$ by the relation

$$M(q) = -\frac{(2\pi)^2}{\hbar^2}\frac{m}{2}t(q) \tag{2.2}$$

where m is the nucleon mass.

The wave functions for the incoming and outgoing particle are denoted by $\chi^+(\boldsymbol{r})$ and $\chi^-(\boldsymbol{r})$ respectively, and they contain isotopic spin functions besides the angular and spin functions. In the two-body centre-of-mass system $M(q)$ is given by

$$M = A + B\boldsymbol{\sigma}.\hat{\boldsymbol{n}}\,\boldsymbol{\sigma}_j.\hat{\boldsymbol{n}} + C(\boldsymbol{\sigma}.\hat{\boldsymbol{n}} + \boldsymbol{\sigma}_j.\hat{\boldsymbol{n}}) + E\boldsymbol{\sigma}.\hat{\boldsymbol{q}}\,\boldsymbol{\sigma}_j.\hat{\boldsymbol{q}} + F\boldsymbol{\sigma}.\hat{\boldsymbol{p}}\,\boldsymbol{\sigma}_j.\hat{\boldsymbol{p}} \tag{2.3}$$

where the unit vectors $\hat{\boldsymbol{q}}$, $\hat{\boldsymbol{n}}$, $\hat{\boldsymbol{p}}$ form a right-handed coordinate system and are defined by

$$\begin{aligned} \hat{\boldsymbol{q}} &= \boldsymbol{q}/|\boldsymbol{q}| & \boldsymbol{q} &= \boldsymbol{k}' - \boldsymbol{k} = \boldsymbol{k}_0' - \boldsymbol{k}_0 \\ \hat{\boldsymbol{n}} &= \boldsymbol{n}/|\boldsymbol{n}| & \boldsymbol{n} &= \boldsymbol{k} \times \boldsymbol{k}' = \boldsymbol{k}_0 \times \boldsymbol{k}_0' \\ \hat{\boldsymbol{p}} &= \hat{\boldsymbol{q}} \times \hat{\boldsymbol{n}} \end{aligned}$$

where $\boldsymbol{k}$, $\boldsymbol{k}'$ are the incoming and outgoing nucleon momenta in the nucleon–nucleus system, $\boldsymbol{k}_0$, $\boldsymbol{k}_0'$ are the same for the two-nucleon centre-of-mass system. (We assume $\boldsymbol{q} = \boldsymbol{k}' - \boldsymbol{k}$ where $\boldsymbol{k}'$, $\boldsymbol{k}$ are measured at infinity. Actually $\boldsymbol{k}'$, $\boldsymbol{k}$ should be measured at the point of interaction (Satchler 1966).) The scattering coefficients A, B, C, E and F depend on the momentum transfer and are also functions of isotopic spin. The values have been tabulated for nucleons at several energies (Kerman *et al.* 1959).

Each term in equation (2.3) has the form

$$\begin{aligned} A &= A_\alpha + A_\beta \boldsymbol{\tau}.\boldsymbol{\tau}_j \\ &= \tfrac{1}{4}(3A_1 + A_0) + \tfrac{1}{4}(A_1 - A_0)\boldsymbol{\tau}.\boldsymbol{\tau}_j \end{aligned} \tag{2.4}$$

where A_1 and A_0 are the coefficients for the isotopic triplet and singlet states, respectively. $\boldsymbol{\tau}$, $\boldsymbol{\tau}_j$ are the isotopic spin operators of the incident and the jth target nucleon respectively.

