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# 1.4 Lane Model Analysis for the $^9$Be + Nucleon System

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The single isospin-conserving Lane[1] potential $U(r) = U_0(r) + (4/A)\ \vec{t}\cdot\vec{T}\ U_1(r)$ unifies collision processes involving targets of one isospin multiplet and projectiles of another. For a target with isospin $T_3 = T$, the (p,p), (p,n), and (n,n) channels are coupled by the Lane equations:

$$
\begin{aligned}
U_{pp}(r) &= \langle C|\langle p|U(r)|p\rangle|C\rangle = U_0(r) - (2T/A)\ U_1(r)\\
U_{pn}(r) &= \langle A|\langle n|U(r)|p\rangle|C\rangle = (2\sqrt{2T}/A)\ U_1(r)\\
U_{nA}(r) &= \langle A|\langle n|U(r)|n\rangle|A\rangle = U_0(r) + (2(T-1)/A)\ U_1(r)\\
U_{nn}(r) &= \langle C|\langle n|U(r)|n\rangle|C\rangle = U_0(r) + (2T/A)\ U_1(r)
\end{aligned}
$$

Here C and A label state vectors for the target nucleus and its isobaric analog state, respectively. The potentials $U_{pp}$, $U_{nn}$, and $U_{pn}$ generate proton and neutron elastic scattering, and the quasi-elastic (p,n) reaction, respectively.

The Lane model successfully described the magnitude and character of $\sigma(\theta)$ from the many (p,n) experiments which ensued from its proposal and accounted for the difference in the potential strengths required to describe proton and neutron scattering. The light nuclei received relatively little attention, and the present study of $^9$Be is part of our program at TUNL for exploring this mass region.

The isovector potential $U_1(r)$ that emerged from Lane model studies in the past has a central part which is complex with a surface peaked imaginary part. However, two basic questions about $U_1(r)$ which remained unanswered and are addressed in this paper are: 1) What is the radial shape of the real central part and 2) Is there a spin-orbit term? Although very inconclusive, existing evidence seems to favor a surface-peaked real central potential for the heavier nuclei and a volume-shape for the light nuclei.

The question of an isovector spin-orbit term is a result of the dearth of (p,n) $A_y(\theta)$ data, which should be most sensitive to such a term. The few analyses[2,3,4] which included such data suggested a real part, $V_1^{so}$. An imaginary part was strongly suggested in our recent $^9$Be(n,n) analysis[5], which required a $W^{so}$ term to simultaneously describe both $\sigma(\theta)$ and $A_y(\theta)$. This term is clearly absent in $^9$Be(p,p), and the Lane model demands a $W_1^{so}$ term to account for this difference.

We have now enlarged our $^9$Be Lane model data base to include (n,n) $A_y(\theta)$ and our new time-of-flight measurements of (p,n) $\sigma(\theta)$ and $A_y(\theta)$, thereby establishing the first model-complete data base and increasing the energy to 17 MeV. While earlier studies[4] have investigated the central part of $U_1(r)$ by including $\sigma(\theta)$ for all three channels, this is the first study to investigate a full complex isovector spin-orbit potential by also including the complete set of $A_y(\theta)$ data.

The real central, imaginary central, and spin-orbit (real and imaginary) parts of $U_{nn}(r)$ and $U_1(r)$ were parameterized as Woods-Saxon, derivative Woods-Saxon, and standard Thomas forms, respectively. All other potentials were then calculated point-by-point from these two using the Lane equations. Coulomb corrections were estimated using the approximation of a spherical nuclear charge distribution.

The calculations are shown as solid curves in Fig. 1. It is seen that the model is largely successful in describing the data for all three channels. The most serious deficiencies occur in the forward-angle minimum of $\sigma(\theta)$ and the backward-angle maximum of $A_y(\theta)$ for the (p,n) reaction, both regions in which a simple direct reaction approach is particularly limited. The parameters are listed in Table I. The data unambiguously prefer a volume form for $V_1(r)$, a characteristic also found[6], for $^{13}$C and $^{15}$N, and in our recent study of $^{11}$B. The analysis also confirms the existence of a complex isovector spin-orbit potential.

