Inelastic scattering of protons from $^{6,8}$He and $^{7,11}$Li in a folding model approach

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Abstract

The proton-inelastic scattering from $^{6,8}$He and $^{7,11}$Li nuclei are studied in a folding model approach. A finite-range, momentum, density and isospin dependent nucleon-nucleon interaction (SBM) is folded with realistic density distributions of the above nuclei. The renormalization factors $N_R$ and $N_I$ on the real and volume imaginary part of the folded potentials are obtained by analyzing the respective elastic scattering data and kept unaltered for the inelastic analysis at the same energy. The form factors are generated by taking derivatives of the folded potentials and therefore required renormalizations. The $\beta$ values are extracted by fitting the $p + ^{6,8}$He, $^{7,11}$Li inelastic angular distributions. The present analysis of $p + ^8$He inelastic scattering to the 3.57 MeV excited state, including unpublished forward angle data (RIKEN) confirms $L = 2$ transition. Similar analysis of the $p + ^6$He inelastic scattering angular distribution leading to the 1.8 MeV ($L = 2$) excited state fails to satisfactorily reproduce the data.

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1. Introduction

Recent advances in nuclear physics have given us the opportunity to delve into unique problems, hitherto unknown. An example is the neutron halo in the nucleus $^{11}\text{Li}$, discovered as a consequence of its very large interaction radius, deduced from the measured interaction cross sections of $^{11}\text{Li}$ with various target nuclei [1, 2, 3]. The halo of the nucleus extends its matter distribution to a large radius. Thus, the two valence neutrons in $^{11}\text{Li}$, which form the halo, are extended well beyond the $^9\text{Li}$ core and the 2n separation energy is exceedingly small (0.247 MeV). Besides the renowned example of $^{11}\text{Li}$, there are other neutron rich nuclei, like $^6\text{He}$ and $^8\text{He}$ having extended valence neutron distributions called neutron halos/skins [4, 5]. While $^6\text{He}$ and $^{11}\text{Li}$ have predominant core and two valence neutron structures, the $^8\text{He}$ nucleus has four valence neutrons and has the largest neutron to proton ratio among these three nuclei.

Along with the structures of such exotic nuclei near the drip lines, their excitation modes have also attracted considerable attention in recent times [3, 6, 7]. The existence of the neutron halo around the core, gave birth to the idea of a new resonance mode of excitation called, the soft dipole resonance (SDR) [8, 9], in which the halo neutrons oscillate against the core nucleus. From phenomenological and microscopic analyses of the $^{11}\text{Li}(p,p')^{11}\text{Li}^*$ angular distribution data, excitation of the 1.3 MeV resonant state of $^{11}\text{Li}$ was found to correspond to $L = 1$ transition [3, 10], arising from SDR [11, 12]. Earlier microscopic analysis of $p + ^7\text{Li}$ inelastic scattering, include the work of Mani et al. [13] and Petrovich et al. [14], where abnormally large deformations were predicted in [13]. For $p + ^8\text{He}$ inelastic scattering, coupled channel calculations using a Woods Saxon potential was carried out in Ref. [1] and spin-parity of the excited state ($E^* = 3.57$ MeV) was predicted. The $p + ^6\text{He}$ inelastic angular distribution data leading to $E^* = 1.8$ MeV [15] is also available. Since all of $^7, ^{11}\text{Li}$ and $^6, ^8\text{He}$ are loosely bound, their wave functions are quite extended in space. But, their difference in internal structures could lead to different excitation modes. In fact, SDR has been predicted in $^6\text{He}$ and $^{11}\text{Li}$, but not in $^7\text{Li}$ and $^8\text{He}$. To appreciate this difference, a systematic study of their inelastic proton scattering data is desirable.

In this work we present a consistent analysis of the proton inelastic scattering from $^7, ^{11}\text{Li}$ and $^6, ^8\text{He}$ nuclei in a folding model approach. Although sophisticated folding calculations of two nucleon t- and g-matrices exist in a recent review of Amos et al. [16], we feel that, a simpler calculation is always useful. The folding model is well known as a powerful tool for analyzing nucleus-nucleus scattering data at relatively low incident energies [14, 17, 18, 19]. It directly links the density profile of the nucleus with the scattering cross sections and is thus very appropriate for studying nuclei with exotic
matter distributions. However, in such analysis the choice of the nucleon-nucleon interaction is very crucial. As the unstable radioactive nuclei have different neutron and proton density distributions, an isospin sensitive nucleon-nucleon interaction is required to construct the folded potentials \[14, 20\]. For nuclei with low breakup thresholds, the folding model analysis also gives an estimation of the breakup channel coupling effects \[21\] on the elastic through its requirement of a renormalization factor \((N_R)\) \[22\] on folded potentials. With increasing incident energy, the breakup channel coupling effect decreases, and the value of \(N_R\) approaches 1.0.

