NATIONAL SUPERCONDUCTING CYCLOTRON LABORATORY
PROPOSAL FOR EXPERIMENT

Date Submitted: 04-12-2001 Experiment # ____________________
(Assigned by NSCL)

TITLE: **Proton Induced Stripping Reactions on Radioactive N=6 and N=8 Isotones**

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Is this a thesis experiment? Yes If yes, for whom? X. Liu

OTHER EXPERIMENTERS: (please spell out first name) Check, if applicable

Name	Organization	Grad	Sr. Grad
W. Lynch	NSCL		
X. Liu	NSCL		x
D. Bazin	NSCL		
R. Charity	WU		
M-J. van Goethem	NSCL		
M.B. Tsang	NSCL		
L.G. Sobotka	WU		
G. Verde	NSCL		
M. Wallace	NSCL		
	x		

REQUEST FOR CURRENT PERIOD: BEAM ON TARGET (either primary or rare-isotope)

	Particle	E/A (MeV)	Current (pps)	Desired beam purity (%)	Hours on target
a)	^{9}Li	50	200k	>70	18
b)	^{8}He	50	200k	>70	18
c)	^{11}Li	50	200k	>70	14
d)	^{12}Be	50	200k	>70	18
e)	^{13}C	50	200k	>70	24

TOTAL REQUESTED HOURS: 188 (Calculated per note on beam list. Include time for test runs, for calibration of beams, and for particle/energy changes)

Will further time be requested for a subsequent PAC? If so, estimate additional hours: ____________________

HOURS APPROVED: ____________________

HOURS RESERVED: ____________________

SET UP TIME: (before start of beam):

Access to:	Experimental Apparatus	168	hrs
	Electronics Set-up Area	**168**	hrs (Be realistic--affects scheduling)
	Data Acquisition Computer	**168**	hrs

TAKE DOWN TIME: (After beam, include all calibrations, etc.):

Access to:	Experimental Apparatus	**84**	hrs
	Electronics Set-up Area	**84**	hrs (Be realistic--affects scheduling)
	Data Acquisition Computer	**168**	hrs

WHEN WILL YOUR EXPERIMENT BE READY TO RUN? 4 / 1 / 2002

DATES EXCLUDED: ______

EXPERIMENTAL EQUIPMENT (CHECK WHICH OF THESE DEVICES WILL BE USED):

______	A1900	______	Ge Array
______	4pi Array	______	NaI Array
______	92" Chamber	______	Beta-Decay Station
______	RPMS*	______	Neutron Walls
X	S800 Spectrograph	______	SuperBall
______	Irradiation Station	HiRA	Other (give details)

*The RPMS is being refurbished and is not expected to be available for experiments till the beginning of 2002.

TARGETS: 2 mg/cm^2 CH_2 foil

SPECIAL REQUIREMENTS: (e.g., shipping RADIOACTIVE targets or sources, toxic gases, etc.)

NOTE: Shipping radioactive materials require permission of both your institution and MSU. For information, contact Kristin Erickson (517)355-5008, ERICKS30@MSU.EDU.

SUMMARY (no more than 200 words)

We propose to measure one and two neutron transfer reactions on ^{8}He, ^{9}Li, ^{11}Li and ^{12}Be, extending the investigation of N=6 isotones initiated before the termination of K1200 operations. These measurements will provide information about changes in the occupancies of neutron single particle orbits of N=6 and N=8 isotones with proton number as one approaches the neutron drip line. In this region, breakup reactions have revealed inversions of the usual shell model orbits for the N=8 isotones as the drip-line is approached but not for the N=6 isotones. Transfer reactions can provide independent confirmation of those results as well as provide sensitivity to additional components of the ground state wavefunctions that have not been probed so far.

DESCRIPTION OF EXPERIMENT

1. Physics Justification

The N=6 isotones may show an interesting evolution with proton number. It is generally expected that the shapes of these nuclei evolve from prolate to oblate deformed as the mass number is increased above about A=10 [1,2]. The internal structures of the lightest two N=6 isotones are uncertain and only the ground states of ^{9}Li and ^{8}He have definite spin and parity assignments. Intruder orbits from the next major shell play a significant role in neighboring nuclei. In ^{10}Be, for example, the $2s_{1/2}$ orbits are important for the negative parity 5.960 and 6.263 MeV excited states. In ^{10}Li, the prevailing experimental evidence indicates that the ground state valence neutron is in a $2s_{1/2}$ orbit [3]. The energetics of the single neutron valence orbits in the N=7 isotones, shown in Figure 1, reveal that the $2s_{1/2}$ orbits decrease with energy relative to the 1p orbits with decreasing proton number and become the valence orbits at large neutron excess [4].