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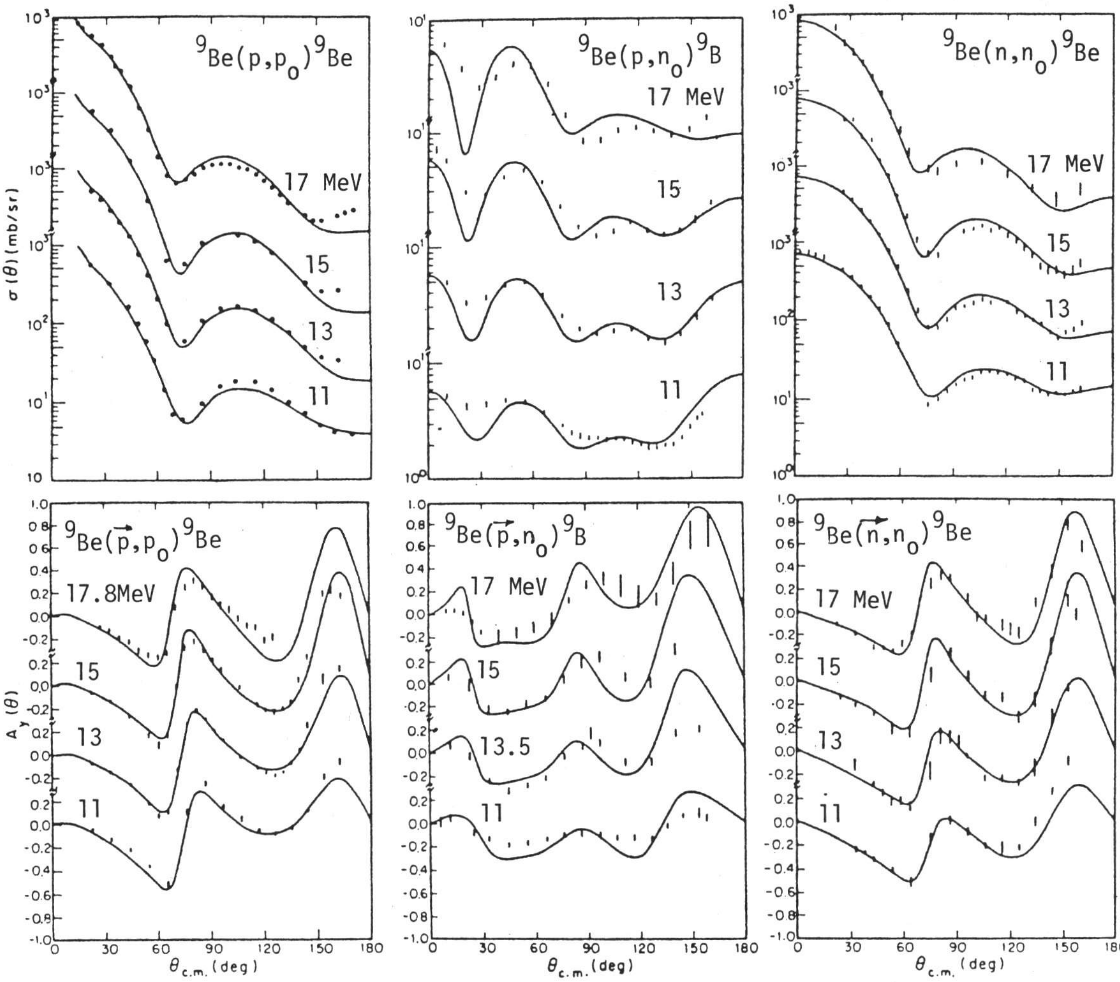


Fig. 1. Comparison of Lane model calculations to data for $^9$Be.

**Table I. Lane Model Potential Parameters**

| E(MeV) | | $V_{nn}$ | $W_{nn}$ | $V_{nn}^{so}$ | $W_{nn}^{so}$ | $V_1$ | $W_1$ | $V_1^{so}$ | $W_1^{so}$ |
|---|---|---|---|---|---|---|---|---|---|
| 11,13 | Depth | 43.95,44.07 | 9.65,9.52 | 3.56,3.94 | 1.91,1.49 | 32.73,30.94 | 5.39,3.86 | 2.66,2.79 | -5.03,-2.97 |
| 15,17 | | 44.19,44.31 | 9.40,9.28 | 4.33,4.71 | 1.08,0.66 | 29.15,27.36 | 2.33,0.79 | 2.92,3.06 | -0.90, 1.16 |
| | $r_0$ | 1.286 | 1.604 | 1.150 | 1.699 | 0.250 | 1.313 | 1.366 | 1.069 |
| 11,13 | a | 0.608,0.529 | 0.287 | 0.279 | 0.187 | 1.971 | 1.023 | 1.314 | 0.232 |
| 15,17 | | 0.460,0.492 | | | | | | | |

| Coulomb Corrections: | $\Delta V_C$(pp) | $\Delta V_C$(nA) | $\Delta V^{so}{}_C$(pp) | $\Delta V^{so}{}_C$(nA) |
|---|---|---|---|---|
| 11,13 | -0.013,-0.021 | 0.030,0.023 | -0.041,-0.066 | 0.096,0.071 |
| 15,17 | -0.029,-0.037 | 0.015,0.007 | -0.090,-0.115 | 0.046,0.022 |

Coulomb radius = 1.300

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