The two-nucleon scattering amplitude may be written as

$$\begin{aligned} M &= M_0 + \boldsymbol{M}_1 . \boldsymbol{\sigma}_j \\ &= M_0 + \sum_\mu (-1)^\mu M_{j,-\mu}\sigma_{1,\mu} \end{aligned} \tag{2.5}$$

where $\sigma_{1,\mu}$ are tensor operators of rank 1 in the spin space of the target nucleon. Since each coefficient is isotopic spin dependent as given by equation (2.4) we may write equation (2.5) as

$$M = M_0(\alpha)+M_0(\beta)\boldsymbol{\tau}\cdot\boldsymbol{\tau}_j+\sum_{\mu}(-1)^{\mu}\{M_{1,-\mu}(\alpha)\sigma_{1,\mu}+M_{1,-\mu}(\beta)\sigma_{1,\mu}\boldsymbol{\tau}\cdot\boldsymbol{\tau}_j\}. \tag{2.6}$$

The quantities $M_0(\alpha)$, $M_{1,-\mu}(\alpha)$ are defined by

$$M_0(\alpha) = A_\alpha+C_\alpha\boldsymbol{\sigma}\cdot\hat{\boldsymbol{n}}$$

$$M_{1,0}(\alpha) = E_\alpha\boldsymbol{\sigma}\cdot\hat{\boldsymbol{q}}$$

$$M_{1,\pm1}(\alpha) = \mp\frac{1}{\sqrt{2}}(C_\alpha+B_\alpha\boldsymbol{\sigma}\cdot\hat{\boldsymbol{n}}\pm iF\boldsymbol{\sigma}\cdot\hat{\boldsymbol{p}}) \tag{2.7}$$

and similarly for the $M_0(\beta)$ and $M_{1,-\mu}(\beta)$ terms. They are operators in the spin space of the incident nucleon.

The differential cross section is given by

$$\frac{d\sigma}{d\Omega} = \left(\frac{2N}{N+1}\right)^2\frac{k'}{k}|T_{\mathrm{if}}|^2 \tag{2.8}$$

where N is the number of the target nucleons.

The above formalism may be used in general not only for inelastic scattering, but also for the charge-exchange reactions due to the inclusion of the isotopic spin dependent term $\boldsymbol{\tau}.\boldsymbol{\tau}_j$. For inelastic scattering all the terms in the two-body scattering amplitude may contribute depending on the selection rules, but for the charge-exchange reactions only the $\boldsymbol{\tau}.\boldsymbol{\tau}_j$ terms would contribute.

3. Results

In this section we calculate the cross sections for the direct (p, n) reactions in ^{7}Li, leading to the excitation of the isobaric analogue state of the target ground state and to the first excited state in ^{7}Be. The ground state and the first and second excited states in ^{7}Be are the isobaric analogue states of the corresponding ones in ^{7}Li. The energy levels are given in figure 1. In a direct reaction both type of transitions may take place, but the

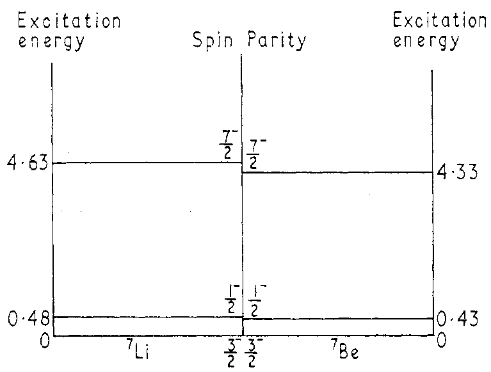


Figure 1. The low-lying levels of ^{7}Li and ^{7}Be.

probability of a ground-state transition is greater, since least rearrangement is needed. In fact if the isobaric analogue state is already there, the direct (p, n) reaction would preferentially excite it.

We use the plane-wave impulse approximation as described in the previous section for our calculation. Hence the transition matrix is given by

$$T_{\mathrm{if}} = \langle \Psi_{\mathrm{f}}\beta_0 | \sum_j M_j(q) \exp(-\mathrm{i}\boldsymbol{q}\,.\,\boldsymbol{r}) | \alpha_0 \Psi_{\mathrm{i}} \rangle \tag{3.1}$$

where α_0, β_0 are the isotopic spin functions for the incident and scattered particle, respectively. The nuclear wave functions are shell-model wave functions in the LS-coupling scheme.