Many of these effects have been studied more extensively in the N=8 isotones. For example, the $2s_{1/2}$ orbits are major components of the valence configurations for ^{11}Li $(\nu 2s_{1/2})^2$ and ^{12}Be $(\nu 2s_{1/2})^2$, consistent with the inversion of $2s_{1/2}$ and $1p_{1/2}$ orbits shown in Figure 1 [5,6]. Shell model calculations predict commensurate admixtures of $2d_{5/2}$ orbits in these states, but experimental evidence for this is currently lacking [6].

The roles of the $2s_{1/2}$ orbits in the ground state wave functions of ^{9}Li and ^{8}He are not well known. Neutron-fragment angular correlations measured at GSI in ^{8}He breakup reactions [7] and (p,d) transfer reactions at RIKEN [8] suggest that 1p orbits dominate the valence structure of ^{8}He as they do for ^{6}He. In contrast, breakup reactions predict nearly equal admixtures of valence 2s and 1p orbits for ^{11}Li and ^{12}Be [5-7]. Additional transfer reactions can supply information needed to confirm the picture. Table I shows a comparison between calculated and measured relative spectroscopic factors for ^{11}B(p,d)^{10}B and the calculated relative spectroscopic factors for ^{9}Li(p,d)^{8}Li [9-12]. For the case of the ^{11}B(p,d)^{10}B reaction, the spectroscopic factors for the strong ^{11}B(p,d)^{10}B transfer reactions to the ground state and the second third and seventh excited states in ^{10}B are in close agreement with the measured values. If $2s_{1/2}$ intruder orbits become increasingly important with increased neutron excess, the measured spectroscopic factors for the strong ^{9}Li(p,d)^{8}Li transfer reactions to the first three states in ^{8}Li will become significantly less than the theoretical values. By measuring the spectroscopic factors for ^{9}Li and ^{8}He relative to those for the other N=6 isotones, the role of intruder configurations in the ^{9}Li and ^{8}He ground states can be assessed. The measurements of (p,t) reactions, in addition, will permit examination of the correlations between neutrons in the ^{9}Li and ^{8}He ground states.

Measurements of the corresponding $^{11}B(p,d)^{10}B$, $^{11}B(p,t)^{9}B$, $^{10}Be(p,d)$ [10] and $^{8}He(p,d)$ reactions [8] exist. In the case of $^{8}He(p,d)$, these measurements have provided evidence of an excited state at 3.3 MeV built upon the $J^{\pi}=2^{+}$ first excited state of ^{6}He [8]. The proposed measurements will reexamine these issues with improved resolution. The proposed measurements of the $^{8}He(p,t)$ reaction will directly test whether the ground state of ^{8}He contains the ^{6}He subsystem predominantly in the excited state 2^{+} state as proposed by ref. [8].

Similar investigations address the shell model occupancies in the N=8 isotones. In particular the ^{11}Li.,^{12}Be isotones have been studied experimentally and theoretically (see for instance [5,6,14]) but no (p,d,) or (p,t) reaction data exist. These nuclei can also be studied using the (p,d) neutron-transfer reaction in same experimental setup as proposed here for the N=6 isotonic chain. These measurements will provide an important confirmation that the spectroscopic factors for $1p_{1/2}{}^{2}$ and $1p_{1/2}{}^{2}$ valence configurations are comparable in these nuclei as determined from breakup reaction measurements. It will also provide the first tests of the expectation that the spectroscopic factors for the $1d_{5/2}{}^{2}$ are of comparable magnitude [6]. The proposed measurements of the $^{12}Be(p,t)$ and $^{11}Li(p,t)$ reaction will directly test whether the ground state of these two halo nuclei consist of a two neutron halo about ground state ^{10}Be or ^{9}Li core or whether there are significant contribution with the core in an excited state as was proposed for ^{8}He [8].

2. Goals of Proposed Experiment

We propose to measure (p,d) and (p,t) stripping reactions induced by radioactive ^{9}Li , ^{8}He, ^{11}Li and ^{12}Be nuclei incident on a CH_2 target. The comparison between these two isotonic chains will address the question of whether the inversion of the neutron orbits, shown in Figure 1 for the N=7 isotonic chain, is limited to nuclei in the N=7 and N=8 isotonic chains or if it is a general feature of light nuclei with large neutron excess. The (p,d) measurements will be compared to spectroscopic factors provided by shell model calculations to determine whether the spectroscopic strength for valence 2s, 1p and 1d orbits are correctly predicted and to the spectroscopic factors from breakup measurements to confirm the admixtures obtained from that work. The (p,t) measurements will provide additional information about pairing effects and core excitation in the ground states of two neutron halo nuclei.