Using a density, momentum and isospin dependent finite range effective interaction \[23\] in a single folding model, the present work analyses the available low energy proton inelastic scattering data from \(^7\)Li \((49.75\text{A MeV})\) \[13\], \(^{11}\)Li \((68.4\text{A MeV})\) \[3\], \(^8\)He \((72.5\text{A MeV})\) \[24, 25\] and \(^6\)He \((40.9\text{A MeV})\) \[15\]. A semi-microscopic analysis in the optical model (OM) framework is carried out for the \(p + ^7\)Li,\(^6\)He elastic scattering data while the OM analysis of \(p + ^{11}\)Li,\(^8\)He elastic scattering at the above energies has already been performed on the same footing in the earlier work \[19\]. In the DWBA calculations of the nuclear excitation, with transferred angular momentum \(L\), the form factors used are obtained by taking the derivative of the semi-microscopic potentials used. The \(p + ^{11}\)Li inelastic scattering though analyzed in \[14, 11, 12\] is repeated here with microscopic real and volume imaginary potentials in addition to phenomenological surface and spin-orbit potentials, and by generating conventional form factors. Slightly different \(N_R\) and \(N_I\) values were obtained by a \(\chi^2\) fit in \[19\] and these new values are used in the present work for the sake of completeness and comparison of the results with other nuclei. The formalism and the analysis are given in section 2 while the summary and conclusions are given in section 3.

### 2. Formalism and Analysis

The form of the single folded potential \[22\], used in the present work is,

\[
U(r_1) = \int \rho(r_2) v_{\text{NN}}(|r_1 - r_2|) d^3 r_2
\]

where, \(\rho(r_2)\) is density of the nucleus and \(v_{\text{NN}}\) is the effective interaction between two nucleons at the sites \(r_1\) and \(r_2\) with densities \(\rho_1(r_1)\) and \(\rho_2(r_2)\) respectively. A finite-range, density, momentum and isospin dependent effective interaction SBM (Modified Seyler Blanchard) is chosen, which has different strengths for pp (or nn) and pn interactions and its form is \[23\],

\[
v_{\text{eff}}(r = |r_1 - r_2|, p, \rho) = -C_{1, u} e^{-r/a} [1 - \frac{p^2}{b^2} - d^2(\rho_1 + \rho_2)^n],
\]

where, the subscripts ‘l’ and ‘u’ refer to like-pair (nn or pp) and unlike-pair (np) interactions, respec-
tively. Here ‘a’ is the range of the two-body interaction in the configuration space, ‘b’ is a measure of the strength of repulsion with relative momentum ‘p’, while ‘d’ and ‘n’ are two parameters determining the strength of density dependence. The parameters n, C₁, Cₜ, a, b, d are given in Table 1. These constants are found to reproduce the bulk properties of nuclear matter and of finite nuclei [23, 26] and are known also to explain the p + 4.6.8He, 6.7.9.11Li scattering data successfully [11, 12, 13, 27]. The parameters are determined without exchange effects and thus they contain the effect indirectly though in a very approximate way.

The 6.8He and 7.11Li densities used in this work are shown in Fig. 1. The density prescriptions remain the same as that used in the earlier work on elastic proton scattering from these nuclei [19]. For 11Li, the cluster orbital shell model (COSM) density [10, 28] has been used. The parametric form of the 7Li density is used from Ref. [14]. The density of 8He [29], was also derived in the COSM approximation. It contains the extended distribution of valence nucleons and correspond to the experimental matter radius. For 6He, the p-inelastic scattering data at 40.9A MeV is recently available [15] and the L-transfer values are already predicted for some excited states [7, 30]. In this work, a number of ground state densities derived [31, 32, 33] by using Faddeev wave function models called, P1, FC, FC6, Q3, Q1, FB, FA, K, C, are employed to predict angular distributions for excitation to the 1.8 MeV state. Those density models incorporate different n-n and n-α potentials with a variation of the two-neutron separation energy E(2n) from about -1.15 MeV to -0.21 MeV and thereby a variation of the root mean squared (rms) radius of 6He. The rms radii corresponding to the above models are 2.32, 2.50, 2.53, 2.54, 2.56, 2.64, 2.64, 2.66, 2.76 fm respectively. These radii were computed assuming that the bare 4He core rms radius is 1.49 fm [32]. The 4He density is also plotted in Fig. 1 to show that all the nuclear densities have a tail extended well beyond the α-core. Since the interaction is isospin sensitive, separate neutron and proton densities of the nuclei are used [19, 29, 34] for folding calculations.