In the limit of LS coupling and central interaction, the ground states and the first excited states of ^{7}Li and ^{7}Be may be described as the members of the ^{22}P doublet having the orbital symmetry [3]. The ground state ($J = \frac{3}{2}^-$) is the higher angular momentum state which lies below the ($J = \frac{1}{2}^-$) state which is the first excited state. The properties of some low-lying states in ^{7}Li and ^{7}Be are shown in table 1. The wave functions for the

Table 1. Character assumed for the three lowest states of ^{7}Li and ^{7}Be

Excitation energy (MeV)	Spin parity $J\pi$	Wave functions: Intermediate coupling	LS limit	*jj limit*
0	$\frac{3}{2}^-$	$^{22}\mathrm{P}_{3/2}{}^{[3]} + {}^{22}\mathrm{P}_{3/2}{}^{[21]} + {}^{24}\mathrm{P}_{3/2}{}^{[21]} + {}^{22}\mathrm{D}_{3/2}{}^{[21]} + {}^{24}\mathrm{D}_{3/2}{}^{[21]}$	$^{22}\mathrm{P}_{3/2}{}^{[3]}$	$\mathrm{p}_{3/2}{}^3$
0·478 ^{7}Li 0·433 ^{7}Be	$\frac{1}{2}^-$	$^{22}\mathrm{P}_{1/2}{}^{[3]} + {}^{22}\mathrm{P}_{1/2}{}^{[21]} + {}^{24}\mathrm{P}_{1/2}{}^{[21]} + {}^{24}\mathrm{D}_{1/2}{}^{[21]} + {}^{22}\mathrm{S}_{1/2}{}^{[111]}$	$^{22}\mathrm{P}_{1/2}{}^{[3]}$	$\mathrm{p}_{3/2}{}^3$
4·63 ^{7}Li 4·53 ^{7}Be	$\frac{7}{2}^-$	$^{22}\mathrm{F}_{7/2}{}^{[3]} + {}^{24}\mathrm{D}_{7/2}{}^{[21]}$	$^{22}\mathrm{F}_{7/2}{}^{[3]}$	$\mathrm{p}_{3/2}{}^3$

$(1\mathrm{s})^4(1\mathrm{p})^3$ configuration are constructed by the method of fractional parentage expansion (Jahn and Wieringen 1951).

3.1. $^7Li\,(p, n)\,^7Be$ (*ground state*)

The transition amplitude for the (p, n) reaction is given by equation (3.1). The final-state wave function Ψ_{f} now refers to that of the ground state of ^{7}Be, the initial-state wave function being that of the ground state of ^{7}Li. The isotopic spin functions α_0 and β_0 refer to that of a proton and neutron respectively. The spin and isotopic spin quantum numbers are the same for the initial and final states ($J = \frac{3}{2}^-$, $T = \frac{1}{2}$). Hence this is a $\Delta T = 0$, $\Delta J = 0$ transition.

The expression for the transition matrix element was evaluated using standard techniques (Edmonds 1957), by substituting the expression for $M(q)$ from (2.6) and using the LS-coupled shell-model wave functions. Only the even values of l, $l = 0$ and 2, are allowed for this transition, the others are forbidden. The spin-flip components as well as the non-spin-flip components contribute to the $l = 0$ and $l = 2$ transitions. The differential cross section for the transition is given by

$$\frac{\mathrm{d}\sigma}{\mathrm{d}\Omega} = 12{\cdot}25\, I_0 \tag{3.2}$$

where

$$\begin{aligned} I_0 = {} & \{(|A_\beta|^2 + |C_\beta|^2) + \tfrac{5}{9}(|B_\beta|^2 + |C_\beta|^2 + |F_\beta|^2 + |E_\beta|^2)\}F_0{}^2(q) \\ & + \tfrac{1}{25}\{9(|A_\beta|^2 + |C_\beta|^2) + 11(|B_\beta|^2 + |C_\beta|^2 + |F_\beta|^2) + 17|E_\beta|^2\}F_2{}^2(q) \\ & - \tfrac{2}{15}\{(|B_\beta|^2 + |C_\beta|^2 + |F_\beta|^2) - 2|E_\beta|^2\}F_0(q)F_2(q). \end{aligned} \tag{3.3}$$

The last term is the interference term between the $l = 0$ and $l = 2$ transitions. The functions $F_0(q)$ and $F_2(q)$ are given by

$$F_l(q) = \int_0^a R_{n'l_1'}(r) j_l(qr) R_{nl_1}(r) r^2 \, dr \qquad l = 0, 2 \tag{3.4}$$

where $R_{nl_1}(r)$ refers to the oscillator radial function for the p nucleon.