3. Experimental Details

We propose to detect the scattered deuterons and tritons with the HiRA array. This device consists of 20 position sensitive silicon strip – silicon strip - CsI(Tl) scintillator telescopes. The pitch of the two silicon strip detectors allows the detectors to be divided into 2 mm x 2 mm wide sections; each telescope subtends a solid angle of about 24 msr when placed at a distance of 40 cm from the target. A sketch showing the 20-telescope array is shown in Figure 2. To minimize the loss of coverage due to detectors mounts and frames, the telescopes at the smaller angles will be place somewhat closer to the target than the telescopes at larger angles. The overall coverage of the array is a good match to the laboratory scattering angles for the scattered deuteron; these are shown as a function of the deuteron center of mass scattering angle in Figure 3. Typical energies for the relevant scattered deuterons range from 7-20 MeV.

The (PLF) will be detected in the S800 spectrometer. This makes the experiment over-determined and aids in the suppression of background from the target (which will be a 1 mg/cm^2 CH_2 foil). This will lead to an estimated energy resolution of better than 200 keV FWHM in the center of mass system. The trajectories of individual beam particles will be measured with tracking counters to ensure an accurate correction for the large radioactive beam emittance. Assuming that one can achieve a position resolution of 1 mm at the target and that the angle of the beam can be measured by beam tracking, the experimental setup will achieve an angular resolution of the order of ±0.16°.

Figure 4 show the data and a DWBA calculation used for the extraction of the experimental spectroscopic factors in Table 1. Unlike the case of (d,p), the (p,d) reaction remains reasonably well matched at energies of E/A = 50 MeV and accurate spectroscopic information can be obtained for low lying transitions [9,10]. The peak of the angular distribution for the proposed measurement is expected at a similar center of mass angle to that of the distribution shown. We plan to measure the cross section in the angular domain $5° \leq \theta_{cm} \leq 20°$ where spectroscopic information can be most accurately obtained. To have an accurate extraction of the weaker transitions, the time estimate was calculated by assuming a cross section of 1 mb/sr for the (p,d) and 0.1 mb/sr for the (p,t) reaction. While the solid angle covered by the array varies with scattering angle, 100 msr represents a conservative estimate of its average value when one bins the data in 5° bins in the center of mass.

Projectile	I (p/s)	(p,d) Cts/hr/(5° bin)	(p,d) Cts/day/(5° bin)	(p,t)Cts/day/(5°bin)	Hours req.
^{9}Li	200k	62	1488	148.8	18
^{8}He	200k	62	1488	148.8	18
^{11}Li	200k	62	1488	148.8	14
^{12}Be	200k	62	1488	148.8	18

The beam intensity is limited by a conservative estimation of the maximum rate at which the particles in the beam can be tracked. If this number should turn out to be higher we can obtain higher statistics in the same amount of time by using higher beam intensity.

For all of these reactions, the scattered projectile-like reaction partner (^{8}Li, ^{7}He, ^{10}Li, ^{11}Be) will be particle unbound for transfer to some or all of the states under investigation. For three of these nuclei, (^{8}Li,

^{7}He, ^{11}Be), two settings for the spectrometer will be require to capture the recoil. In all cases, one of the spectrometer settings needed for the (p,d) reaction will also permit the detection of the recoil for the (p,t) reaction to particle states of remaining nucleus. In order to obtain 200 counts for the ^{9}Li(p,d) reaction, we request a total of 4 hours with the S800 setting for measuring the ^{8}Li nuclei from the (p,d) transfers to the ground and first excited states. We request 14 hours in order to measure 80 counts for the weaker (p,t) reactions and for the weaker (p,d) reactions to the particle unbound higher lying states in ^{8}Li. For the ^{8}He(p,d) reaction we request 4 hours with the S800 setting for ^{4}He and 14 hours with the S800 set to ^{6}He. For the ^{11}Li(p,d) and ^{11}Li(p,t) reactions we request 14 hours with the S800 setting for measuring the ^{9}Li as the ^{10}Li does not have particle stable states. Similarly, the ^{12}Be(p,d) we request 4 hours with the S800 set for ^{11}Be and 14 hours with the S800 set for ^{10}Be which will also measure the ^{12}Be(p,t) reaction and the important $1d_{5/2}$ transfer which goes to particle unbound states in ^{11}Be .