Both the real (V) and volume imaginary (W) parts of the potentials (generated microscopically by folding model) are assumed to have the same shape, as in Ref. [19], i.e. \( V_{micro}(r) = V + iW = (N_R + iN_I)U(r_1) \) where, \( N_R \) and \( N_I \) are the renormalization factors for the real and imaginary parts respectively [18]. These folded potentials with appropriate \( N_R \) and \( N_I \) as required for elastic scattering fits (Table 3 of Ref. [19] and this work), are used subsequently for inelastic scattering analysis in this work. The spin-orbit and the surface imaginary parts are taken from the phenomenological best fit calculations as before (Table 2 of Ref. [19] and this work). They needed minor adjustments in some cases for best fits as reported earlier [19] and in this work. The phenomenological potentials
had the following form,

\[ V_{\text{pheno}}(r) = -V_o f_o(r) - i W_v f_v(r) + 4 i a_s W_s (d/dr) f_s(r) + 2(\hbar/m_\pi c)^2 V_{s.o} 1/r (d/dr) f_{s.o}(r) (\mathbf{L.S}) + V_{\text{coul}}, \]

where, \( f_o(r) = [1 + \exp(\frac{r-R_x}{a_x})]^{-1} \) and \( R_x = r_x A^{1/3} \). The subscripts \( o, v, s, s.o \) denote real, volume imaginary, surface imaginary and spin-orbit respectively and \( V_o, W_v (W_s) \) and \( V_{s.o} \) are the strengths of the real, volume (surface) imaginary and spin-orbit potentials respectively. \( V_{\text{coul}} \) is the Coulomb potential of a uniformly charged sphere of radius 1.40 \( A^{1/3} \).

For each angular distribution studied before [19] as well as here, best fits are obtained by minimizing \( \chi^2/N \), where \( \chi^2 = \sum_{k=1}^{N} \left[ \frac{\sigma_{th}(\theta_k) - \sigma_{ex}(\theta_k)}{\Delta\sigma_{ex}(\theta_k)} \right]^2 \), \( \sigma_{th}/\sigma_{ex} \) are the theoretical/experimental cross sections at angle \( \theta_k \), \( \Delta\sigma_{ex} \) is the experimental error and \( N \) is the number of data points.

The best fit OM parameters for the \( p + ^7\text{Li} \) elastic scattering at \( E = 49.75 \text{A MeV} \) are given in Table 2. In the present semi-microscopic analysis, a search on \( N_R \) and \( N_I \) is carried out for minimum \( \chi^2/N \) and the values are given in Table 3 and the fit is shown in Fig. 2a. The surface imaginary and spin-orbit potentials remain the same as obtained from the phenomenological best fits. For the \( p + ^8\text{He}, ^{11}\text{Li} \) elastic scattering data at 72.5A and 68.4A MeV respectively, the required \( N_R, N_I \) and phenomenological potentials \( (W_s \text{ and } V_{s.o}) \) are already available from the earlier analysis [19]. Using OM parameter setII of \( p + ^8\text{He} \) elastic scattering [5] yields much lesser \( N_R \) value and a better fit to the inelastic data. The corresponding best fit parameters for \( p + ^6\text{He} \) scattering at 40.9A MeV are also given in Table 2,3. To yield minimum \( \chi^2/N \), the \( r_s \) value had to be changed from 1.6 to 1.43, 1.32 and 1.26 fm for the P1, Q1 and C density models of \( ^6\text{He} \). These potentials are therefore used in the DWBA calculations of inelastic scattering with transferred angular momentum \( L \). The calculations are performed by using the code DWUCK4 [36]. The conventional form factors, i.e. derivative of the potentials are used. The microscopic real and imaginary form factors have the same shape with strengths \( N_{R,I}^{FF} \) and \( N_{I}^{FF} \) respectively, where \( N_{R,I}^{FF} = N_{R,I} r_{rms}^{V} \), where the radius parameter \( r_{rms}^{V} \) is the rms radius of the folded potential. Thus the renormalization of the form factors is consistent with that for the folded potential. Form factors derived from phenomenological surface imaginary and spin-orbit potentials are also included.