3.2. $^7Li\,(p, n)\,^7Be^*$ (0·431 MeV)

We now consider the second type of transition in the (p, n) reaction, leading to the excitation of the 0·431 MeV level in ^{7}Be, which is the isobaric analogue state of the 0·478 MeV level in ^{7}Li. The final state Ψ'_f now refers to the 0·431 MeV state in ^{7}Be ($J = \frac{1}{2}^-$, $T = \frac{1}{2}$). This is also a $\Delta T = 0$ transition, with $\Delta J = 1$. In this case the selection rules allow only the $l = 2$ transition for the non-spin-flip components, whereas for the spin-flip components $l = 0$ and 2 transitions are allowed. The differential cross section for the 'excited state' transition becomes

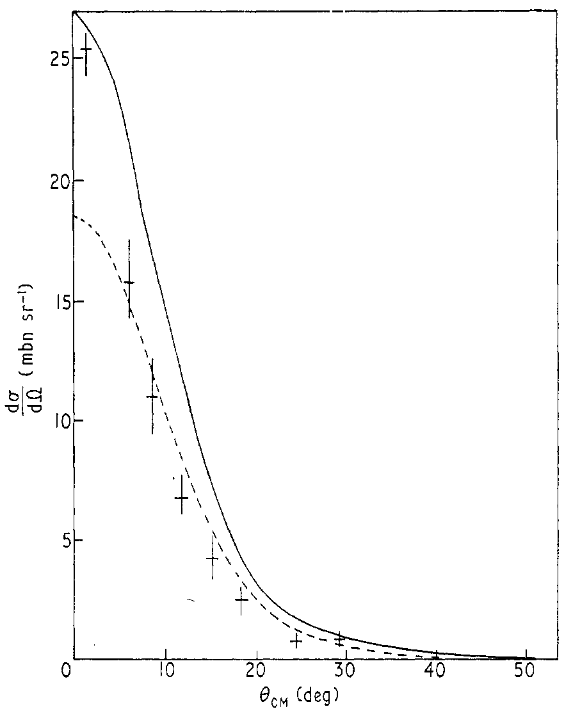
$$\frac{d\sigma}{d\Omega_{exc}} = 12{\cdot}25\, I_1 \tag{3.5}$$

where

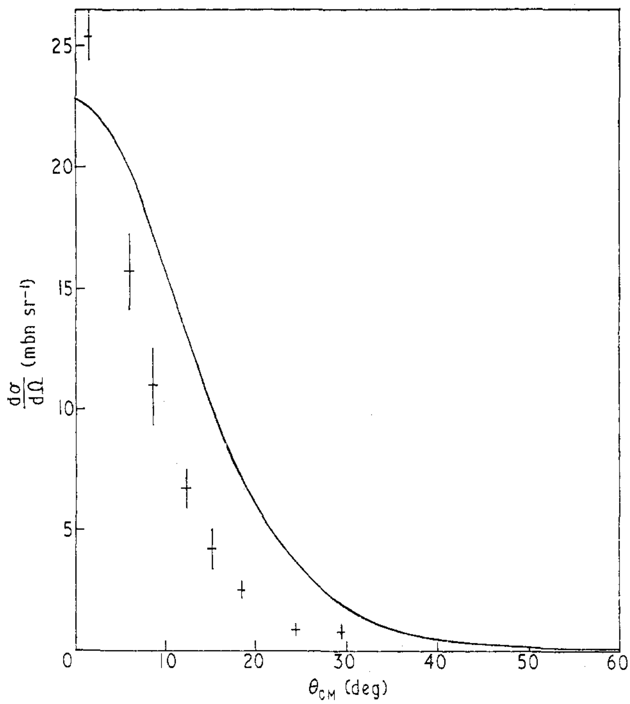
$$\begin{aligned} I_1 = {} & \tfrac{4}{9}(|B_\beta|^2 + |C_\beta|^2 + |F_\beta|^2 + |E_\beta|^2) F_0{}^2(q) \\ & + \tfrac{1}{25}\{9(|A_\beta|^2 + |C_\beta|^2) + 7(|B_\beta|^2 + |C_\beta|^2 + |F_\beta|^2) + |E_\beta|^2\} F_2{}^2(q) \\ & + \tfrac{2}{15}\{(|B_\beta|^2 + |C_\beta|^2 + |F_\beta|^2 - 2|E_\beta|^2\} F_0(q) F_2(q). \end{aligned} \tag{3.6}$$