We also request 24 hours of ^{13}C beam for tests and calibration of this complex experiment prior to data taking. This makes the total request of beam on target of 92 hours. Including the time needed for beam preparation and the switching of the beams (4 * 24 hours) we request a total of 188 hours. It would be ideal if some of the test time with the ^{13}C beam can be separated by several days from the remainder of the experimental run.

References

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5. H. Simon et al, Phys. Rev. Lett. 83 (1999) 496.
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9. D. Dehnhard, N. Williams and J.L. Yntema, Phys. Rev. 180, (1969) 967.
10. L.A. Kull and E. Kashy, Phys. Rev. 167, (1967) 963.
11. A. Brown, private communication (1999).
12. (To reduce the influence of uncertainties in the overlap integral, all spectroscopic factors have been normalized to that for the ^{11}B(p,d)^{10}B ground state transition.)
13. Measurements of the ^{10}Be(p,d)^{9}Be reaction have been performed at the NSCL in reverse kinematics with a radioactive ^{10}Be beams as a part of the thesis of X. Liu and analysis is an advanced stage.
14. F. Auger, Y. Blumenfeld, and J.E. Sauvestre, Nucl.Phys. News 8, (1998) 18.

Table 1 : Relative spectroscopic factors for low lying states populated via ^{11}B(p,d)^{10}B and ^{9}Li(p,d)^{8}Li reactions. (All spectroscopic factors have normalized to the ground state ^{11}B(p,d)^{10}B transition.) Both experimental and theoretical values are consistent for the ^{11}B(p,d)^{10}B reactions. Measurements of the strong transitions for ^{9}Li(p,d)^{8}Li can provide information about the occupancies of the 1p orbits in ^{9}Li.

^{11}B(p,d)^{10}B				^{9}Li(p,d)^{8}Li		
J^{π} , T (^{10}B)	E^{*} (^{10}B) MeV	S_{theory}	S_{exp}	J^{π} (^{8}Li)	E^{*} (^{8}Li) MeV	S_{theory}
3^{+}, 0	0	1.00	1.00	2^{+}, 1	0	0.83
1^{+}, 0	0.718	0.08	0.21	1^{+}, 1	0.981	0.30
0^{+}, 1	1.74	0.55		3^{+}, 1	2.26	1.21
1^{+}, 0	2.15	0.44	0.48	1^{+}, 1	3.21	0.03
2^{+}, 0	3.59	0.05	0.09			
3^{+}, 0	4.77	0.13	0.16			
2^{+}, 1	5.16	1.91	2.22			