To fit the \( p + ^7\text{Li} \) inelastic angular distributions leading to the 0.478 and 4.63 MeV excited states of \( ^7\text{Li} \), \( N_{R,I} \) values from elastic scattering fits and the corresponding \( N_{R,I}^{FF} \) are employed. In the former, the best fit yields for the deformation parameter \( \beta \) a value of 0.59 (Fig. 2b, Table 3) for transferred angular momentum \( L = 2 \) \((3/2^- \text{ to } 1/2^-)\). For the 4.63 MeV excited state of \( ^7\text{Li} \) best fit gives a \( \beta = 0.82 \) for \( L = 2 \) \((3/2^- \text{ to } 7/2^-)\). The calculations could explain the data up to \( \theta_{cm} \sim 110^\circ \) and
\( \chi^2 \) value is calculated by incorporating the data points only up to that (Fig. 2c, Table 3). Earlier works \([3, 10, 11, 12]\) showed that the \( p + ^{11}\text{Li} \) inelastic scattering data at \( E = 68.4 \text{A MeV} \) could be satisfactorily explained for angular momentum transfer \( L = 1 \). The \( N_R = 0.50 \) and \( N_I = 0.15 \) values are used in the present work as obtained from earlier work on \( p \)-elastic scattering \([19]\). The \( \chi^2 \) minimum test for best fit resulted in a \( \beta \) value of 0.58 (Fig. 3, Table 3), with \( L = 1 \). Changing the form factors generated from the surface imaginary and spin-orbit phenomenological potentials have negligible effects on the angular distribution.

The \( ^8\text{He} \) nucleus has a very high neutron-to-proton ratio. To confirm the spin-parity of the excited state \( E^* = 3.57 \text{ MeV} \), studies over wide angular range are carried out. We try to fit both the reported \( ^8\text{He}^* \) data (setI) \([24]\) as well as the unpublished angular distribution data (setII) \([25]\). The setII data were obtained from invariant mass measurements as reported in \([24]\). They were measured not by proton detection (like above), but by detecting \( ^6\text{He} + n + n \) coincidences. Namely, the shape of the angular distribution for the inelastic scattering was extracted, while absolute value of the cross section was simply normalized in consistency with the above given inelastic data from proton measurements. It is seen that \( L = 2 \) (\( J^\pi = 2^+ \)) gives best fit. \( L = 1 \) is excluded by the new measurement (setII) and \( L = 3 \) is excluded by all experimental points at larger angles (Fig. 4, Table 3). The \( \beta = 0.28 \) is lesser than 0.44 in \([3]\).

Similar analysis is extended to the recently available \( p + ^6\text{He} \) inelastic angular distributions at 40.9A MeV (Fig. 5). The Faddeev wave function densities of \( ^6\text{He} \) \([31, 32]\) are employed and the \( N_R, N_I \) values extracted from elastic scattering (Fig. 5a) are used. The angular distribution for the 1.8 MeV (\( J^\pi = 2^+ \)) excitation is shown in Fig. 5b. For the sake of clarity only three calculations (P1, Q1, C models) are plotted and the rest lie between P1 and C. It is found that contrary to very good fits to the inelastic data for \( p + ^8\text{He}, ^7, ^{11}\text{Li} \), the present formalism is unable to give satisfactory fit to the \( p + ^6\text{He} \) data. But the \( \beta \) value extracted from the optimized fit agrees closely with that of Aumann et al. \([37]\) and Rusek et al. \([38]\) (\( \beta \sim 0.78 \)). It is observed that though the three \( ^6\text{He} \) densities correspond to a variation of rms radius from 2.32 fm to 2.76 fm, the corresponding change in the angular distributions of inelastic scattering is negligible.