The functions $F_0(q)$ and $F_2(q)$ are defined by equation (3.4). A similar expression was obtained for inelastic proton scattering to the 0·478 MeV state in ^{7}Li (Mahalanabis 1964) but the scattering coefficients were appropriate combinations of α and β terms, whereas in the (p, n) transitions only β terms appear.

The cross sections for ^{7}Li(p, n) ^{7}Be and ^{7}Li(p, n) ^{7}Be* (0·431 MeV) were calculated by the above formulae, using the values of two-nucleon phase shift as tabulated in Kerman *et al.* (1959), for 90 MeV incident energy of the proton. The oscillator length parameter



(*a*)



(*b*)

Figure 2. (*a*) The cross section as obtained in the plane-wave impulse approximation for the ^{7}Li (p, n) ^{7}Be and ^{7}Li (p, n) ^{7}Be* (0·431 MeV) reaction for E_p = 90 MeV, and the experimental results for E_p = 94 MeV (Saltmarsh 1965). The value of oscillator parameter used is b = 1·718 fm. All the experimental cross sections are subject to a 12% normalization error. —— ^{7}Li (p, n) ^{7}Be (ground state), - - - ^{7}Li (p, n) ^{7}Be* (0·431 MeV state), ┼ experimental results (Saltmarsh 1965), θ_{CM} centre-of-mass angle in degrees, dσ/dΩ in mbn sr^{-1}. (*b*) The sum of the theoretical cross sections for the two reactions shown in figure 2(*a*) and the experimental results. The theoretical values have been multiplied by $\frac{1}{2}$. —— [^{7}Li(p, n) ^{7}Be + ^{7}Li (p, n) ^{7}Be*] × $\frac{1}{2}$, ┼ experimental results (Saltmarsh 1965), θ centre-of-mass angle in degrees, dσ/dΩ in mbn sr^{-1}.

was taken to be 1·72 fm as obtained from the analysis of electron scattering data (Rand *et al.* 1966). We have used the same oscillator parameters for ^{7}Li and ^{7}Be as they are mirror nuclei. The results are shown in figure 2(*a*) together with the experimental results at 94 MeV (Saltmarsh 1965). The experimental results have contributions from the ground state as well as from the 0·431 MeV state in ^{7}Be, since they were not resolved. In both the reactions the theoretical cross sections show a strong forward peak due to the $l = 0$ transition. The magnitude of the 'excited state' (p, n) transition is smaller than that of the ground-state transition but certainly not an order of magnitude smaller. The ratio of the theoretical cross sections for the excited-state to the ground-state transitions in ^{7}Be is approximately 68%.