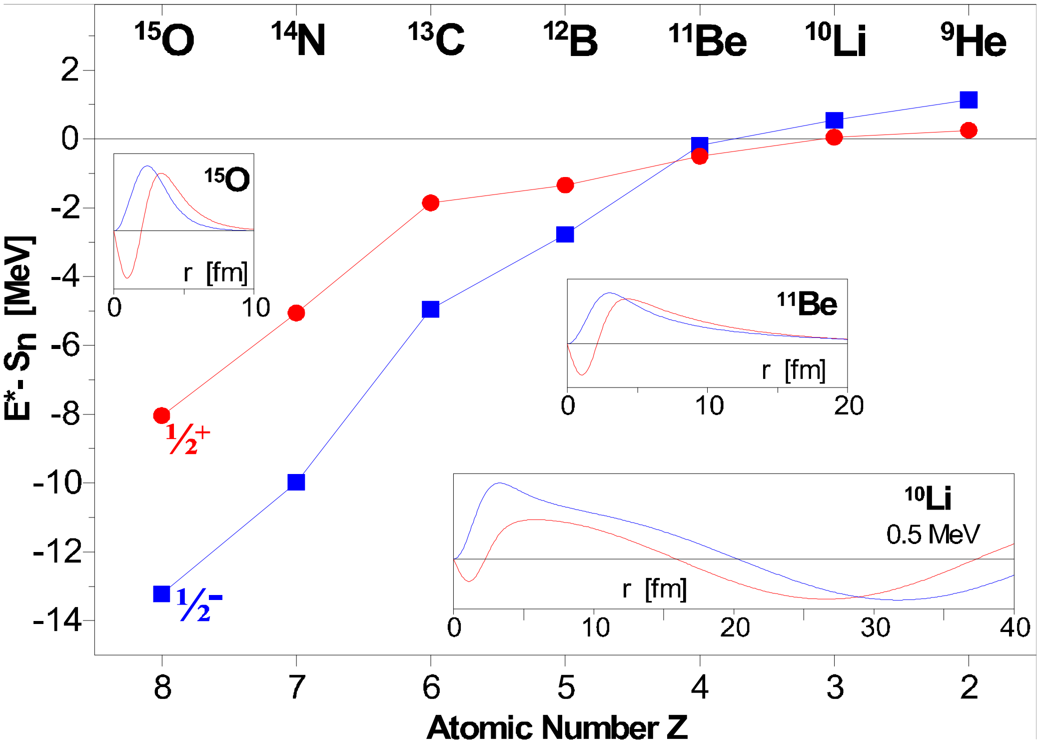

Figure 1 : Evolution of the neutron ½$^+$ and ½$^-$ orbits in the N=7 isotonic chain showing the inversion of the two orbits.

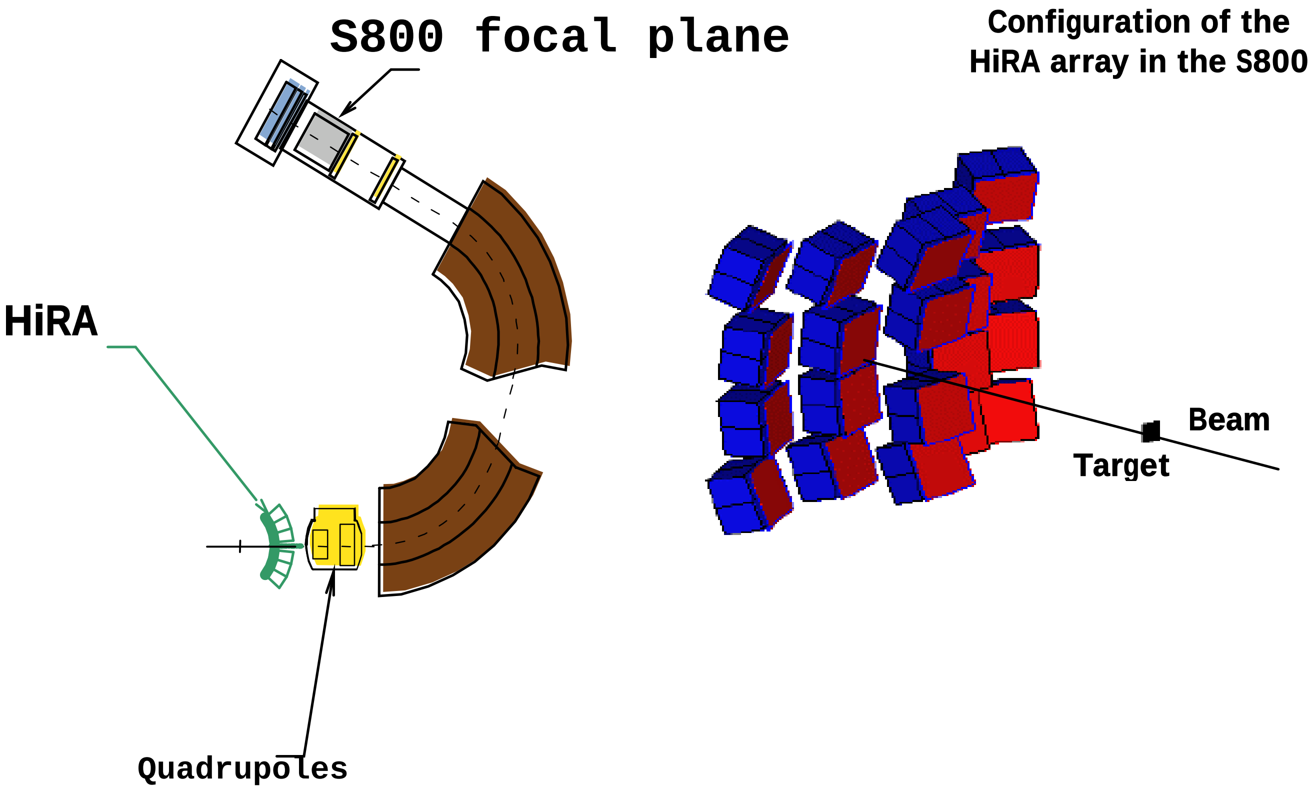

Figure 2: Diagram showing the configuration of the 20 telescopes of HiRA.