3. Summary and Conclusions

A consistent folding model analysis of \( p \)-inelastic scattering of stable and unstable nuclei can provide valuable insight into their structure and reaction dynamics. The present work aims at
studying the inelastic scattering of protons from $^6,^8$He and $^7,^{11}$Li nuclei. The semi-microscopic analysis followed here, involves a finite-range, momentum, density and isospin dependent nucleon-nucleon effective interaction (SBM) and realistic densities of different nuclei. Earlier, a similar analysis of p-elastic scattering data on these nuclei showed that renormalizations ($N_R$ and $N_I$) of the real and volume imaginary part of the folded potentials [19] are required. These factors, once determined from the elastic data, are kept unaltered for the inelastic data analysis to ensure a model independent study.

The conventional way of generating the form factors is followed, i.e., by taking the derivatives of the potentials (microscopic real and imaginary as well as phenomenological surface imaginary and spin orbit). Deformation parameters ($\beta$) are extracted from the analyses. The unpublished [25] forward angle data of p + $^8$He inelastic angular distribution shows that best fit implies an $L = 2$ transition (i.e $J_{3.57}^T = 2^+$) whereas $L = 1, 3$ fail to reproduce the exact structure.

Analysis on the same footing enables us to study elastic and inelastic p + $^6$He scattering at $E = 40.9$A MeV. In contrast to the other nuclei the p + $^6$He inelastic scattering to the 1.8 MeV state ($J_{1.8}^T = 2^+, L = 2$) could not be satisfactorily explained by the present formalism, though the extracted $\beta$ value agrees closely with previous works [37, 38]. Moreover, inclusion of various ground state density prescriptions of varying r.m.s radii (from 2.32 fm to 2.76 fm) have negligible influence on the inelastic observables studied here.

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Table 1:
Parameters of the SBM interaction in MeV-fm units

| n  | C_l | C_u  | a   | b   | d   |
|----|-----|------|-----|-----|-----|
| 2/3| 215.7 | 669.3 | 0.554 | 668.7 | 0.813 |

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Table 2:
Optical potential parameters used in p + nucleus elastic scattering

| Nucleus | E/A (MeV) | V_o (MeV) | r_o (fm) | a_o (fm) | W_v (MeV) | r_v (fm) | a_v (fm) | W_s (MeV) | r_s (fm) | a_s (fm) | V_{s.o} (MeV) | r_{s.o} (fm) | a_{s.o} (fm) | J/A (MeV fm^3) | Ref. |
|---------|-----------|-----------|---------|---------|-----------|---------|---------|-----------|---------|---------|-------------|-----------|---------|----------------|------|
| ^7Li    | 49.8      | 36.70     | 1.210   | 0.550   | 5.62      | 1.730   | 1.220   | 4.90      | 1.000   | 0.530   | 424.6       |           |         | 35              |      |
| ^11Li   | 68.4      | 14.50     | 1.385   | 0.546   | 4.26      | 0.560   | 1.160   | 5.90      | 0.800   | 0.630   | 211.5       |           |         | 19              |      |
| ^8He    | 72.5      | 21.60     | 0.970   | 0.857   | 1.43      | 0.820   | 0.633   | 6.39      | 1.430   | 0.801   | 246.1       |           |         | 5               |      |
| ^6He    | 40.9      | 45.40     | 0.990   | 0.612   | 2.60      | 1.101   | 0.690   | 3.47      | 1.600   | 0.772   | 397.7       |           |         | 3               | [*]  |

[*] this work

Figure Captions

1. The densities of (a) ^4,^6,^8He (b) ^4He, ^7,^11Li used in this work (see the text for references).

2. The experimental angular distributions and folding model calculations (employing SBM interaction) of ^7Li at 49.75A MeV for (a) elastic and (b) E^* = 0.478 MeV (1/2^−), (c) E^* = 4.63 MeV (7/2^−) state for inelastic scattering. Here L = 2 in (b) and (c). The corresponding N_R, N_I, N^{FF}_R, N^{FF}_I values and phenomenological surface imaginary and spin-orbit parameters are given in Table 2, 3.

3. The same as in Fig. 2 for ^11Li at 68.4A MeV and E^* = 1.3 MeV state for inelastic scattering. Here L = 1.

4. The same as in Fig. 2 for ^8He at 72.5A MeV for (a) elastic and (b) E^* = 3.57 MeV state for inelastic scattering. In (b) the data represented by solid circles (Set I) are from [24] while the data represented by hollow circles (Set II) are yet unpublished and obtained from [25]. The L = 1 , 2 , 3 calculations are shown by dashed, solid and dotted curves respectively.