4. Discussion

It is evident from figure 2(*a*) that there is a good shape agreement between the theoretical values and the experimental results, but a discrepancy exists in the magnitude of the cross sections. The theoretical value of the 0° cross section for the ground-state transition agrees fairly well with the experimental results for the sum of both reactions. In figure 2(*b*) we have plotted the theoretical values (multiplied by $\frac{1}{2}$) of the sum of the cross sections for the two reactions together with the experimental results. It is seen that by reducing the theoretical values by a half, good agreement is obtained. It may be noted that we have used plane waves only and the effects of distortion have not been considered in the calculation. (Similar calculations for ^{6}Li (Jackson and Mahalanabis 1965) show that use of distorted

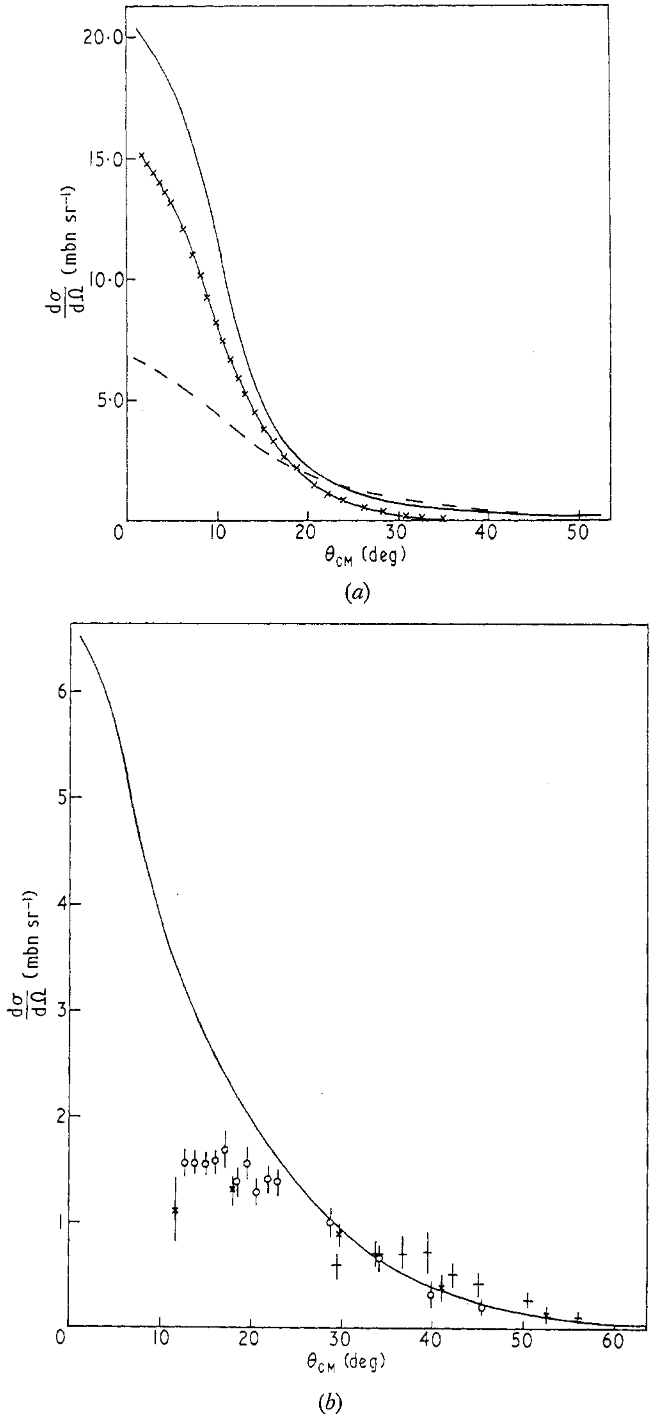


Figure 3. (*a*) The differential cross sections for the (p, p′) and the (p, n) reactions in ^{7}Li as obtained in the plane-wave impulse approximation at 156 MeV. The value of oscillator parameter used is $b = 1{\cdot}718$ fm. —— ^{7}Li (p, n) ^{7}Be (ground state), –x–x–x– ^{7}Li (p, n) ^{7}Be* (0·431 MeV state), – – – ^{7}Li (p, p′) ^{7}Li* (0·478 MeV state), θ centre-of-mass angle in degrees, dσ/dΩ in mbn sr^{-1}. (*b*) The cross section obtained in the plane-wave impulse approximation for the inelastic proton scattering to the 0·478 MeV state in ^{7}Li at 156 MeV, and the experimental results ($b = 1{\cdot}718$ fm). ⁎ Newton *et al.* 1962 (155 MeV), + Tatischeff *et al.* 1964 (156 MeV), ϕ Hasselgren *et al.* 1965 (181 MeV), θ centre-of-mass angle in degrees, dσ/dΩ in mbn sr^{-1}.