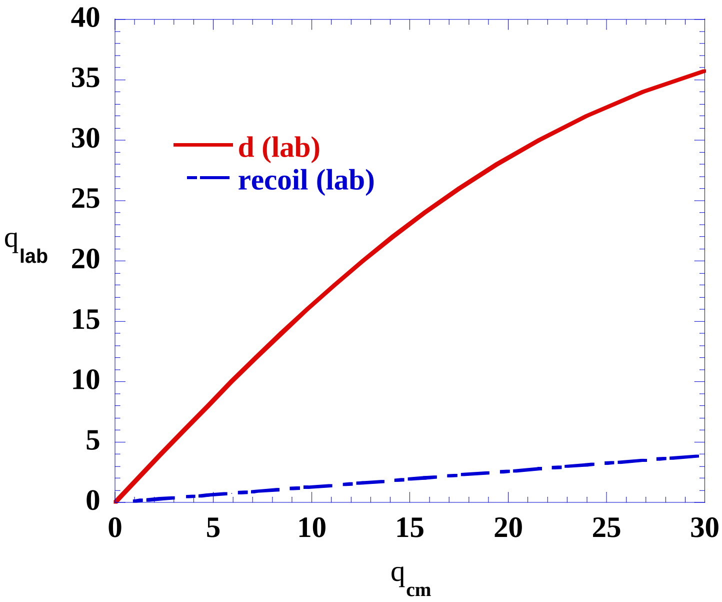

Figure 3 : The dependence of the deuteron (solid) and PLF (dashed) laboratory scattering angles are shown as functions of the deuteron center of mass scattering angle.

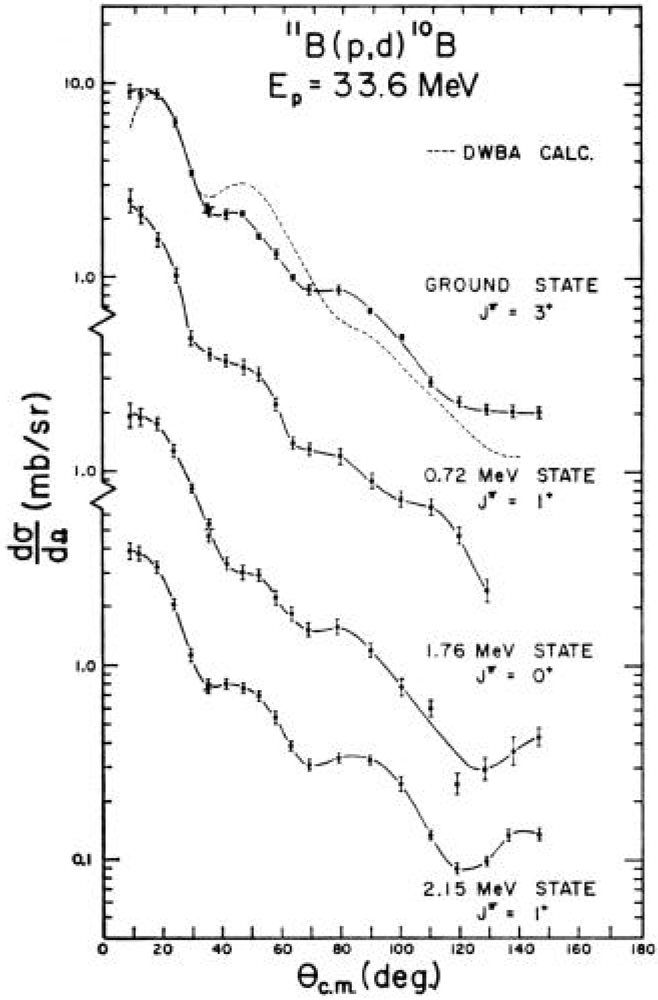

Figure 4:Data from ref. [7] used for extracting the spectroscopic factors in Table 1. The data points in the region of the peak near $\theta_{cm} \approx 10$ are the ones most important for this purpose. The shape of the angular distribution at $\theta > 20°$ is sensitive to uncertainties in the optical model potential. The data for the proposed measurement will display a peak at nearly the same angle.

LIST OF EQUIPMENT REQUIRING NSCL DEVELOPMENT AND DIAGRAMS OF EXPERIMENTAL APPARATUS (include for all experiments)

1. The HiRA or LASSA arrays. (LASSA can be used but has lower resolution and efficiency.)
2. The S800 or sweeper spectrograph . (The sweeper magnet with a focal plane detector would also work.)
3. Beam tracking counters.