5. The same as in Fig. 2 for ^6He at 40.9A MeV for (a) elastic and (b) E^* = 1.8 MeV state for inelastic scattering. Here L = 2. The calculations are shown by the dashed, solid and dotted curves for the P1, Q1 and C models.
Table 3:
Renormalizations of SBM folded potentials and form factors for p-nucleus scattering at incident energy (E/A) and excited state energy (E*) in MeV, angular momentum transfer (L), deformation parameter (β), volume integral (J/A) of the real folded potential in MeV fm$^3$ and χ$^2$/N values from the elastic and inelastic scattering best-fits

| Nucleus | E/A  | E*   | N_R  | N_I  | $r_{rms}$ | N$_{R}^{FF}$ | N$_{I}^{FF}$ | L | β  | $\chi^2_{el}$/N | $\chi^2_{inel}$/N | J/A |
|---------|------|------|------|------|-----------|--------------|--------------|----|----|----------------|-----------------|-----|
| 7Li$^*$ | 49.8 | 0.478| 0.75 | 0.24 | 2.853     | 2.140        | 0.685        | 2  | 0.59| 5.681          | 6.692           | 423.8|
| 7Li$^*$ | 49.8 | 4.630| 0.75 | 0.24 | 2.853     | 2.140        | 0.685        | 2  | 0.82| 5.681          | 1.369           | 423.8|
| 11Li$^*$| 68.4 | 1.300| 0.50 | 0.15 | 3.909     | 1.954        | 0.586        | 1  | 0.58| 0.488          | 0.353           | 282.6|
| 8He$^*$ | 72.5 | 3.570| 0.41 | 0.00 | 3.300     | 1.353        | 0.000        | 1  | 0.32| 0.594          | 37.007          | 247.7|
| 8He$^*$ | 72.5 | 3.570| 0.41 | 0.00 | 3.300     | 1.353        | 0.000        | 2  | 0.28| 0.594          | 0.452           | 247.7|
| 8He$^*$ | 72.5 | 3.570| 0.41 | 0.00 | 3.300     | 1.353        | 0.000        | 3  | 0.55| 0.594          | 24.777          | 247.7|
| ^6He$^*$ (P1) | 40.9 | 1.800| 0.68 | 0.00 | 3.125     | 2.125        | 0.000        | 2  | 0.71| 6.247          | 11.361          | 444.1|
| ^6He$^*$ (Q1) | 40.9 | 1.800| 0.68 | 0.00 | 3.358     | 2.283        | 0.000        | 2  | 0.71| 6.907          | 14.743          | 469.8|
| ^6He$^*$ (C) | 40.9 | 1.800| 0.68 | 0.00 | 3.558     | 2.419        | 0.000        | 2  | 0.71| 7.980          | 18.178          | 484.8|
$^{4}\text{He}$

$^{8}\text{He}$
$d\sigma /d\Omega$ (mb/sr)

(a) $^7\text{Li}(p,p)^7\text{Li}$

$E = 49.75A$ MeV

(b) $^7\text{Li}(p,p')^7\text{Li}^*_{0.478}$

$E = 49.75A$ MeV

(c) $^7\text{Li}(p,p')^7\text{Li}^*_{4.63}$

$E = 49.75A$ MeV

$\theta_{\text{cm}}$ (deg)

$L = 2$
\[ \frac{d\sigma}{d\Omega} (\text{mb/sr}) \]

(a) $^8\text{He}(p,p)^8\text{He}$

\[ E = 72.5 \text{ A MeV} \]

\[ L = 1 \]
\[ L = 2 \]
\[ L = 3 \]

(b) $^8\text{He}(p,p)^8\text{He}^\ast_{3.57}$

\[ E = 72.5 \text{ A MeV} \]
\[ \frac{d\sigma}{d\Omega} (\text{mb/sr}) \]

\[ \theta_{\text{cm}} \text{ (deg)} \]

(a) \[ ^6\text{He}(p,p)^6\text{He} \]
\[ E = 40.9\text{A MeV} \]

(b) \[ ^6\text{He}(p,p)^6\text{He}^{*1.8} \]
\[ E = 40.9\text{A MeV} \]

\[ L = 2 \]