waves does not significantly affect the results regarding inelastic scattering.) The effect of optical absorption is well known; the main effect will be a reduction of the cross section, perhaps as much as a half. It has been shown (Hayborn and McManus 1964) that distortion effects are essentially the same for the spin-flip and non-spin-flip matrix elements. Hence, if these distortion effects are taken to be significantly large the discrepancy in the magnitude may be removed.

Experimentally the two transitions were not resolved. However, an attempt was made (Saltmarsh 1965) to determine R, the ratio of the cross sections for the excited-state transition to the ground-state transition. Two different methods were used but the results of the analysis were rather uncertain. The values of R as obtained by the two different methods are: (i) $0{\cdot}25 \pm 0{\cdot}25$, (ii) $(8\ {}^{+25}_{-8})\%$. If the value of R is taken to be small, the cross section for the excited-state (p, n) transition would be very small at 0° angle contrary to that predicted by the theory. Owing to the large uncertainty in the value of R, no definite conclusions can be drawn until some more experimental data are available.

The inelastic proton scattering to the 0·478 MeV state in ^{7}Li at 156 MeV has been studied earlier (Mahalanabis 1964, Mahalanabis and Jackson 1966). The theoretical angular distribution for this reaction is similar to that of the (p, n) transitions, but much smaller in magnitude. The theoretical cross section for the (p, p′) reaction is shown in figure 3(a) together with the cross sections for the (p, n) reactions in ^{7}Li for 156 MeV protons. All three curves are dominated by the $l = 0$ transitions and a forward peak in the cross section is obtained. The theoretical cross section for the 156 MeV proton scattering to the 0·478 MeV level in ^{7}Li is shown in figure 3(b) together with the experimental results at 156 and 181 MeV (Newton *et al.* 1962, Tatischeff *et al.* 1964, Hasselgren *et al.* 1965 and private communication). The theoretical cross section is dominated by the $l = 0$ spin-flip transitions at small angles and at large angles the main contribution to the cross section is due to the $l = 2$ transition which is very small. Experimentally no forward peak has been observed and the large-angle results show significant contributions from the $l = 2$ transition. It is of course known that the $l = 2$ transitions are underestimated by shell-model theory and they will be enhanced when the effects of higher configurations are included using Nilsson's wave function (Pinkston and Satchler 1961). Calculations (Johansson 1967, Mahalanabis 1967) were done using Kurath's wave function (Kurath 1965), obtained by the method of generator coordinates to study the effects of configuration mixing resulting from a quadrupole deformation. This could explain the large-angle results for a suitable choice of the admixture coefficients, but could not explain the small-angle results. In fact even with configuration mixing the cross section for 0° is dominated by the forward peak due to the $l = 0$ transition and its magnitude remains unchanged. A complete suppression of the $l = 0$ contribution is difficult to explain because such a contribution is not forbidden by the shell model or the unified model, since the selection rules are the same in both cases. However, it may be noted that the small-angle results for this reaction are very few, and the experimental results are mainly at large angles, outside the main impulse approximation peak, and they are mostly very inaccurate. Hence, from the absence of a forward peak in the experiment, it is rather difficult to draw any definite conclusion regarding the structure effects until small-angle measurements (less than 10°) are done and the magnitude of the $l = 0$ component is firmly established.

Recently Bouten *et al.* (1967) have used wave functions for ^{7}Li obtained from a projected Hartree–Fock calculation and have obtained excellent agreement for the electromagnetic properties and form factors for the electron scattering. They have included in their calculation the possibility of excitation of the inner-core particles, and indeed their results after variational calculation for the energy did produce significant core excitations. We are at present making use of their wave functions to calculate the (p, n) and (p, p′) cross sections.

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